THE ABC'S OF PROBES

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INTRODUCTION

Nearly all general purpose and laboratory oscilloscopes use probes to make a direct, flexible and convenient connection to a device-under-test (DUT).

Of all the different types of measurements, voltage measurements top the list by a wide margin. This primer, therefore, concentrates on voltage probes, their many applications, electrical and mechanical characteristics/specifications and, above all, how to select the correct voltage probe for **your** application.

Although the correct selection of basic voltage probes is of prime importance, we have not forgotten the specialty probes. These include probes that enable an oscilloscope to measure current; probes that measure only the difference between two voltages (differential probes); and probes designed for ultra-low loading at high frequencies.

The ideal probe/oscilloscope combination should acquire your signal and truly represent it on the cathode ray tube (CRT) **without** changing the signal source. Unfortunately, the ideal "non-invasive" probe does not exist. This primer explains why trade-offs are needed, what they entail and how to select the best probe for your application.

This primer has been divided into two sections, **Understanding Probes** and **Selecting Probes.** The first section covers probes in general, their features and specifications and how they may affect your measurements. The second section concentrates on what should be considered when selecting a probe and, most importantly, how to select the probe **you** need to make **your** measurement.

Handy charts, tables and graphs help make probe selection easy—as easy as ABC.

If you have comments or questions about the material in this primer, please don't hesitate to contact your local Tektronix Sales Engineer, or write to:

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PART I: UNDERSTANDING PROBES

The vital link in your measurement system

Probes connect the measurement test points in a DUT (device under test) to the inputs of an oscilloscope. Achieving optimized system performance depends on selecting the proper probe for your measurement needs.

Though you could connect a scope and DUT with just a wire, this simplest of connections would not let you realize the full capabilities of your scope. By the same token, a probe that is not right for your application can mean a significant loss in measurement results, plus costly delays and errors.

Why not use a piece of wire?

Good question: There are legitimate reasons for using a piece of wire or, more correctly, two pieces of wire; some low bandwidth scopes and special purpose plug-in amplifiers only provide binding post input terminals, so they offer a convenient means of attaching wires of various lengths.

DC levels associated with battery operated equipment could be measured. Low frequency (audio) signals from the same equipment could also be examined. Some high output transducers could also be monitored. However, this type of connection should be kept away from line-operated equipment for two basic reasons, safety and risk of equipment damage.

Safety: Attachment of hookup wires to line-operated equipment could impose a health hazard, either because the "hot" side of the line itself could be accessed, or because internally generated high voltages could be contacted. In both cases, the hookup wire offers virtually no operator protection, either at the equipment source or at the scope's binding posts.

Risk of Equipment Damage: Two unidentified hookup wires, one signal lead and one ground, could cause havoc in line-operated equipment. If the "ground" wire is attached to **any** elevated signal in line-operated equipment, various degrees of damage will result simply because both the scope and the equipment are (or should be) on the same three-wire outlet system, and short-circuit continuity is completed through one common ground.

Performance Considerations: In addition to the hazards just mentioned, there are two major performance limitations associated with using hookup wires to transfer the signal to the scope: circuit loading and susceptibility to external pickup.

Circuit Loading: This subject will be discussed in detail later, but circuit loading by the test equipment (scope-probe) is a combination of resistance and capacitance. Without the benefit of using an attenuator (10X) probe, the loading on the device under test (DUT) will be 1M ohm (the scope input resistance) and more than 20 picofarad (20pF), which is the typical scope input capacitance plus the stray capacitance of the hookup wire.

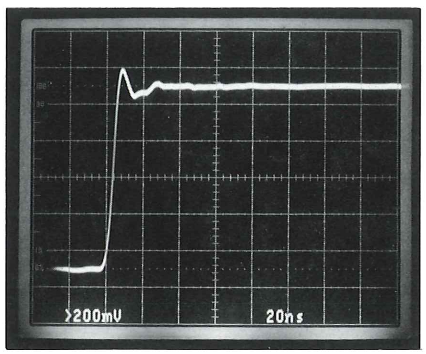


Figure 1

Figure 1 shows what a "real world" signal from a 500 ohm impedance source looks like when loaded by a 10M ohm 10 pF probe: the scope-probe system is 300MHz. Observed risetime is 6 Sec.

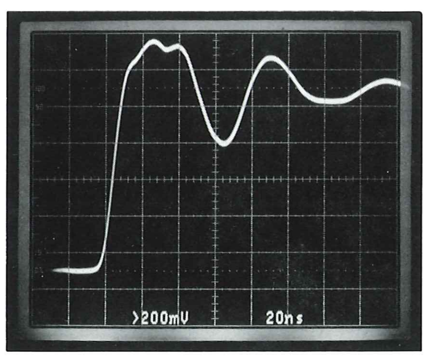


Figure 2

Figure 2 shows what happens to the same signal when it is accessed by two 2-meter lengths of hookup wire: loading is 1M ohm (the scope input resistance) and about 20 pF (the scope input capacitance, plus the stray capacitance of the wires). Observed risetime has slowed to 10 nSec and the transient response of the system has become unusable.

Susceptibility to External Pick-up: An unshielded piece of wire acts as an antenna for the pickup of external fields, such as line frequency interference, electrical noise from fluorescent lamps, radio stations and signals from nearby equipment. These signals are not only injected into the scope along with the wanted signal, but can also be injected into the device under test (DUT) itself.

The source impedance of the DUT has a major effect on the level of interference signals developed in the wire. A very low source impedance would tend to shunt any induced voltages to ground, but high frequency signals could still appear at the scope input and mask the wanted signal. The answer, of course, is to use a probe which, in addition to its other features, provides coaxial shielding of the center conductor and virtual elimination of external field pickup.

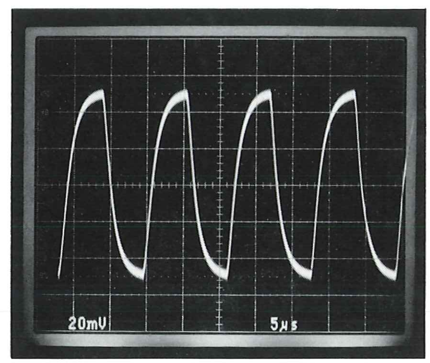


Figure 3

Figure 3 shows what a low level signal from a high impedance source (100MV from 100K ohm) looks like when accessed by a 300MHz scope-probe system. Loading is 10M ohm and 10 pF. This is a true representation of the signal, except that probe resistive loading has reduced the amplitude by about 1%: the observed high frequency noise is part of the signal at the high impedance test point and would normally be removed by using the BW (bandwidth) limit button on the scope. (See Figure 4.)

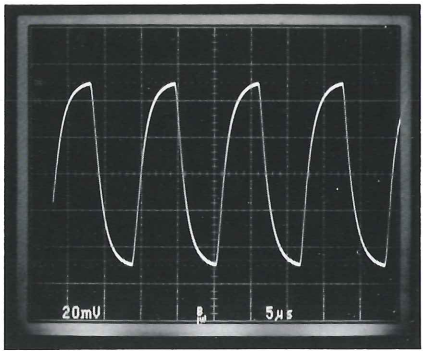


Figure 4

If we look at the same test point with our pieces of wire, two things happen. The amplitude drops due to the increased resistive and capacitive loading, and noise is added to the signal because the hookup wire is completely unshielded. (See Figure 5)

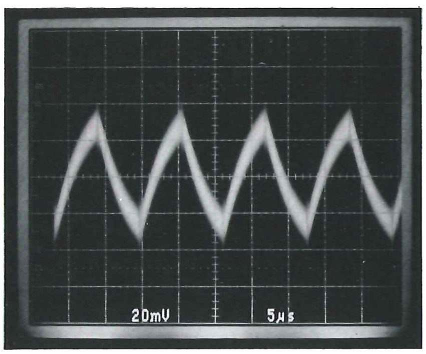


Figure 5

Most of the observed noise is line frequency interference from fluorescent lamps in the test area.

Probably the most annoying effect of using hookup wire to observe high frequency signals is its unpredictability. Any touching or rearrangement of the leads can produce different and nonrepeatable effects on the observed display.

Benefits of using probes

Not all probes are alike and, for any specific application, there is no one ideal probe; but they share common features and functions that are often taken for granted.

Probes are convenient. They bring a scope's vertical amplifier to a circuit. Without a probe, you would either need to pick up a scope and attach it to a circuit, or pick up the circuit and attach it to the scope. Properly used, probes are convenient, flexible and safe extensions of a scope.

Probes provide a solid mechanical connection. A probe tip, whether it's a clip or a fine solid point, makes contact at just the place you want to examine.

Probes help preserve a DUT. To a certain extent, all probes load the DUT—the source of the signal you are measuring. Still, probes offer the best means of making the connections needed. A simple piece of wire, as we have just seen, would severely load the DUT; in fact, the DUT might stop functioning altogether.

Probes are designed to minimize loading. Passive, non-attenuating 1X probes offer the highest capacitive loading of any probe type—even these, however, are designed to keep loading as low as possible.

Probes protect a signal from external interference. A wire connection, as described earlier, in addition to loading the circuit, would act as an antenna and pick up stray signals such as 60Hz power, CBers, radio and TV stations. The scope would display these stray signals as well as the signal of interest from the DUT.

Probes extend a scope's signal amplitude-handling ability. Besides reducing capacitive and resistive loading, a standard passive 10X (ten times attenuation) probe extends the on-screen viewability of signal amplitudes by a factor of ten.

A typical scope minimum sensitivity is 5V/division. Assuming an eight-division vertical graticule, a 1X probe (or a direct connection) would allow on-screen viewing of 40V pp maximum. The standard 10X passive probe provides 400V pp viewing. Following the same line, a 100X probe should allow 4kV on-screen viewing. However, most 100X probes are rated at 1.5kV to limit power dissipation in the probe itself.

Check the specs. Bandwidth is the probe specification most users look at first, but plenty of other features also help to determine which probe is right for your application. Circuit loading, signal aberrations, probe dynamic range, probe dimensions, environmental degradation and ground-path effects will all impact the probe selection process, as discussed in the pages that follow.

By giving due consideration to probe characteristics that your application requires, you will achieve successful measurements and derive full benefit from the instrument capabilities you have at hand.

How probes affect your measurements

Probes affect your measurements by loading the circuit you are examining. The loading effect is generally stated in terms of impedance at some specific frequency, and is made up of a combination of resistance and capacitance.

Source Impedance. Obviously, source impedance will have a large impact on the net affect of any specific probe loading. For example, a device under test with a near zero output impedance would not be affected in terms of amplitude or risetime to any significant degree by the use of a typical 10X passive probe. However, the same probe connected to a high impedance test point, such as the collector of a transistor, could affect the signal in terms of risetime and amplitude.

Capacitive Loading. To illustrate this effect, let's take a pulse generator with a very fast risetime. If the initial risetime was assumed to be zero ($t_r = 0$), the output t_r of the generator would be limited by the associated resistance and capacitance of the generator. This integration network produces an output rise time equal to 2.2 RC. This limitation is derived from the universal time-constant curve of a capacitor.

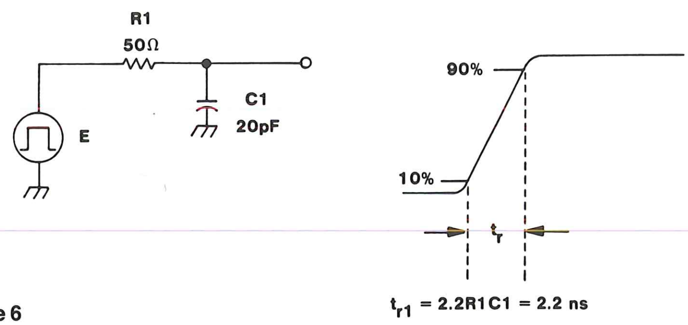


Figure 6

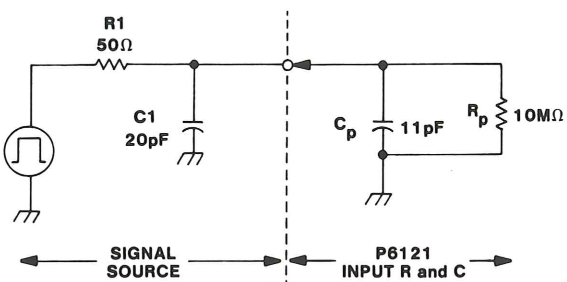


Figure 7

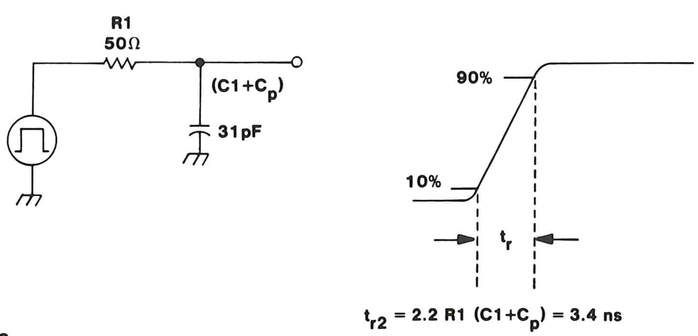


Figure 8

Figure 6 shows the effect of internal source resistance and capacitance on the equivalent circuit. At no time can the output risetime be faster than 2.2 RC or 2.2 nSec.

If a typical probe is used to measure this signal, the probe's specified input capacitance and resistance is added to the circuit as shown in Figure 7.

Because the probe's 10M ohm resistance is much greater than the generator's 50 ohm output resistance, it can be ignored.

Figure 8 shows the equivalent circuit of the generator and probe, appling the 2.2 RC formula again. The actual risetime has slowed from 2.2 n Sec. to 3.4 nSec.

Percentage change in risetime due to the added probe tip capacitance:

$$\% \text{ change} = \frac{tr_2 - tr_1}{tr_1} \times 100 = \frac{3.4 - 2.2}{2.2} \times 100 = 55\%$$

Another way of estimating the affect of probe tip capacitance on a source is to take the ratio of probe tip capacitance (marked on the probe compensation box) to the known or estimated source capacitance.

Using the same values:

$$\frac{C_{\text{probe tip}}}{C_1} \times 100 = \frac{11\text{pF}}{20\text{pF}} \times 100 = 55\%$$

To summarize, any added capacitance slows the source risetime when using high impedance passive probes. In general, the greater the attenuation ratio, the lower the tip capacitance. Here are some examples:

Probe	Attenuation	Tip Capacitance
Tektronix P6101A	X1	54 pF
Tektronix P6105A	X10	11.2 pF
Tektronix P6007	X100	2 pF

Capacitive Loading: Sinewave. When probing continuous wave (cw) signals, the probe's capacitive reactance at the operating frequency must be taken into account.

The total impedance, as seen at the probe tip, is designated Rp and is a function of frequency. In addition to the capacitive and resistive elements, designed-in inductive elements serve to offset the pure capacitive loading to some degree.

Figure 9 shows a typical plot of Xp and Rp versus frequency.

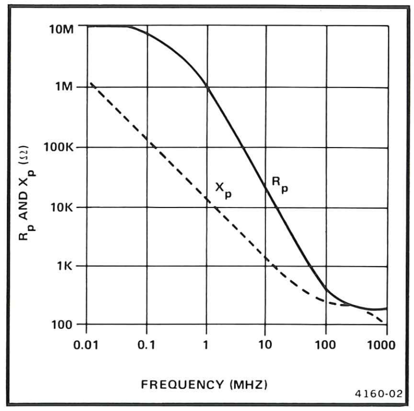


Figure 9. Typical Xp and Rp versus frequency

These curves are included in Tektronix probe instruction manuals, but if you do not have ready access to the information and need a worst-case guide to probe loading, use the following formula:

$$Xp = \frac{1}{2\pi FC}$$

Xp = Capacitive reactance (ohms)
F = Frequency of interest
C = Probe tip capacitance (marked on probe body or compensation box.)

For example, a standard passive 10M ohm probe with a tip capacitance of 11 pF will have a capacitive reactance (Xp) of about 290 ohm at 50MHz. Depending, of course, on the source impedance, this loading could have a major effect on the signal amplitude and even on the operation of the circuit itself.

Resistive Loading. For all practical purposes, a 10X 10M ohm passive probe has little effect on today's circuitry in terms of resistive loading, however, they do carry a trade-off in terms of relatively high capacitive loading as we have previously discussed.

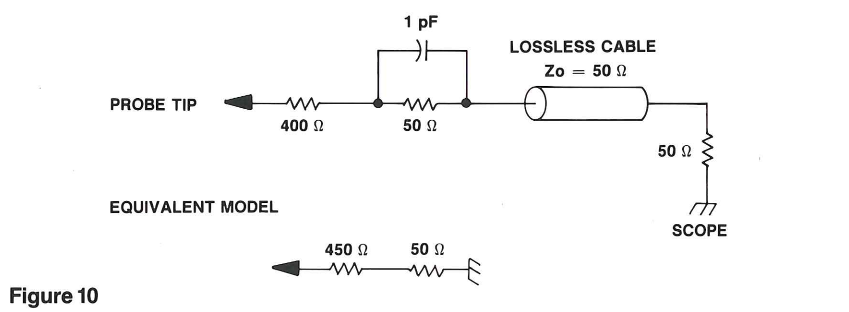


Figure 10

Low Z Passive Probes. A "Low Z" passive probe offers very low tip capacitance at the expense of relatively high resistive loading. A typical 10X "50 ohm" probe has an input C of about 1 pF and a resistive loading of 500 ohm: Figure 10 shows the circuit and equivalent model of this type of probe.

This configuration forms a high frequency 10X voltage divider because, from transmission line theory, all that the 450 ohm tip resistor "sees" looking into the cable is a pure 50 ohm resistance, no C or L component. No low frequency compensation is necessary because it is not a capacitive divider. Low Z probes are typically high bandwidth (up to 3.5GHz and risetimes to 100 pS) and are best suited for making risetime measurements. They can, however, affect the pulse amplitude by simple resistive divider action between the source and the load (probe). Because of its resistive loading effects, this type of probe performs best on 50 ohm or lower impedance circuits under test.

Note also that these probes operate into 50 ohm scope inputs only. They are typically teamed up with fast (500MHz to 1GHz) real time scopes or with scopes employing the sampling principle.

The Best of Both Worlds. From the foregoing, it can be seen that the totally "non-invasive" probe does not exist. However, one type of probe comes close—the active probe.

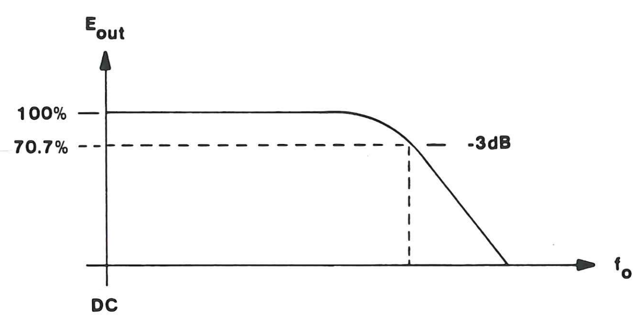


Figure 11

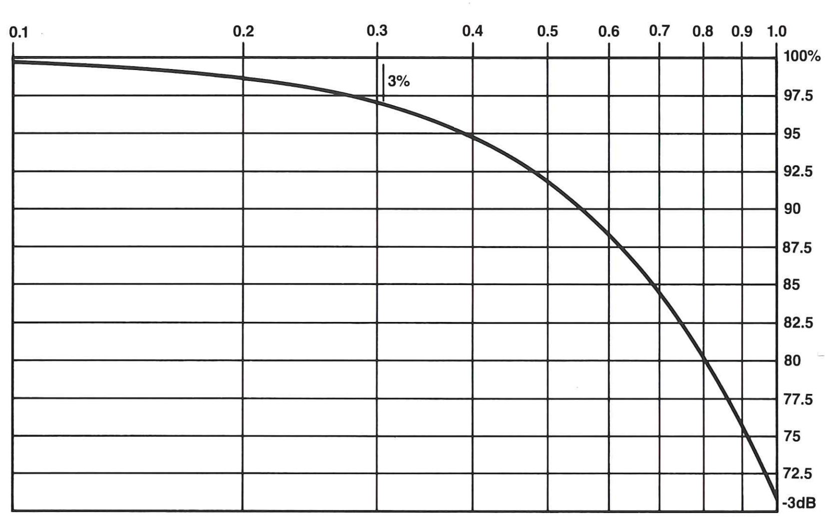


Figure 12

Active probes are discussed under "How to Select the Best Probe" (page 16), but in general, they provide low resistance loading (10M ohm) with very low capacitive loading (1 to 2 pF). They do have tradeoffs in terms of limited dynamic range, but under the right conditions, do indeed offer the best of both worlds.

Bandwidth. Bandwidth is the point on an amplitude versus frequency curve where the measurement system is down 3dB from a starting (reference) level. Figure 11 shows a typical response curve of an oscilloscope system.

Scope vertical amplifiers are designed for a Gaussian roll-off at the high end (a discussion of Gaussian response is beyond the scope of this primer). With this type of response, risetime is approximately related to bandwidth by the following equation:

$$Tr = \frac{.35}{BW} \quad \text{or, for convenience:}$$

$$\text{Risetime (nanoseconds)} = \frac{350}{\text{Bandwidth (MHz)}}$$

It is important to note that the measurement system is −3dB (30%) down in amplitude at the specified bandwidth limit.

Figure 12 shows an expanded portion of the −3dB area. The horizontal scale shows the input frequency derating factor necessary to obtain accuracies better than 30% for a specific bandwidth scope. For example, with no derating, a "100MHz" scope will have up to a 30% amplitude error at 100MHz (1.0 on the graph). If this scope is to have an amplitude accuracy better than 3%, the input frequency must be limited to about 30MHz (100MHz X .3).

For making amplitude measurements within 3% at a specific frequency, choose a scope with at least four times the specified bandwidth as a general rule of thumb.

Probe Bandwidth. All probes are ranked by bandwidth. In this respect, they are like scopes or other amplifiers that are ranked by bandwidth. In these cases we apply the square root of the sum of the squares formula to obtain the "system risetime." This formula states that:

$$\text{Risetime system} = \sqrt{Tr^2 \text{ displayed} - Tr^2 \text{ source}}$$

Passive probes do not follow this rule and should not be included in the square root of the sum of the squares formula.

SCOPE	BW (1 MΩ input)	PROBE	BW	SYSTEM
2235	100	P6122	100	100
2236	100	P6121	100	100
2237	100	P6108A	100	100
2445	150	P6133	150	150
2465	<300	P6131	300	300
485	250	P6106A	250	250
2467	<350	P6136	350	350

Figure 13

Tektronix provides a probe bandwidth ranking system that specifies "the bandwidth (frequency range) in which the probe performs within its specified limits. These limits include: total abberrations, risetime and swept bandwidth."

Both the source and the measurement system shall be specified when checking probe specifications (see Test Methods, this page).

In general, a Tektronix "100MHz" probe provides 100MHz performance (− 3dB) when used on a compatible 100MHz scope. In other words, it provides full scope bandwidth **at the probe tip.**

Figure 13 shows examples of Tektronix scopes and their recommended passive probes. Note that their system bandwidths are equal to the specified probe bandwidth, with two exceptions—the 2465/P6131 & 2467/P6133 combinations actually provide greater bandwidth at the probe tip than provided by the scopes. 1M ohm input alone. This is because inductive peaking in these probes work in conjunction with the scopes input circuitry to provide the desired response **at the probe tip.**

Test Methods: As with all specifications, matching test methods must be employed to obtain specified performance. In the case of bandwidth and risetime measurements, it is essential to connect the probe to a properly terminated source. Tektronix specifies a 50 ohm source terminated in 50 ohm, making this a 25 ohm source impedance. Furthermore, the probe must be connected to the source via a proper probe tip to BNC adaptor. (Figure 14).

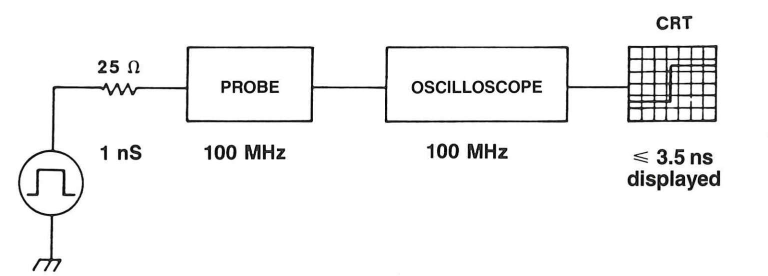


Figure 14

Figure 14 shows an equivalent circuit of a typical setup. The displayed risetime should be a 3.5 nSec or faster.

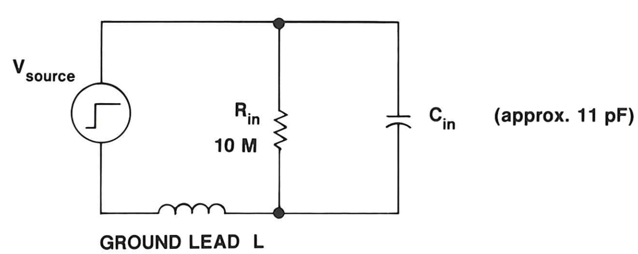


Figure 15

Figure 15 shows an equivalent circuit of a typical passive probe connected to a source.

How ground leads affect measurements

A ground lead is a wire that provides a local ground-return path when you are measuring any signal. An inadequate ground lead (one that is too long or too high in inductance) can reduce the fidelity of the high frequency portion of the displayed signal.

What grounding system to use. When making **any** measurement, some form of ground path is required to make a basic two-terminal connection to the DUT. If you want to check the presence or absence of signals from low-frequency equipment, **and** if the equipment is line-powered and plugged into the same outlet system as the scope, then the common 3-wire ground system provides the signal ground return. However, this circuitous route adds inductance in the signal path—it can also produce ringing and noise on the displayed signal and is not recommended.

When making any kind of absolute measurement, such as amplitude, risetime or time delay measurements, you should use the shortest grounding path possible, consistent with the need to move the probe among adjacent test points. The ultimate grounding system is an in-circuit ECB (etched circuit board) to probe tip adaptor. Tektronix can supply these for either miniature or subminiature probe configurations.

Figure 15 shows an equivalent circuit of a typical passive probe connected to a source. The ground lead L and C_{in}, form a series resonant circuit with only 10M ohm for damping. When hit with a pulse, it will ring. Also, excessive L in the ground lead will limit the changing current to C_{in}, limiting the risetime.

Without going into the mathematics, an 11pF passive probe with a 6-inch ground lead will ring at about 140MHz when excited by a fast pulse. As the ring frequency increases, it tends to get outside the passband of the scope and is greatly attenuated. So to increase the ring frequency, use the shortest ground lead possible and use a probe with the lowest input C.

Probe Ground Lead Effects. The effect of inappropriate grounding methods can be demonstrated several ways. Figs. 1A, 1B, and 1C show the effect of a 12-inch ground lead when used on various bandwidth scopes.

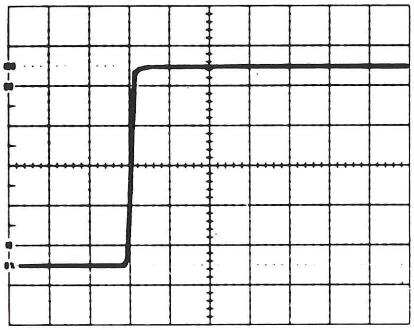


Figure 1A

0.1 μs/div. Scope BW = 15MHz
Ground lead 12 inches

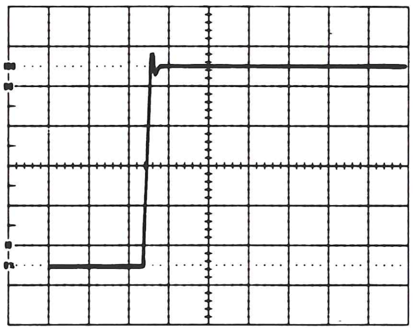


Figure 1B

0.1 μs/div. Scope BW = 50MHz
Ground lead 12 inches

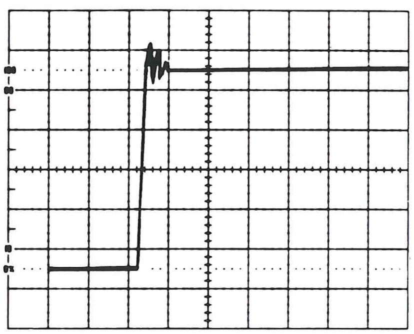


Figure 1C

0.1 μs/div. Scope BW = 100MHz
Ground lead 12 inches

In Figure 1A, the display on the 15MHz scope looks OK because the ringing abberations are beyond the passband of the instrument and are greatly attenuated. Figs. 1B and 1C show what the same signal looks like on 50MHz and 100MHz scopes.

Even with the shortest ground lead, the probe-DUT interface has the **potential** to ring. The potential to ring depends on the **speed** of the step function. The ability to **see** the resultant ringing oscillation depends on the scope system bandwidth.

Figs. 2A through 2F show the effects of various grounding methods and ground lead lengths on the display of a very fast pulse. This is the most critical way of looking at ground lead effects: we used a fast pulse, with a risetime of about 70 pico seconds and a fast (300MHz) scope with a matching P6131 probe.

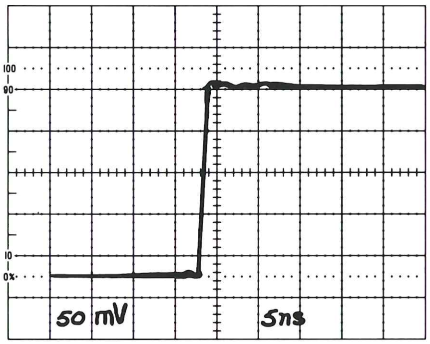


Figure 2A

50 ohm Source/Cable/2465/50 ohm input

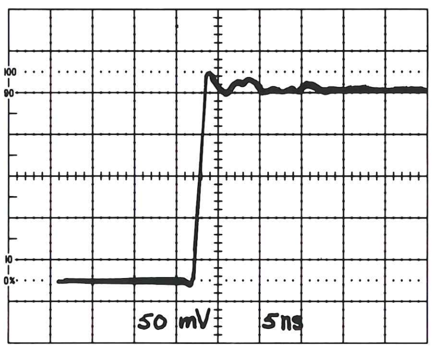


Figure 2B

P6131-BNC/Probe Adaptor Tr = 1.1 NS

Fig. 2A shows the input pulse under the most optimum conditions when using 50 ohm coax cable. Scope: the Tektronix 2465 with 50 ohm input and 50 ohm cable from a 50 ohm source. Displayed risetime is 1.1 nSec.

Fig. 2B shows the same signal when using the scope-probe combination under the most optimum conditions. A BNC to probe adaptor or an in-circuit test jack provides a coaxial ground that surrounds the probe ground ring. This sytem provides the shortest probe ground connection available. Displayed risetime is 1.1 nSec.

Figures 2C through 2E show the effects of longer ground leads on the displayed signal. Fig. 2C shows the effect of a short semi-flexible ground connection, called a "Z" lead. Finally, Fig. 2F shows what happens when no probe ground lead is used.

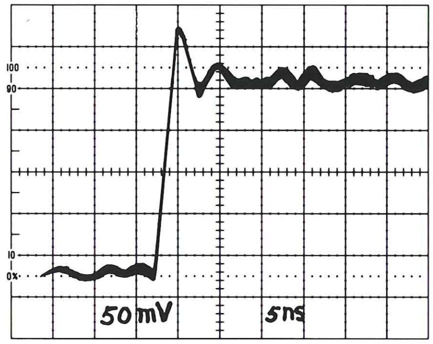


Figure 2C

P6131 - Probe/Z Ground Tr = 1.5 NS

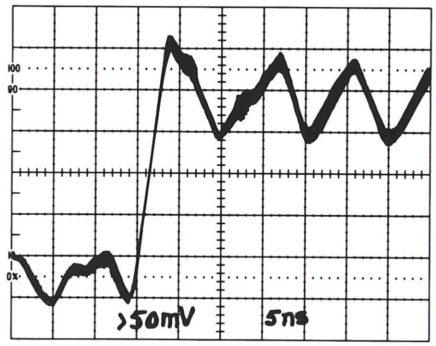


Figure 2D

P6131 - Probe/3" Gnd Lead Tr = 4 NS

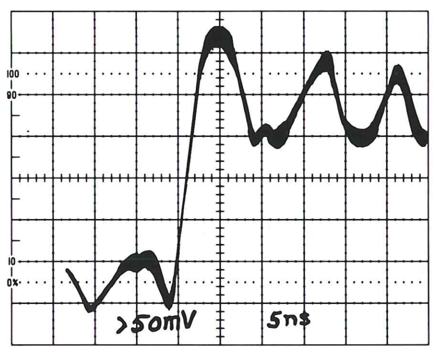


Figure 2E

P6131 - Probe/6" Gnd Lead Tr = 4 NS

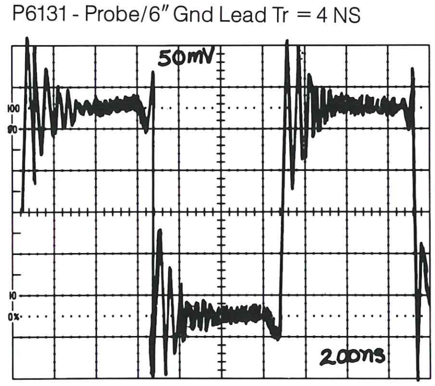


Figure 2F

No Ground Lead

How probe design affects your measurements

Probes are available in a variety of sizes, shapes and functions, but they do share several main features: a probe head, coaxial cable and either a compensation box or a termination.

The probe head contains the signal-sensing circuitry. This circuitry may be passive (such as a 9-M ohm resistor shunted by an 11 pF capacitor in a passive voltage probe or a 125-turn transformer secondary in a current probe); or active (such as a source follower or Hall generator) in a current probe or active voltage probe.

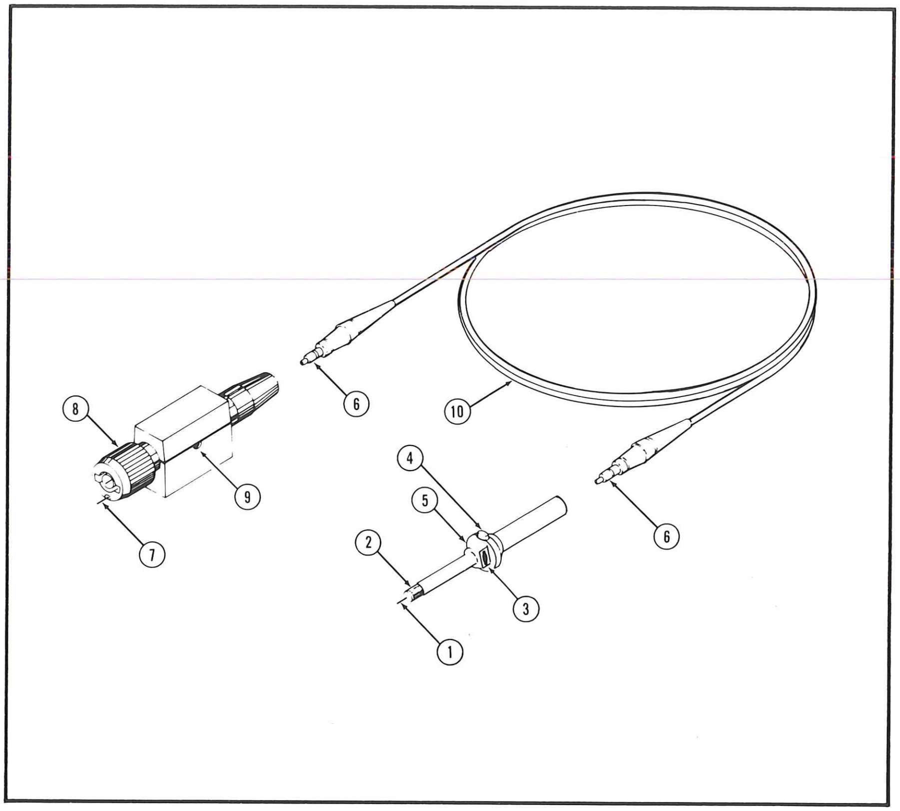
The coaxial cable couples the probe head output to the termination. Cable types vary with probe types.

The termination has two functions:

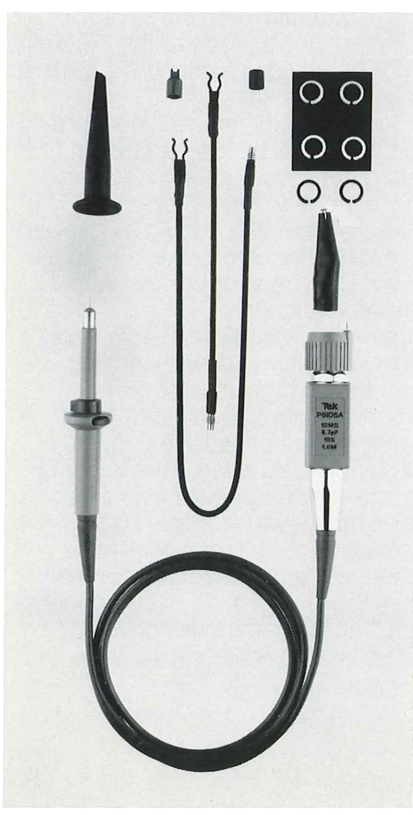
- to terminate the cable in its characteristic impedance.
- to match the input impedance of the scope.

The termination may be passive or active circuitry. For easy connection to various test points, many probes feature interchangeable tips and ground leads.

A unique feature of most Tektronix probes is the Tektronix-patented coaxial cable that has a resistance-wire center conductor. This distributed resistance suppresses ringing caused by impedance mismatches between the cable and its terminations when you're viewing fast pulses on wideband scopes.



1. A low-inductance tip reduces ringing, minimizes aberrations and improves signal fidelity.
2. The ground ring provides the shortest possible path between the circuit ground plane and the probe ground in order to reduce ground lead inductance and improve signal fidelity. In-circuit probe tip adaptors maximize performance by providing direct connection to the ECB (etched circuit board) ground plane.
3. A covered ground lead connection point eases the job of connecting a variety of lead lengths for general probing applications.
4. The ground-reference button on some probes allows you to quickly indicate ground reference and to position the trace to some convenient place on the screen. Some probes (such as the Tektronix P6053B) have a TRACE IDENTIFY button that you can use with scopes that have CRT readout. With this button, you can show IDENTIFY in the appropriate scale-factor readout, which also slightly offsets the display associated with the probe to give positive identification of the source.
5. The finger guard keeps fingers out of the DUT, thus protecting you and enormously improving signal fidelity.
6. An integrated interconnection system provides modular replacement and low-impedance interconnections.
7. Special connector provides coding of attenuation (1X - 10X) for probes used with scopes that have a vertical scale factor readout or knob-skirt readout).
8. The large-diameter knurled plastic BNC housing provides easy connection to the scope.
9. The compensation box houses factory-adjusted termination components and also provides access via a side-mounted hole for the user-adjustable low frequency compensation adjustment (LF COMP).
10. The cable is designed for low capacitance/foot (and, therefore, lower input capacitance) and is tangle-free, small in diameter, lightweight, flexible and provides maximum operating life. The cable is available in various lengths: 1 meter, 2 meters and 3 meters. Generally, specific cable lengths are teamed with specific probe heads and compensation boxes. The three items should not be mixed.



Typical probe & accessories package.

The types of probes available

Tektronix designs and manufactures over 150 probe models. What is the most meaningful way to classify this wide variety of probes? The first and simplest way is by purpose—is a particular probe's purpose to sense voltage or current?

Voltage-Sensing Probes. The two main types of voltage-sensing probes, active and passive, differ in their internal circuitry and mode of operation. Passive voltage-sensing probes are built with passive circuit components: resistors, capacitors and inductors. Their main advantages are:

- Ruggedness
- Relatively low cost
- Wide dynamic range (therefore, less liable to electrical damage).
- Simplicity (which makes them easy to use and calibrate).
- Fast risetime.

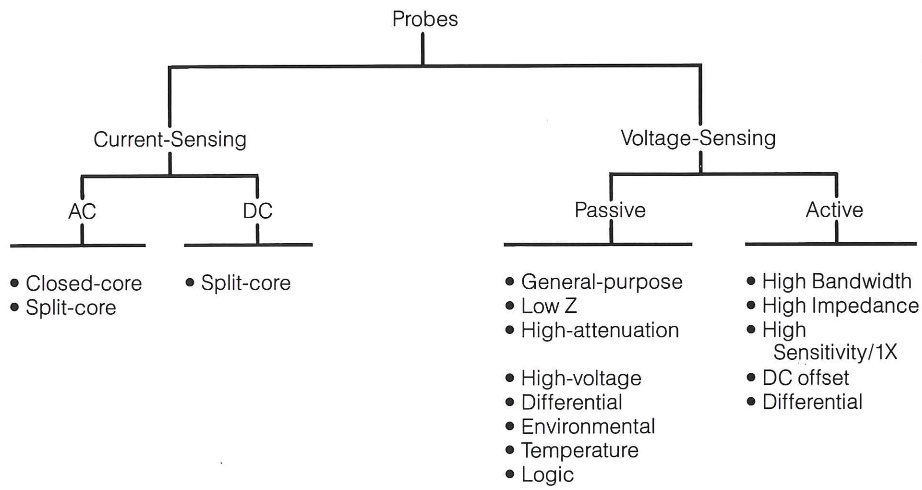
Their main limitation is that they present lower input impedance as the input signal frequency increases. Adding attenuation to the probe increases the impedance, but it reduces the displayed signal level.

Passive voltage-sensing probes may be further classified by their attenuation of signals:

- 1X (no attenuation)
- 10X (10 to 1) probe-input-to probe-output attenuation working with the resistance of the scope.
- 100X (100-to-1 attenuation)
- 1000X (1000-to-1 attenuation)

Attenuation is neither good nor bad in itself. For example, high attenuation probes are very useful for measuring high-voltage signals while protecting your scope input circuits. On the other hand, a high attenuation probe may attenuate a low voltage signal so much that you can't measure it.

Basic Probe types



Low Z passive probes are specially designed for measuring very high frequency signals. The benefits of Low Z probes (also called "low capacitance" probes) include:

- Consistent and predictable loading through a wide range of frequencies.
- Probe impedance matched to the 50 ohm input of high-bandwidth scopes, thus enabling probe designers to use a transmission-line approach in the design of the probe termination and cable. This design cancels the effects of cable capacitance and allows you to use longer cables at bandwidths up to 3.5 GHz.

Probes for Making Differential Measurements. Signals which are not referenced to ground, such as the voltage drop across a collector load resistor or the gate drive signal in a three-phase switching power supply, require differential measurement techniques to extract the signal in the presence of unwanted information.

This unwanted information may be the power supply voltage (elevated signal) or line frequency signals associated with switching power supplies.

Differential amplifiers measure only the difference signals between two points and reject the unwanted common mode signal (a signal or DC voltage common to both test points).

In order to preserve the high common mode rejection ratio (CMRR) of scope differential amplifiers, it is necessary to use one of the following methods: direct connections, specially designed differential probe pairs or differential probes (probes that provide differential processing in the probe itself).

For reasons discussed elsewhere, direct connections load the DUT, so probes such as the Tektronix P6055, used in pairs, are matched in length (for equal transit-time) loading and attenuation. (Attenuation is adjustable over about a plus or minus 1% range to ensure maximum CMRR performance.)

A differential probe (one probe with two inputs, such as the Tektronix P6046) provides maximum CMRR at high frequencies.

In general, differential measurements should be made **without** using the probe ground leads on signal connections (probe pairs). The ground leads should be clipped to each other or removed altogether to avoid accidental contact with elevated circuitry.

Specialty Probes. A special category of passive voltage-sensing probes are high-voltage probes, which handle signals up to 40kV. Another type of passive voltage-sensing probe is the environmental probe, which operates over a very wide temperature range. Logic probes sense logic states. Temperature probes are used to measure the temperature of components such as solid-state devices and other head-generating items.

Active voltage-sensing probes are built with active circuit components such as FETS, and transistors. (Some active voltage-sensing probes are called "FET probes.") Their main advantage: they provide less signal attenuation **and** less circuit loading than passive probes. (They offer high input impedance and low input capacitance.)

Other advantages of active voltage-sensing probes are:

- Full probe bandwidth with no signal attenuation.
- Fast risetime and minimal pulse-amplitude error.
- Ability to use a longer 50 ohm probe cable without more loading.
- Selectable probe output impedance (so that you can use the probe either with the usual 1M ohm or with 50 ohm scope inputs).

Active voltage-sensing probes, like all probes, have some limitations. They are usually more expensive, have a smaller dynamic range and require more careful handling.

Current-Sensing Probes. Current-sensing probes use transformers (or a combination of transformers and Hall Effect devices) to convert flux fields to voltage signals.

A Hall Effect device produces an output in the presence of magnetic fields, including steady-state fields, making it an essential component of DC current probes.

Flux fields are the electromagnetic fields around a wire created by the current flowing through the wire.

The main advantage of current-sensing probes is that they impose the lowest possible load on the DUT, usually without breaking circuit connections, and give the most accurate amplitude and risetime measurements.

Most current-sensing probes allow you to make measurements without breaking connections to the DUT, allowing part of the split transformer core to slide back and then clipping the probe over the wire carrying the current being measured. Examples of the split-core probe are the Tektronix P6021 and A6302. Some special purpose, high frequency current probes, such as the Tektronix CT-1 and CT-2, require a wire to be threaded from the DUT through the closed core of the probe.

Current probes may be classified as either ac or ac and dc responding. Ac current probes are basically transformers. They have an upper and lower frequency roll-off characteristic. They can be either a fixed-core or split-core type.

The easiest way to classify the main types of probes is by purpose first (current or voltage-sensing), then by circuit type (ac or dc responding) and finally by use.

Dc current probes combine transformers and Hall Effect devices. The Hall Effect device provides the dc response while the transformer takes over at a predetermined cross-over point to provide extended high-frequency response. Dc current probes, therefore, have a frequency characteristic from dc to some upper 3 dB roll-off point. An example is dc to 50MHz, for the Tektronix A6302. Dc current probes are typically split-core probes. They employ active circuit elements such as Hall devices and associated circuitry.

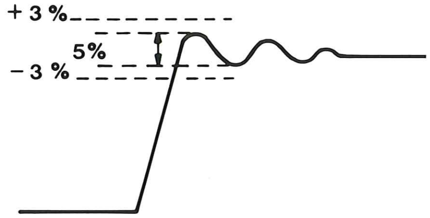
How to interpret probe specifications

This list of key parameters, and comments about them, will help you evaluate specs published by the probe manufacturer.

Some of the parameters discussed here may not show up on manufacturer's probe charts due to lack of space, but the information should be available and be part of the overall probe specifications.

See the glossary of probe terms, beginning on page 21.

Aberrations. An aberration is a deviation from a theoretically correct response to an input signal. In practice, aberrations usually occur on the leading edge of a step function. Aberrations are measured as a +/− percentage deviation from the final level (flat top). Aberration specs sometimes specify time as well. Example: "abberation specifications are +3%, −3% and 5% pp within the first 30 nanoseconds." Before assuming that aberrations are caused by a probe, consider scope aberrations, the probe grounding techniques used and the signal source.



Accuracy: For voltage-sensing probes, accuracy generally refers to the probe's attenuation of a dc signal. The calculations and measurements of probe accuracy generally include the scope input resistance. An example specification is: 10X within 3% (scope input 1M ohm within 2%).

For current-sensing probes, this spec is actually the accuracy of the current-to-voltage conversion. The accuracy of the conversion depends on the current transformer turns-ratio and the value and accuracy of the terminating resistance.

Current probes that work with dedicated amplifiers (such as the Tektronix A6302/AM503) read directly in amps/div, and specify attenuator accuracy as a percentage of the current/division setting. This specification is similar to scope attenuator specs.

Amp-Second Product. For current probes, this spec is a measure of the current transformer core's energy-handling capability. If the peak current times the pulse width exceeds the amp-second product rating, the core saturates and clips portions of the displayed signal.

Attenuation. A high-attenuation probe allows you to safely view large signals and minimize probe tip capacitance. However, a disadvantage of high attenuation probes is that it may prevent you from measuring small signals.

Bandwidth. Most Tektronix passive voltage probes are designed to provide a specified scope bandwidth at the probe tip. These probes will not degrade the upper 3 dB bandwidth spec of the scope with which they are compatible. The risetime formula (square root of the sum of the squares) that usually applies to active probes does not apply to these passive voltage probes.

The following bandwidth guidelines make probe selection a little easier:

- Choose a probe that has a bandwidth spec equal to or higher than the scope's bandwidth spec. For example, the Tektronix 2335 100MHz Dual Trace Portable Oscilloscope includes, as standard accessories, two P6108A 10X probes, also specified at 100MHz. The Tektronix 2465 300MHz Four Channel Portable Oscilloscope includes the 300MHz P6131 10X Probe as a standard accessory.
- You can use a higher bandwidth probe on a lower bandwidth scope if the probe is otherwise compatible. (See Electrical Requirements on page 14.) Behind Tektronix bandwidth figures is the assumption that the probe performs within *all* advertised specs, including maximum aberrations. Manufacturers who do not couple bandwidth specs to realistic aberration specs may claim enhanced bandwidth without delivering total performance.
- Do not use a lower bandwidth Tektronix (or any manufacturer's) probe on a higher bandwidth scope unless the signals you are measuring are within the probe's frequency range. The lower of the two bandwidth specs determines the probe-scope system upper frequency limit.
- Passive 1X probes have an upper frequency limit between 4 and 34MHz, depending on their type and cable length. These limits control the probe-scope system's upper 3 dB point. Either 1X or 1X/10X switchable probes may be used with wide bandwidth scopes. These probes may be the perfect match for your application.

Capacitive Loading. For voltage probes, probe capacitance is important because lower capacitance minimizes risetime errors. Probe capacitance affects pulse amplitude measurements if pulse duration is less than five times longer than the probe RC time constant.

CW Frequency Current Derating. Current probe specs include amplitude versus frequency derating curves that relate core saturation to increasing frequency. If the average direct current is zero amps, the waveform peaks progressively clip as the frequency rises or the amplitude increases.

Decay Time Constant. For current probes, the decay time constant indicates a probe's pulse-supporting capability. This time constant is the secondary inductance divided by the terminating resistance. The decay time constant is sometimes called the probe L/R ratio.

Direct Current. For current probes, dc decreases permeability which in turn decreases the effective secondary inductance and L/R (decay) time constant. The high frequency response usually doesn't change. As dc current flows through the probe, the operating point frequency rises and low frequencies are lost. Some current probes have current-bucking options that null the effects of dc.

Insertion Impedance. For current probes, insertion impedance is the impedance reflected from the current transformer's secondary circuit. Typically, a current probe's reflected impedance has an insignificant effect on circuits that have more than 25 ohms impedance. Typical insertion loss values are 0.03 ohms and 0 to 5 micro-Henries.

Input Resistance. A probe's input resistance is the resistance that the probe offers to signals from the DUT at dc. (See "How Probes Affect your Measurements," page 4.)

Input Capacitance (Probe). The probe capacitance measured at the tip.

Maximum Input Current Rating. Maximum input current is the total current (dc + peak ac) that the probe will accept and still perform as specified. In ac current measurements, peak-to-peak values must be derated versus frequency to calculate the maximum total input current.

Maximum Input Voltage. Maximum continuous input voltage at dc.

Maximum Peak Pulse Current Rating. This rating takes into account core saturation and development of potentially damaging secondary voltages and must not be exceeded. The maximum peak pulse current is usually specified with an amp-second product. Exceeding the amp-second product saturates the transformer core and distorts the output.

Maximum Voltage Rating. A voltage probe's maximum voltage rating is determined by the breakdown voltage rating of the probe body or the probe components at the measuring point.

Propagation Delay. Every probe introduces some time delay or phase shift with frequency. A 42-inch probe cable has a 5ns signal delay. At 1MHz, a 5ns signal delay causes a 2-degree phase shift. Propagation delay should only be of concern when measuring time time differences of two or more waveforms, or when making power measurements with a combination of current and voltage probes.

Risetime. A probe's 10% to 90% response to a step function should include aberration limits. (See Aberrations, page 11.) Approximately related to bandwidth by the factor 0.35. (See Bandwidth, page 6.)

Ringing. Damped oscillation response usually caused by inductive effects of poor probe grounding techniques. (Long leads, no ground leads, non-use of probe tip adaptors.)

RMS Current—Root Mean Square. A parameter describing the equivalent heating effect (power) of CW waveforms in relation to steady-state DC. Both will be equal. For sinewaves, the conversion is peak time 0.707 = RMS.

Temperature Range (Rating) For current probes, the temperature range is the probe operating temperature. Like voltage probes, current probes have a maximum amplitude versus frequency derating. The heating effects of energy induced into the current transformer magnetic shielding require the derating. Increasing temperature causes increasing losses.

Tangential Noise. A practical method of specifying probe generated noise (active probes). Tangential noise figures are approximately two times RMS noise.

PART II: SELECTING PROBES

What to consider: Your scope

What is your scope's input capacitance? Scope input capacitance is normalized at the factory to a certain value such as 20pF. This normalization ensures proper attenuator stacking (the ability of the scope to provide flat response at each volts/division setting). The normalization also allows you to use probes previously compensated. (Nevertheless, it is wise to check probe compensation whenever you reconnect a probe.)

What are your scope's capabilities and limits? Consider these scope features when you look for probes:

- **What is your scope's bandwidth?** (Select a probe with equal or greater bandwidth specs.)
- **What is your scope's input capacitance?** (Select a probe with a compensation range covering the scope's nominal input capacitance.)
- **Does your scope have CRT of knob-skirt readout coding capability?** (Select a probe that provides automatic coding for scale factor equipped scopes.)
- **Does your scope have a 50 ohm 1M ohm input provision (switchable or fixed)?** (Consider a 50-ohm passive probe or an active (FET) probe for the 50 ohm inputs, in addition to standard passive probes for the 1M ohm inputs.)
- **Does your scope have side mounted input connectors?** (Select probes with right-angle connectors for compact routing of probe cables.)
- **Does your scope have true differential input capability?** (Select a differential probe or matched differential probe pair for maximum CMRR.)

What are the Trade-Offs? Generally, high-frequency (specialty) probes also perform satisfactorily in low frequency applications **if**:

- They are compatible with the scope input capacitance.
- They can interface with the DUT.

Drawbacks to using high-frequency probes for low-frequency applications are:

- Their higher price, compared to low-frequency probes offering the same performance at lower frequencies.
- They are physically more delicate, especially for most on-site service use.

Likewise, low-frequency (general purpose) probes may be perfect for many applications, even on high-frequency scopes, but they do put a ceiling on scope performance.

What to consider: Your application

You may be able to select a probe that serves many similar measurement needs. For three broad areas of interest, the tables below list typical measurement requirements and suggest probe parameters and probe choices that fill the requirements. If your needs fit those listed for one of these areas, you may pick a probe simply by choosing one that has:

- Wide enough bandwidth
- Ability to compensate to the scope input capacitance
- Ability to operate CRT or knob-skirt readout, if needed.
- Required attenuation.
- Mechanical requirements (such as length and available accessories).

For specific needs, and for applications that don't fit into these basic categories, see "What to Consider: Your Electrical and Mechanical Requirements," page 15.

Typical engineering and design application

High-frequency, specialty, absolute-measurement applications:

Typical measurement requirements:

- Circuit design and performance evaluation.
- High speed, fast risetime, low circuit loading.
- Measurements of pulse risetime, duration, propagation delay and time coincidence.
- Small size.
- Direct access to I.C. pins.
- Direct access to circuit board.
- Test points accessible via probe to etched circuit board adaptors.

Probe parameters needed:

- Bandwidth: 200-300MHz.
- Risetime: 1.75ns/1.16ns.
- Low tip capacitance (for example, 8 to 10 pF) for minimum loading at high frequencies.
- Compatible with scope input impedance of 1M ohms and 20 pF. (50 ohm scopes are suitable for general engineering applications under certain conditions; for example, where low capacitive loading is required and where low - 500 ohms-5K ohms - resistive loading can be tolerated).
- Cable length: 1 to 2 meters; typically 1 meter for the maximum bandwidth, fastest risetime and lowest tip capacitance.
- Short ground leads to minimize ringing.
- Probe-tip-to-ECB adaptor (for minimum ringing and maximum performance).

Typical service application

Mixture of high- and low-frequency, specialty and general purpose, absolute- and relative-measurement applications.

Typical measurement requirements:

- On-site troubleshooting: computers; office equipment; plant installations, electrical and electronic.
- Ruggedness, portability, low cost of ownership.
- Verification of signal presence or absence.
- Verification of signal waveform shape.
- Measuring signal amplitude and timing.
- Strong tips for reliability.
- Availability of medium and long ground leads to provide freedom of movement while probing several test locations.

Probe parameters needed:

- 100-300MHz, but typically 100MHz.
- Risetime = 3.5ns to 1.16 ns (3.5ns at 100MHz).
- Medium tip capacitance: 11 to 14 pF.
- 10X, 1X or 10X-1X switchable attenuation. (1X limits bandwidth to about 20MHz.)

- Cable length: 2 or 3 meters.
- Strong tips.
- Strong cables.
- Medium to long ground leads: 130mm to 300mm.
- Low cost of replacement or repair. (Low cost of ownership.)

Typical Manufacturing Application

Low-frequency, general purpose, relative-measurement applications.

Typical measurement requirements:
- Production testing: repetitive testing of specified parameters on a bench or production line.
- Go/no-go tests (is the waveform within given limits?)
- Measuring medium-speed to low-speed signals (depends on products tested).
- Adjusting and monitoring signal sources.
- Viewing product test points to verify or adjust to specs.
- Final testing.
- QC and audit applications.

Probe parameters needed:
- 50-200MHz (over 200MHz requires engineering probe).
- 10X to 1X or switchable attenuation.
- Medium tip capacitance: 11 to 14 pF.
- Strong tip and cable.
- Medium cable length (2 meters), to reach DUT.
- Low cost of ownership.
- 1X probe for maximum sensitivity to small signals (<100mV).

What to consider: Your electrical requirements

What is your specific test or measurement need? Are you making tests or measurements? Are you measuring amplitude (sinewave or pulse), pulse risetime, frequency or duty cycle? Are you making differential measurements?

Strictly speaking, a test produces a yes/no, go/no-go, pass/fail answer. For example: 3.25 V pp - risetime, 5.8nSec; pulse width, 1 μSec. For simplicity's sake, we will generally use "measurement" to cover both.

How will probe loading affect your measurement? A high impedance probe is important for both pulse risetime and amplitude measurements. But, the capacitive and resistive elements of the impedance are not equally important in both measurements.

In pulse risetime measurements, capacitance is more important than resistance because minimizing probe capacitance reduces risetime error. (See "How Probes Affect Your Measurement," page 4.) For flat top (amplitude) measurements, probe capacitance is less important if the pulse duration is at least five times longer than the RC time constant. However, the probe capacitance still degrades the risetime.

When measuring pulse amplitude, a high resistance probe (10M ohm) will give minimum amplitude error; however, any significant tip capacitance will still degrade the leading edge.

For sinewave amplitude measurements, a probe should have the highest possible impedance at the frequency of interest. Loading varies directly with frequency.

What is the waveform risetime? Observed risetime is the speed with which a scope responds to a changing signal level. For active (FET) probes, observed risetime is approximately equal to the square root of the sum of the squares of all the risetimes in the system (scope, probe and DUT). However, passive probes don't follow this rule. In fact, some actually enhance the performance of specific scopes by working in conjunction with the scope's input circuitry to provide a system bandwidth greater than that obtained by injecting the signal directly into that input. (Example: Tektronix 2465/P6131, 1M ohm inputs.)

As a general guide, however, take the lower of the two bandwidth figures as the limit: for example, for a 150MHz scope and a 250MHz probe, assume the system bandwidth is 150MHz. For a 300MHz scope and a 300MHz probe, assume the system bandwidth is 300MHz. (Risetime is related to bandwidth by the factor .35 as discussed on page 6.)

Accurately measuring very fast DUT risetimes requires minimal probe and scope risetimes.

What is the peak voltage? If you are measuring signals in circuits that have large voltage peaks, then you need a probe which can safely handle the signals.

For passive probes, the maximum input voltage is typically 500V peak. Active probes usually have a small dynamic range: typically +/−0.6V to +/−60V. High voltage probes can handle peak voltage from 2KV to 40KV, depending on type. All probes follow a voltage derating with frequency and/or pulse width spec.

What is the waveform amplitude? Manufacturers state probe maximum input voltage for passive probes (or dynamic range for active probes) as dc plus peak ac. To cover all situations, dc max (dc plus peak ac) is also the maximum safe input before electrical damage occurs. For example, ignoring frequency derating, we can say that a passive probe is linear from 0V to 500V.

Dynamic range specifications imply a linear operating range. Outside the range, we have the maximum safe input specification (before damage). For example, for the Tektronix P6201 FET Probe, the dynamic range is +/−0.6V and the maximum input is +/−100V (or +/−200V with attenuators).

What is the duty cycle? A waveform's duty cycle is the ratio of the pulse train's "on" time to its period. A symmetrical square wave has a 50 percent duty cycle. Duty cycle (also called "duty factor") is important only when you are using the probe near its maximum peak pulse limits—with high voltage probes, in particular. For example, Tektronix specifies its P6015 High-Voltage Probe at 40 KV peak with a 10 percent maximum duty cycle.

What is the bandwidth? For amplitude accuracy, the bandwidth of your scope/probe combination must be wider than the DUT bandwidth. As a rule-of-thumb, use a scope/probe combination that has a risetime at least four times faster than the measurement you expect to make. A 4.1 ratio gives you a risetime measurement within ± 3%.

A narrow probe bandwidth (relative to the DUT's maximum frequency content) attenuates high frequency sinewaves and rounds the edges of pulses.

Probe bandwidth is affected by the probe resistance and capacitance, as well as by the cable and connector transmission characteristics.

How important are system aberration specs? Aberrations are variations in the signal caused by the probe or the scope, or both. Typically, +/−4% peak-to-peak aberrations are tolerable. This percentage is a measure of the deviation from the flat section following the leading edge, assuming an ideal step function at the input.

Is timing coincidence important to your measurement? When two or more signals are being compared, it may be important to consider the effects, if any, of any differences in transit time through the probe cables. Applications where transit time is important are: time coincidence measurements, propagation delay measurements and power measurements (when a combination of voltage and current probes are used.)

Transit time is a fixed quantity and is a function of the length and propagation velocity of a specific probe cable. A typical Tektronix probe cable has a propagation velocity of about 4.2 nanoseconds per meter.

Phase shift implies a frequency component and is stated in degrees. It is related to transit time (propagation delay) by the following formula:

$$\frac{\text{transit time seconds}}{\text{period}} \times 360° = \text{phase shift degrees}$$

$$(\text{period} = 1/F)$$

Factors that contribute to phase error are:

- The cable length (because it affects transit time).
- The difference between the two transit times.
- Capacitive loading, which causes slew (degraded risetime) at the source, which in turn causes timing errors. (See note below.)
- Digital miscounting caused by capacitive loading induced slew.

NOTE: Probes that have wide compensation ranges (15 to 60 pF) and high tip capacitance can introduce phase error problems. It can be shown that probes with an excessive compensation range have a necessarily high tip capacitance, all other factors being equal. That's why Tektronix probes, in general, limit the upper compensation range to cover only the scope input capacitance they are designed to work with.

What to consider: Your mechanical requirements

Probe mechanical requirements are easy to overlook, but they are just as important as the electrical requirements. Answering the following questions should help you decide which mechanical features are important in selecting the probe that provides the perfect match for your application. (Also see "How Probe Design Affects Your Measurements," on page 9).

What size probe do you need? Shrinking integrated circuit packages and a rising number of pinouts make attaching a probe—especially several probes, close together—more difficult. Small probes are usually easier to handle and attach to test points. Sometimes, however, larger probes are better because they can be made more durable and can include a wider range of adaptors. The **standard** Tektronix probe is called a "miniature, modular" type probe. The lightweight, smaller versions are called "subminiature, modular" types.

What kind of tip do you need? Features to look for in probe tips are durability and type (either a fixed point or a retractable point that you can attach to a test point).

Probe tip durability is determined by the material and by quality of design and construction. The tip diameter and other features are set by industry standards and by reuirements for compatibility with adaptors, test points and other devices.

No matter how well made it is, **every probe has its breaking point.** All probes should be used with care, as you would with any other precision tool.

What cable length do you need? Cable lengths may be specified in inches, feet or meters. Most newly introduced Tektronix probes are specified in meters. Common lengths are: 1, 2 and 3 meters. Your application will determine what length you need.

A typical probe cable has a capacitance of about 7 pF/foot. With 1X probes, this capacitance, plus the scope input C, is presented at the probe tip. However, with attenuator probes (10X, 100X, etc.) the effect of this balk capacitance, as seen at the probe tip, is reduced by approximately the attenuation factor. It follows, therefore, that short (1M) passive attenuator probes will have the least tip capacitance while long 1X passive probes will have the most tip capacitance. (See capacitive loading.)

Modular or monolithic construction? Tektronix modular probes have three easily replaceable parts: a probe head, cable and compensation box. This approach enables the user to stock spares and make repairs to the probe in a matter of minutes by replacement of the defective module.

Some monolithic probes can also be repaired but they require a technician's time and materials; so it may be more cost-effective to simply replace them.

Miniature or subminiature configuration? The most common configuration for passive probes is the miniature type. These probes have a standardized tip and ground ring configuration that allows them to interface with a wide variety of tip accessories and ECB test points. They have a nominal tip diameter of 0.04 in. and a nominal ground ring diameter of 0.19 in.

Miniature probes are available in all performance ranges and are used where high density use of multiple probes is not the prime consideration.

The subminiature probe configuration is useful for probing high density circuitry and for use where several probes have to be attached in close proximity. These probes have a nominal tip diameter of 0.02 in. and a nominal ground ring diameter of 0.14 in.

Subminiature probes have their own wide range of tip accessories and ground lead arrangements and can interface with ECB test points designed for this series.

Tektronix subminiature probes also interface with the Tektronix KLIPKIT. Up to 16 probes can be inserted to allow hands-free connection to an integrated circuit.

What are the environmental conditions? Especially in field applications, probes are sometimes exposed to harsh conditions. Probe parameters drift with changing humidity, temperature and aging.

In high humidity, the attenuator in the probe head absorbs moisture from the air. The moisture distorts the probe's response, an effect called "dielectric absorption" or "hook." Hook is strongest at 1KHz. It shows up as a spike or roll-off of a 1KHz square-wave leading edge. Hook is usually noticeable during low-frequency compensation of the probe.

How to select the best probe for your needs

This process may be as simple as selecting the probe supplied or recommended by the manufacturer of the scope, or as complex as selecting a probe to make high current measurements on new power supply designs.

The correct attenuator (10X) or active probe should provide specified scope bandwidth **at the probe tip.** With few exceptions, probes are not designed to **increase** the bandwidth of your scope.

Characteristics

	Attenuation	Accuracy	Input Resistance	Input Capacitance 3½ ft	6 ft	9 ft	Probe Risetime	Aberrations	Bandwidth	Nominal Cable Length (ft)	Maximum Dc Voltage	Derated Above	Derated to @Frequency	Compen-sation Range (pF)
P6007	100X	3%	10 MΩ	2 pF	2.2 pF	2.4 pF	14.0 ns	±3	25 MHz	3½, 6, 9, 12	1.5 kV	200 kHz	2 kV @5 MHz	15 to 55
P6009	100X	3%	10 MΩ		2.5 pF		2.9 ns	± 3	120 MHz	9	1.5 kV	200 kHz	300 V @20 MHz	15 to 47
P6015	1000X	Adjustble	100 MΩ		3 pF (10 ft only)		4.0 ns	± 5	75 MHz	10	20.0 kV	100 kHz	2 kV @20 MHz	12 to 47

Table 1: Tektronix High Voltage Probes

Bearing these facts in mind, check the following guidelines for the type of application area you are interested in and then refer to manufacturer's spec sheets for your scope model, or if not listed, select a probe to match your scope's BW and input capacitance. Remember that Tektronix probes are compatible with other manufacturers' scopes, provided that the basic requirements of BW and input C are met. Tektronix probe features, such as CRT or knob-skirt readout and identify functions, are also compatible with scopes not incorporating these features; however, they will be non-functional.

Selection Guidelines:

For general purpose, maximum bandwidth applications:

1 Select or use the probe specified by the scope manufacturer as the standard accessory or recommended accessory probe for that scope. In the case of Tektronix probes and scopes, this will ensure scope bandwidth **at the probe tip,** unless otherwise specified.

2 Select an active 10X probe providing about 2 pF capacitive loading and 10M ohm input resistive loading if your circuit output level is no greater than 12 volts pp, or 120 volts pp with a 100X attenuation probe. (For 1M ohm or 50 ohm inputs.)

For general purpose, maximum sensitivity applications:

1 Select a 1X/10X switchable probe that gives you high sensitivity at 1X at reduced bandwidth (about 12MHz) and low capacitive and resistive loading at 10X, up to 200MHz.

For maximum sensitivity applications:

1 For low frequency use, choose a 1X probe for low-cost, wide dynamic range, and low bandwidth applications (up to 30 MHz). Use 10X probes for general purpose work.

2 For high frequency use, choose an active probe (FET) with a 1X sensitivity. These will provide high sensitivity, low capacitive loading and wide bandwidth (up to 900MHz). Trade-offs are their price and narrow dynamic range.

For minimum circuit loading at high frequencies:

1 Select a passive 50 ohm type probe providing about 1 pF capacitive loading if your circuit can accept a resistive loading of 500 ohms (10X) or 5K ohms (100X). This requires the scope to have a 50 ohm input provision.

2 Select an active 10X probe providing about 2 pF capacitive loading and 10M ohm input resistive loading if your circuit output level is no greater than 12 volts pp, or 120 volts with a 100X attenuation probe. (For 1M ohm or 50 ohm inputs.)

3 Select a bias/offset probe for high speed ECL probing. This provides about 1.3 pF loading and 450 ohm resistive loading. The dc offset feature helps cancel the effects of probe resistive loading under user-selectable conditions.

For high voltages:

High voltage probes are derated with frequency, so it is important to know your signal characteristics before choosing a specific probe. If your signals are from dc to about 100 KHz, you can select a high voltage probe from its **maximum dc voltage** specs.

If your signals are beyond about 100 KHz, or are pulses, single-shot or repetitive, you will need to consult the manufacturer's detail specs to determine if your first-look probe will do the job. (Table 1.)

Here is an example:

Signal: 800V, RMS, 5MHz Sine

First-look probe: Tektronix P6009 1.5KV probe

Frequency Derating: The 6009 is derated to 700V RMS at 5MHz. Probe would be overstressed (derating curves are included in the instruction manuals).

Final Choice: Tektronix P6015 20KV probe

Frequency Derating: The P6015 is derated to about 6KV at 5MHz. This probe will make your measurement with headroom to spare.

Worksheets: If you have a unique or specific voltage probing application not resolved by the foregoing selection guidelines, refer to the completed examples of worksheets 1, 2 and 3 on Page 22, then fill out copies of the appropriate blank worksheets found at the back of this primer.

Selecting the right current probe

Current can be derived from voltage measurements made across an added or existing resistor and simply appling ohms law, I = E/R.

This may be a valid method for some applications, but in the majority of cases, the added resistance and/or probe capacitive loading can change the circuit operation and, therefore, produce inaccurate test results.

A current probe offers the minimum circuit loading possible and, therefore, gives the most accurate test results.

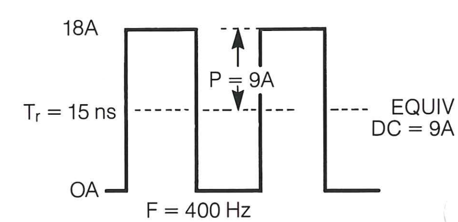
Current probes are classified as either AC responding (AC) or AC and DC responding (DC), and are either a fixed core or split-core configuration, as described under **Types of Probes.** We need to know a lot more about the total signal being measured when selecting a current probe. This will become evident when examining the tables and worksheets that follow.

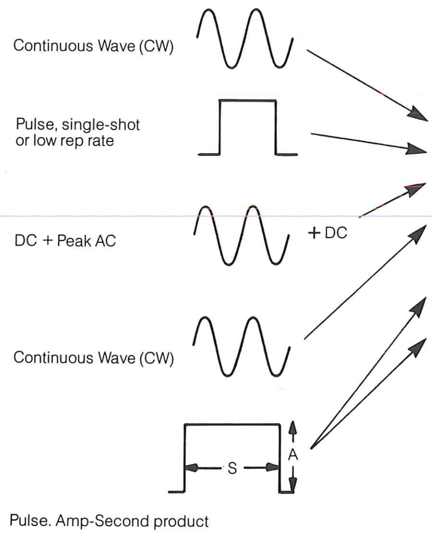
The terms used are the same as found in Tektronix catalogs and spec sheets.
(Table 2.)

Application Example: Repetitive Signals.

To illustrate the use of the catalog information, we will take a typical switching power supply application as an example.

• I need to measure current, risetime, repetition rate (frequency) and monitor waveshape. Output signal is unidirectional, based at ground potential. What probe do I need?





Characteristics

	A6302 & AM 503	A6303 & AM 503
Sensitivity: Scope @10 mV/div Accuracy 3%	1 mA/div to 5 A/div	10 mA/div to 50 A/div
Bandwidth	Dc to 50 MHz	Dc to 15 MHz
Risetime	7 ns	23 ns
Max Ac Current CW	40 A p-p	200 A p-p
Derated above	20 kHz 2.5 A @10 MHz	20kHz 12 A @10 MHz
Maximum Current Peak Not to Exceed A-S product	50A	500A
A-S Product	100×10^{-6}	$10{,}000 \times 10^{-6}$
Insertion Z	0.1 Ω @5 MHz 0.5 Ω @50 MHz	0.02 Ω @1 MHz 0.15 Ω @15 MHz
Max Hardware Volts	500 V	700 V
Max Conductor Diameter	0.15 inch	0.83 inch
System Prop Delay	≈30 ns	≈40 ns
Cable Length	2 m	2 m
Tangential Noise	0.3 mA	3 mA
Aberrations	±5%	±5%
Magnetic Susceptability	250 μA/Gauss	25 mA/Gauss
Operating Temp	0°C to +50°C	0°C to +50°C

Note: A6302/AM 503 or A60303/AM 503 calibrated as a set.

Table 2 Basic Specs
The basic specs involved in selecting a current probe for making either continuous or single-shot measurements.

Selection Steps: This is a repetitive waveform with a substantial DC content (because it's unidirectional). Most AC current probes cannot handle more than 0.5A DC without special techniques, such as DC current bucking; so we will only consider DC current probes for this application.

Question	Answer
1. What is the expected maximum continuous current?	18A pp. made up of 9A equiv. DC + 9A peak AC.
2. What is the operating frequency?	400 Hz, but the frequency content of the leading/falling edges will take precedence. See Risetime.
3. Do I need to derate the max. AC current (cw) specs at my operating frequency?	No. (Determined by final probe choice).
4. What is the waveshape?	Square.
5. What is the risetime?	15ns: Risetime is related to bandwidth by the factor 0.35. Therefore, the equiv. frequency is 23MHz.
6. What is the DC content, (if any), of the waveform.	9A: (A symmetrical waveform starting from ground will have an equiv. DC content of .5 X p-p.)

Summary. In order to make the required measurements on this particular power supply we need a probe that:

Requirements	Probe Choice: A6302/AM503
1. Can handle 18A PP continuous	40A P-P (or 20A DC + peak AC)
2. Has an equiv. bandwidth of at least 23MHz	50MHz
3. Does not need to be derated at the operating frequency (400 Hz) - Derating for risetime-derived frequency does not apply because the duty-cycle of the high frequency content is very low.	Derated beyond 20KHz
4. Can I see a true representation of my waveform?	Yes: DC to 50 MHz
5. Can I measure my risetime of 15nS	Yes. T_r of A6302 is 7nS; however, the square root of the sum of the squares formula will apply. This includes the source, A6302/AM503 and the scope.

$$T_r \text{ displayed} = \sqrt{Tr^2\text{scope} + Tr^2\text{ probe} + Tr^2\text{ scope}}$$

For example: If the A6302/AM503 is used with a 400MHz scope, the displayed risetime will be 16.57nS - about 10 percent slower than actual.

If you need to know the actual risetime more precisely, use the following formula:

$$Tr\text{ source} = \sqrt{Tr^2\text{displayed} - Tr^2\text{ probe} - Tr^2\text{ scope}}$$

Remember, probes should only be included in these formulas if they are *active* types, such as FET voltage probes or current probes employing active elements in their basic design.

To determine the correct current probe for your application, fill out a copy of the appropriate worksheets found on pages 23 & 24.

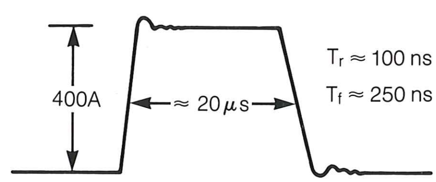
Fill out either the worksheet for continuous wave (cw) applications, or the worksheet for single-shot applications plus the common worksheet for all current measurement applications.

Use the "Your Requirements" column to determine the best probe for your needs based on manufacturers specifications.

Application Example: Single-Shot Signals

To illustrate the use of the catalog information again, we will take a single-shot current pulse application as an example.

- I need to measure the peak current, risetime, falltime and pulse width of my single-shot current pulse. I think my waveform should look similar to the illustration below. My conductor diameter is 3/8", what probe should I use?



Solution Steps: This time we will go directly to the worksheet "Selecting a Current Probe to Measure Single-Shot and Low-Rep-Rate Pulses" and use this in conjunction with the manufacturers specs.

By answering the questions on worksheets #5 & #6 as shown on page 18 in conjunction with the manufacturers specs (Table 2) you can make a quick selection of the current probe for your application.

Curent Probes - Summary

Space does not permit a more thorough discussion of current probes. Factors such as range extension, increasing the amp-second rating and DC current bucking may enter into the selection process. If you have questions, please call your local Tektronix sales engineer—He has the means to get you the answers to your unique application needs.

Tips on using probes

Compensating the probe. The most common mistake in making scope measurements is forgetting to compensate the probe. Improperly compensated probes can distort the waveforms displayed on the scope. The probe should be compensated as it will be used when you make the measurement.

The basic low frequency compensation (L.F. comp.) procedure is simple:

- Connect the probe tip to the scope CALIBRATOR (refer to Scope Calibrator Outputs.)
- Switch the channel 1 input coupling to dc.
- Turn on the scope and move the CH1 VOLTS/DIV switch to produce about four divisions of vertical display.
- Set the sweep rate to 1mSec/div. (for line-driven calibrators see Scope Calibrators Outputs.)
- Use a non-metalic alignment tool to turn the compensation adjust until the tops and bottoms of the square-wave are flat.

Scope calibrator outputs

Most scopes provide a square-wave amplitude calibrator signal accessible from the front panel. It provides two primary functions:

1 A peak-to-peak reference voltage for checking scope amplitude calibration and overall probe scope calibration accuracy.

2 A square-wave repetition rate and frequency content suitable for checking and adjusting the low frequency compensation (L.F. comp.) of passive attenuator probes.

In addition to its primary functions, some calibrator outputs also provide:

- A reference current via a built-in current loop for checking calibration of current probes.
- A frequency reference for checking basic scope timing.

Scope calibrators are either a fixed frequency type or a tracking frequency type.

Fixed frequency calibrators (line frequency calibrators). These square-wave calibrator signals operate at two times the line frequency (120Hz for 60Hz lines, 100Hz for 50 Hz lines). Because of the inherent accuracy of the power line grid frequency, these calibrators can also be used to check basic scope timing accuracy.

One kilohertz (1KHz) calibrators. These are the most common form of scope calibrator signals, providing an approximate 1KHz repetition rate square-wave suitable for checking or adjusting scope or probe-scope amplitude accuracy and for checking or adjusting probe L.F. comp.

Tracking-frequency calibrators. Scopes such as the Tektronix 2445 and 2465, provide a calibrator signal keyed to the sweep rate. This feature ensures that there will always be five complete cycles on screen (at 1X sweep magnification) and provides an easy means of checking sweep calibration over a wide range of sweep rates. The frequency operating range of this type of calibrator is 5Hz to 5MHz.

When checking or adjusting probe L.F. comp., it is important to set the sweep rate at 1mSec div. This ensures that the calibrator square-wave frequency will be optimized for viewing the time constant associated with the low frequency compensation adjustment (L.F. comp).

Worksheet No. 5

SELECTING A CURRENT PROBE TO MEASURE SINGLE-SHOT AND LOW-REP-RATE PULSES

Major Parameters (Questions to be answered)	Current Probe Terms	Your Requirements (your answer here)	Your Selection (from Mfgrs. spec. sheets) Probe Spec. (≥ Your Requirements)	Probe Model (Meeting Your Requirements)
1. What is the expected maximum peak current?	Max. peak current	≈400A	500A	A6303/AM503
2. Do I have to apply the Amp-Second formula? You can only answer this question after making a preliminary selection based on your answer to question #1. RULE: If the combined DC plus peak pulse is greater than the max. AC current (cw) spec. of the selected probe, apply the formula. If it is less than this spec, ignore the A-S formula.	Max. AC current (cw) (convert specs to peak if necessary)	YES. MAX AC CURRENT SPEC IS 100A PEAK. MY PULSE IS 400A I MUST APPLY A-S FORMULA	X	X
3. What is the pulse width at the 50% point? NOTE: It may be more convenient to deal in A − µs. A − µs product = A × µs or Width µs = $\frac{A-\mu s\ Prod.}{A\ Peak}$	Amp-Second Product (A-S Product)	20µS 400 × 20 = 8000 A-µS	10000 A-µS	A6303/AM503
4. What is the risetime/falltime?	Risetime	≈ 100nS	23nS	A6303/AM503
5. What is the DC content?	Maximum DC: AC current probes, listed as a separate line item. DC current probes: Max. DC = Max. peak AC (cw), made up of DC + peak AC.	NONE	NA	A6303/AM503
6. Now answer the questions common to all applications on worksheet 6 before making a final selection.				

Worksheet No. 6

SELECTING A CURRENT PROBE QUESTIONS COMMON TO ALL APPLICATIONS

Major Parameters (Questions to be answered)	Current Probe Terms	Your Requirements (your answer here)	Your Selection (from Mfgrs. spec. sheets) Probe Spec. (≥ Your Requirements)	Probe Model (Meeting Your Requirements)
NOTE: Your application will determine whether the following parameters are of major or minor importance. Answer the questions to find out.				
Will my circuit be affected by the inclusion of a small series impedance? (usually less than 0.1 ohm). A function of frequency and probe type, can vary from low micro ohms to 2 ohm at high frequencies.	Insertion Z INSERTION Z	NO		A6303/ AM503
Am I measuring current through a bare wire? Is is elevated? What is the voltage?	Max. hardware volts. (varies from 500v to 3Kv. Depends on probe type. Range may be extended with insulation or bushing material.	NO		A6303/ AM503
What is the diameter of my current carrying conductor? (include insulation, if any)	Max. conductor diameter	0.375"	0.83"	A6303/ AM503
Am I making simultaneous voltage & current (power) measurements? Am I comparing one waveform against another in terms of propagation delay or phase shift? Is this important to me? (See Timing coincidence: What to Consider Your Electrical Requirements, page 15)	System Prop. delay. Must consider DIFFERENCE between the two signal paths.	NO SINGLE CHANNEL ONLY	N/A	

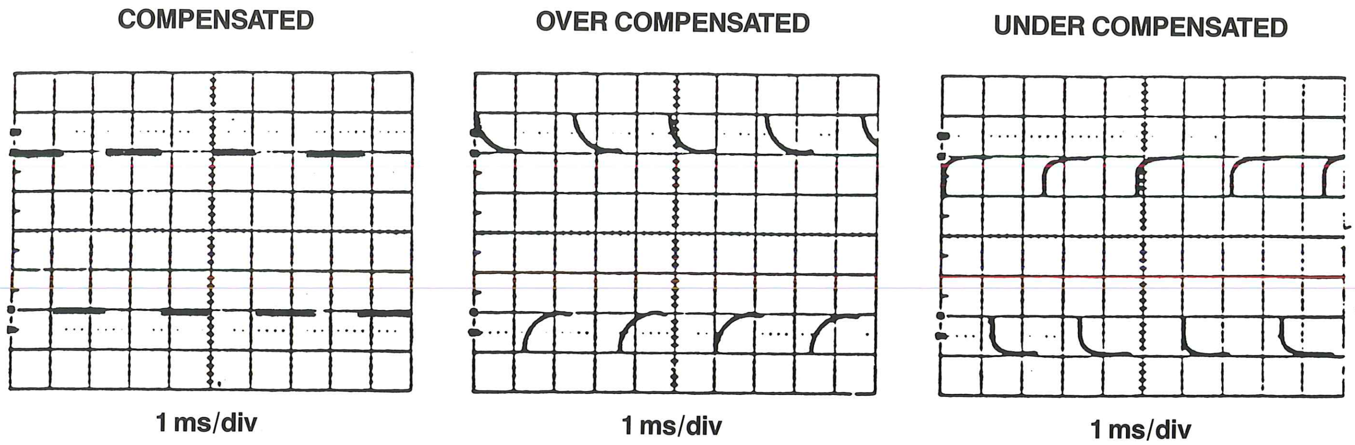


Figure 16

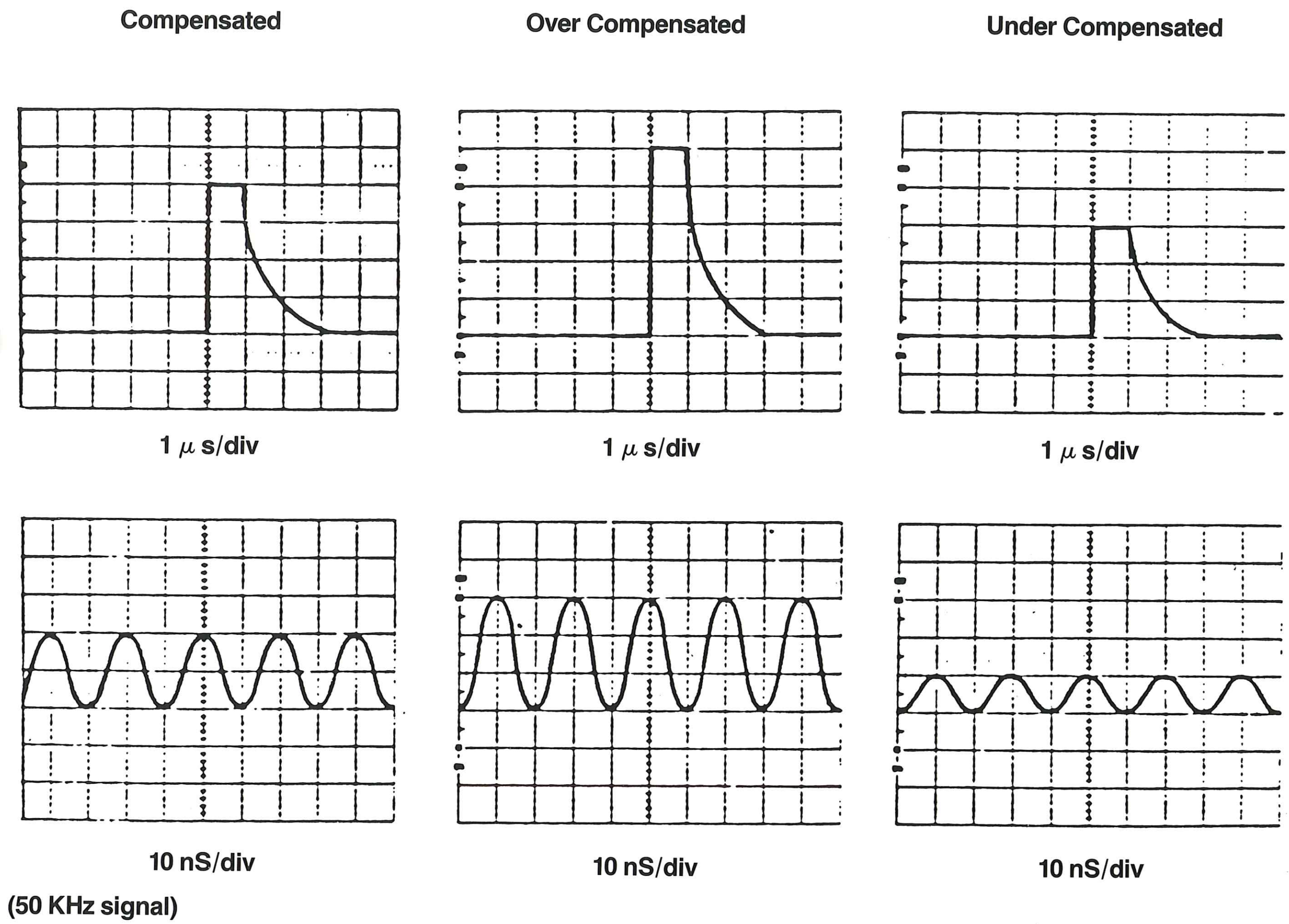


Figure 17 Effects of probe compensation.

Figure 16 shows the display associated with correctly and incorrectly compensated probes.

Figure 17 shows the effects on faster pulses and sinewaves when an incorrectly compensated probe is used. Note that the much faster sweep rates used to correctly view these waveforms does not warn the user of an adjustment problem.

Choosing the right ground option. Make sure the ground in the DUT is the same as the scope ground (don't assume it is). The scope ground is always common to the DUT ground if you are using the power cord and plug and it's plugged into the same three wire outlet system as used by the DUT. Check the circuit ground by touching the probe tip to the point you think is ground—before making a hard ground by attaching the ground strap of your probe.

If you intend to probe many points in the same circuit and measure low frequencies, you can ground the circuit to your scope once, instead of every time you move the probe. Connect the circuit ground to the GND jack on the scope front panel.

A special problem that occurs when measuring very high speed signals is ringing due to inductance in the ground-return path. (See "How Ground Leads Affect Your Measurements," page 7.) Probes come with a wide range of grounding accessories, allowing you to pick the right ground leads for the DUT's signal frequency range.

Optional accessories include BNC to probe tip adaptors and etched circuit board (ECB) probe test jacks.

Choosing the right tip for the frequencies measured can minimize ground-path ringing.

Caring for the probe tip. Following a few guidelines will prolong the lifetime of your probe tip:

- When you are not using the probe, cover the tip with the tip protector that is supplied with most probes.
- Use the correct adaptor, such as an IC grabber or a retractor tip.
- Don't use the probe to scrape through insulation, pry components from their sockets, or to move components.
- Don't use the probe to hold down components while soldering in place.
- Remember—no matter how well it is made, **every probe has its breaking point.** All probes should be used with care, as you would any other precision tool.

Pitfalls in using probes: Watch out for these pitfalls in using probes:

- Using probes without checking L.F. comp.
- Not using ground leads or using ground leads that are too long (causing ringing).
- Connecting a probe ground lead to elevated ("hot") circuitry. The resulting damage is not covered by probe warranties.

The Care and Handling of Tektronix Split-Core Current Probes

Tektronix split-core current probes incorporate a precision pick-up assembly in the probe head. This assembly is designed to sense current flowing in the user's circuit and present an accurate representation of this current to the input of an oscilloscope.

Tektronix pick-up heads employ a transformer or a combination of transformers and Hall effect devices in a ferrite core assembly. This assembly includes a sliding ferrite/shield section which, when closed, forms a completed magnetic circuit.

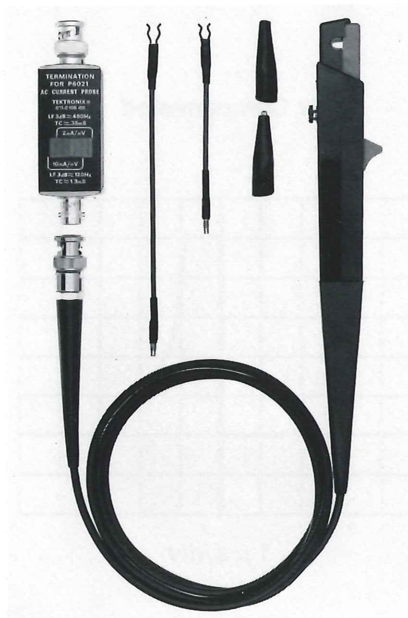


Figure 18. P6021 Current Probe and termination.

The Importance of The Sliding Magnetic Interface: The split-core magnetic surfaces are lapped by means of optical quality grinding equipment to an overall surface flatness of 34 micro inches or better. This high degree of flatness and finish is necessary in order to preserve the amplitude accuracy and the low frequency response of the probe.

Any dirt, grease or other contaminates on the surfaces can cause separation sufficient to degrade performance. For example: a 300 micro inch separation can cause up to 30 percent reduction in signal amplitude and also seriously degrade low frequency performance. Any physical shock or damage resulting in surface misalignment can have similar effects.

Care of Tektronix Split-Core Current Probes: Tektronix split-core current probes are precision instruments and must be handled carefully in order to preserve their specified performance.

1. The precision-lapped surfaces are vulnerable to damage when the sliding core is open, so place the probe gap ("U" shaped section) carefully over the wire carrying the current to be measured. Do not scrape the probe ovr the measurement point or otherwise scratch the exposed surface.
2. Do not "flick" the sliding section forward. Move it gently but firmly forward under thumb control. Make sure that it is fully forward in the locked position.
3. Do not force too large a diameter wire into the probe gap.
4. Do not measure conductors dissipating sufficient heat to raise the interior of the probe to above 50°c.
5. Do not drop the probe or subject it to twisting or pulling motions.
6. Do not lay the probe or probe cable near hot soldering irons.
7. Do not perform soldering operations adjacent to the probe with the probe in place.

Calibration and Maintenance: Follow the instructions outlined in the specific probe manual for calibration, cleaning and maintenance. The following extract from the Tektronix P6021 manual can be used as a guide for cleaning of Tektronix split-core current probes.

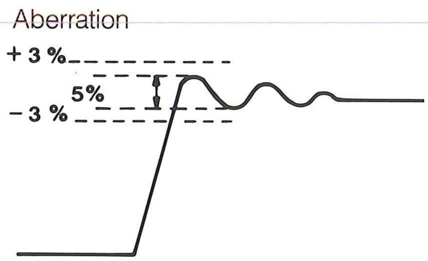
"Cleaning the Current Probe: The current probe should be taken apart and cleaned periodically, depending upon the local conditions. Use a soft bristle brush to dislodge the dust and wipe clean with a soft cloth. If a persistent coating of dirt remains, it can be removed by washing the plastic portions of the probe in warm water with some liquid detergent added. Allow the parts to air dry thoroughly, or wipe dry with a lint-free cloth. Apply a coating of Lubriplate or similar lubricant to the contact areas of the spring. Keep lubricant away from the ferrite core surfaces.

While cleaning the probe, make a visual check of the probe parts. Look for any excessive wear of the slide parts which might cause improper operation later on. Dirty or worn mating surfaces between the transformer and the lid will degrade low-frequency response. Clean these surfaces if necessary.

NOTE: Do not use any organic solvents to clean the probe."

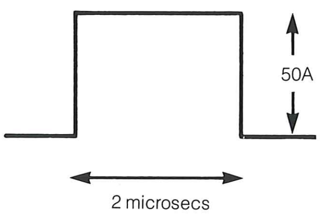
GLOSSARY OF PROBE TERMS

Aberrations are a measurement system's response to a pulse input. Manufacturers specify aberrations as a percentage deviation from a flat response.



Amp-second product is a specification used with current probes. It defines the maximum area under the curve of a single pulse, when the peak amplitude exceeds the continuous rating or the probe. For example for a Tektronix A6302 Current Probe, the amp-second product is 100 X 10^{-6} AS., the maximum CW current is 40 A pp (14 A rms), and the maximum peak is 50A. In this case, the maximum time is 2 microseconds:

$$\text{Time} = \frac{\text{AS (in microsecs)}}{\text{A peak}} = \frac{100}{50} = 2 \text{ microsec}$$



Attenuation factor is the ratio of a probe input signal amplitude to its output signal. For example: 10X is the attenuation factor of a 10-to-1 attenuation probe.

Bandwidth limitation is a measurement system's highest useful operating frequency. This measurement is made at the system's 3 dB point (the point at which the input signal magnitude drops to 0.707 of its zero-frequency value, which is dc).

Capacitive loading is the effect of probe tip capacitance on the circuit you are testing. Generally, FET (active) probe and 50 ohm probe capacitive loading is minimal at higher attenuation ratios (X100) and short cable lengths (1 meter). For 10X passive probes, high bandwidth specs, short cable lengths, and restricted upper compensation range (15 to 35 pF) generally produce low tip capacitance.

Circuit loading is the effect that a probe has on the DUT. Touching a probe to the DUT adds the probe resistance, capacitance and inductance to the circuit. Because the DUT provides current for this new load, the signal passing through the DUT changes. Minimizing the load on the DUT minimizes changes in the signal. (Also called "loading effect.")

A compensated divider is a signal-divider circuit that provides an equal division ratio over a wide frequency band (for example: dc to 300MHz). In other words, the ac division ratio equals the dc division ratio when the divider is properly compensated.

Compensation range is the range of the scope input amplifier input capacitances for which you can compensate your probe. For example: a probe with a compensation range of 15 to 35 pF can be compensated to any scope with nominal input capacitance of 15 to 35 pF. A common example is a scope that has a 20 pF input.

CW frequency current derating is a current probe spec that is a function of power dissipation. This curve is similar to the curve for voltage derating with frequency.

Duty cycle is the ratio of pulse width to signal period, expressed as a percentage and synonymous with Duty factor, which is duty cycle expressed as a decimal, not a percentage.

Falltime is the time required for the trailing edge of a pulse to fall from 90% to 10% of its final value.

Ground lead effects are the oscillation and ringing that appear on a signal when the probe ground path adds inductance to the signal path.

Impedance is the total opposition that a circuit presents to ac. It includes resistance, capacitance and inductance.

Input attenuation is the decrease in signal amplitude resulting from the probe/scope attenuation ratio. Scopes have an input resistance of approximately 1M ohm; most probes have a 9M ohm input resistance. The combined resistance attenuates the signal by 10 to 1. The tolerance of the probe input resistance directly affects the measurement system accuracy.

Input capacitance is the total capacitance at the probe tip. Because capacitors in series add inversely, the only significant value is the capacitance in the probe head, which is designed to be as small as possible. For example:

$$C = \frac{1}{\frac{1}{12} + \frac{1}{58}} = 9.9 \text{ pF at the tip}$$

Input resistance is the total probe and scope series resistance seen by the DUT.

Insertion impedance is the effect on a circuit of connecting a current probe to the circuit. Connecting the probe, in effect, adds a small series impedance (usually less than 1 ohm) at a specific frequency.

Maximum input current rating is a spec for current probes. It is the maximum continuous (CW) current (in peak, peak-to-peak or rms) that the probe will safely accept. Maximum input current rating is derated with frequency.

Maximum peak pulse current is the maximum peak pulse current that a probe can safely accept, under any conditions. For a specific probe system, the A-S (amp-second) product dictates the maximum pulse duration.

Maximum voltage rating is a spec for standard 10X probes. It is the maximum voltage the probe can accept without power-dissipation damage to the probe head or breakdown in the cable connector. A typical value is 500V (dc plus peak ac).

Measurement system includes the DUT, probe and scope.

Period is the time required for one cycle of a signal, if the signal repeats itself.

Phase shift results from adding inductive or capacitive elements to the signal path. The practical effect is retarding or advancing a time point on a waveform. Phase shift is frequency-dependent and most important in power measurements.

Propagation delay is also called "transit time." It is a term usually applied to pulse signals and is frequency independent. It is the time, in picoseconds or nanoseconds, taken by a wavefront to travel a given distance in a conductor. Cables and active components introduce some delay, and delay lines are designed to introduce delay. Example: probe cable propagation delay is 4.19 ns/meter.

Probe compensation is the adjustment of a probe capacitance so that the probe attenuates all input signals equally across a range of frequencies.

Pulse parameters are risetime, falltime, amplitude and width.

Repetition rate states how often a rectangular waveform (a pulse) occurs. (Frequency states how often a sinewave occurs.)

Risetime is the time required for a leading edge of a pulse to rise from 10% to 90% of its final value.

Sensitivity is a function of system gain and (for scopes) is stated in volts per division or amps per division. Sensitivity may be stated as gain (for example: 100.000) for free-standing devices such as amplifiers that have no display devices attached.

Temperature rating specifies the temperature range over which the probe will operate within the published electrical specifications. Operating temperature and storage temperature specs usually follow military standards (especially, MIL-T-28800).

Time constant is the product of a circuit's resistance and capacitance. It usually determines the 3 dB roll-off point for ac-coupled devices. Whether the capacitance is in series or in parallel determines the effect on source risetime.

Voltage/frequency/derating is the maximum voltage (dc plus ac) that a probe can safely handle at a given frequency. The maximum voltage drops with rising frequency.

Worksheet No. 1

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What is my scope's bandwidth?	BW Scope BW System	Scope/plug-in (system) BW follows the square root of the sum of the squares (risetime) formula.	Refer to manufacturer's scope or scope/plug-in system specs.	≈ 400 MHZ	?
What probe bandwidth do I need?	BW Probe	With few exceptions, probes can not increase the BW of your scope. Standard accessory probes generally provide full scope BW at the probe tip	1) Choose the probe supplied or recommended by the scope manufacturer 2) Or choose a probe with equal or greater BW than your scope.	AT LEAST 400 MHZ	?
Do I need a probe other than the specified standard accessory item? If so, answer the following questions.					
What is my scope's input resistance; 1MΩ or 50Ω?	Input R Scope	Marked on the scope (or plug-in) front panel	For passive probes, choose a probe to match the scope's input system (50Ω or 1MΩ). Active (Fet) probes will match either system	50Ω	?
What is my scope's input capacitance?	Input C Scope	Marked on the scope (or plug-in) front panel	Choose a probe with a compensation range that covers your scopes input C. (Does not apply to 1X Probes, Active Probes, or 50Ω systems)	N/A	?

Worksheet No. 2

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What overall sensitivity (attenuation) do I need or can tolerate?	Attenuation Probe. (1X,10X etc.)	Attenuation is a necessary trade-off for reduced Tip C. (except active probes)	• If your signals are between 100mV and 400V peak to peak; choose a 10X probe. • If they are less than 100mV, choose a 1X probe. • If they are greater than 400V, choose a 100X or 1000X probe.	10X	P6056? P6230? P6202A ?
What resistive loading can my circuit tolerate?	Resistive loading Probe	Typical 10X passive probe is 10MΩ. Resistive loading is usually not a factor, except when using "50Ω type" probes.	For general purpose work, choose a 10X passive probe. For high frequency and fast risetime observation, choose a 50Ω type, a bias-offset type, or an active (Fet) probe.	50Ω ENVIRONMENT	P6056? P6230?
What capacitive loading can my circuit tolerate? (capacitive reactance Xc)	Capacitive loading Probe.	Capacitive loading becomes the major factor at high frequencies. (See "How Probes Affect Your Measurements" page xx)	For general purpose work, choose a passive 10X probe. For high frequency and fast risetime observation, choose a probe with the lowest input C. Either a 50Ω type or an active (Fet) probe.	VERY LOW	P6056
Are my signals referenced to ground? If not, I may need differential probes	Elevated, Isolated Differential. CMRR	True differential measurement capability requires either a differential probe or a true differential amplifier with specially matched probes.	Do not "float" your scope. Use differential probe power with scope differential amplifier, or differential probes with standard (single ended) inputs. Or special isolation amplifier (A6902B).	NO	P6056

Worksheet No. 3

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What cable length (reach) and type of accessories do I need? Is physical size a problem?	Cable length (feet or meters)	Cable length increases the probe tip capacitance — except active (Fet) probes.	Choose the shortest cable length for lowest input C (passive probes). Choose miniature probes for maximum availability of accessories. Choose sub-miniature probes where space is a major consideration.	6' OR LESS	P6056 (6')
Does my scope have CRT or knob-skirt readout?	CRT readout. Knob-skirt readout	Compatible probes code the readout to show the actual sensitivity at the probe tip; such as 10V/div etc. No calculations are needed.	If your scope has this feature, choose a probe offering "readout", unless other features take precedence.	YES	P6056
Do I need to locate where ground (OV) is on my CRT, on a regular basis?	Ground ref.	Many probes have a "ground ref" button as a standard feature. This button shows where ground is on your CRT. Functions with all scopes.	Select a probe that combines this feature with the other functions you need if possible.	NO	↓
Does my scope have a "trace identify" or "sequencing" function?	Identify sequence	Some scopes respond to an "Identify" command by showing "Identify" in the CRT readout and by shifting the appropriate display slightly. Some respond by sequencing digital program steps.	If these features are important to you, select a probe that provides these functions, such as the Tektronix P6053B	COULD USE IT (IS ON P6056)	↓

Worksheet No. 3

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What cable length (reach) and type of accessories do I need? Is physical size a problem?	Cable length (feet or meters)	Cable length increases the probe tip capacitance — except active (Fet) probes.	Choose the shortest cable length for lowest input C (passive probes). Choose miniature probes for maximum availability of accessories. Choose sub-miniature probes where space is a major consideration.		
Does my scope have CRT or knob-skirt readout?	CRT readout. Knob-skirt readout	Compatible probes code the readout to show the actual sensitivity at the probe tip; such as 10V/div etc. No calculations are needed.	If your scope has this feature, choose a probe offering "readout"; unless other features take precedance.		
Do I need to locate where ground (OV) is on my CRT, on a regular basis?	Ground ref.	Many probes have a "ground ref" button as a standard feature. This button shows where ground is on your CRT. Functions with all scopes.	Select a probe that combines this feature with the other functions you need if possible.		
Does my scope have a "trace identify" or "sequencing" function?	Identify sequence	Some scopes respond to an "Identify" command by showing "Identify" in the CRT readout and by shifting the appropriate display slightly. Some respond by sequencing digital program steps.	If these features are important to you, select a probe that provides these functions, such as the Tektronix P6053B.		

Worksheet No. 4

SELECTING A CURRENT PROBE TO MEASURE CONTINUOUS WAVE (CW) SIGNALS

Major Parameters (Questions to be answered)	Current Probe Terms	Your Requirements (your answer here)	Your Selection (from Mfgrs. spec. sheets)	
			Probe Spec. (≥ Your Requirements)	Probe Model (Meeting Your Requirements)
1. What is the expected maximum continuous current (in peak, peak-to-peak or RMS)?	Max. AC current (CW)			
2. What is the operating frequency? Include risetime-derived bandwidth if you need a true representation of leading/falling edges.	Bandwidth (probe)			
3. Do I need to derate the max. AC current (cw) specs. at my operating frequency? (fundamental frequency only).	Derating with frequency spec sheets give basic "derated above/below" info. Detailed curves are in the instruction manuals. If in doubt call your Tektronix Sales Engineer			
4. What is the waveshape (sine pulse or square)? If pulse or square, what is the risetime/falltime?	Risetime			
5. What is the DC content (if any) of the waveform? Include any standing DC current, or equiv. DC from unidirectional waveforms (signals starting from ground)	Maximum DC: AC current probes, listed as a separate line item. DC current probes: Max. DC = Max. peak AC (cw), made up of DC + peak AC.			
6. Now answer the questions common to all applications on worksheet 6 before making a final selection.				

Worksheet No. 5

SELECTING A CURRENT PROBE TO MEASURE SINGLE-SHOT AND LOW-REP-RATE PULSES

Major Parameters (Questions to be answered)	Current Probe Terms	Your Requirements (your answer here)	Your Selection (from Mfgrs. spec. sheets) Probe Spec. (≥ Your Requirements)	Probe Model (Meeting Your Requirements)
1. What is the expected maximum peak current?	Max. peak current			
2. Do I have to apply the Amp-Second formula? You can only answer this question after making a preliminary selection based on your answer to question #1. RULE: If the combined DC plus peak pulse is greater than the max. AC current (cw) spec. of the selected probe, apply the formula. If it is less than this spec, ignore the A-S formula.	Max. AC current (cw) (convert specs to peak if necessary)			
3. What is the pulse width at the 50% point? NOTE: It may be more convenient to deal in A − μs. A − μs product = A × μs or Width μs = $\frac{A-\mu s\ Prod.}{A\ Peak}$	Amp-Second Product (A-S Product)			
4. What is the risetime/falltime?	Risetime			
5. What is the DC content?	Maximum DC: AC current probes, listed as a separate line item. DC current probes: Max. DC = Max. peak AC (cw), made up of DC + peak AC.			
6. Now answer the questions common to all applications on worksheet 6 before making a final selection.				

Worksheet No. 6

SELECTING A CURRENT PROBE QUESTIONS COMMON TO ALL APPLICATIONS

Major Parameters (Questions to be answered)	Current Probe Terms	Your Requirements (your answer here)	Your Selection (from Mfgrs. spec. sheets) Probe Spec. (≥ Your Requirements)	Probe Model (Meeting Your Requirements)
NOTE: Your application will determine whether the following parameters are of major or minor importance. Answer the questions to find out.				
Will my circuit be affected by the inclusion of a small series impedance? (usually less than 0.1 ohm). A function of frequency and probe type, can vary from low micro ohms to 2 ohm at high frequencies.	Insertion Z			
Am I measuring current through a bare wire? Is is elevated? What is the voltage?	Max. hardware volts. (varies from 500v to 3Kv. Depends on probe type. Range may be extended with insulation or bushing material.			
What is the diameter of my current carrying conductor? (include insulation, if any)	Max. conductor diameter			
Am I making simultaneous voltage & current (power) measurements? Am I comparing one waveform against another in terms of propagation delay or phase shift? Is this important to me? (See Timing coincidence: What to Consider Your Electrical Requirements, page 15)	System Prop. delay. Must consider DIFFERENCE between the two signal paths.			

Worksheet No. 1

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What is my scope's bandwidth?	BW Scope BW System	Scope/plug-in (system) BW follows the square root of the sum of the squares (risetime) formula.	Refer to manufacturer's scope or scope/ plug-in system specs.		
What probe bandwidth do I need?	BW Probe	With few exceptions, probes can not increase the BW of your scope. Standard accessory probes generally provide full scope BW at the probe tip	1) Choose the probe supplied or recommended by the scope manufacturer 2) Or choose a probe with equal or greater BW than your scope.		
Do I need a probe other than the specified standard accessory item? If so, answer the following questions.					
What is my scope's input resistance; 1MΩ or 50Ω?	Input R Scope	Marked on the scope (or plug-in) front panel	For passive probes, choose a probe to match the scope's input system (50Ω or 1MΩ). Active (Fet) probes will match either system		
What is my scope's input capacitance?	Input C Scope	Marked on the scope (or plug-in) front panel	Choose a probe with a compensation range that covers your scopes input C. (Does not apply to 1X Probes, Active Probes, or 50Ω systems)		

Worksheet No. 2

SELECTING A VOLTAGE PROBE

Major Parameters (Questions to be Answered)	Terms	Notes	Instructions	Your Requirements	Probe Choice
What overall sensitivity (attenuation) do I need or can tolerate?	Attenuation Probe. (1X.10X etc.)	Attenuation is a necessary trade-off for reduced Tip C. (except active probes)	• If your signals are between 100mV and 400V peak to peak; choose a 10X probe. • If they are less than 100mV, choose a 1X probe. • If they are greater than 400V, choose a 100X or 1000X probe.		
What resistive loading can my circuit tolerate?	Resistive loading Probe	Typical 10X passive probe is 10MΩ. Resistive loading is usually not a factor, except when using "50Ω type" probes.	For general purpose work, choose a 10X passive probe. For high frequency and fast risetime observation, choose a 50Ω type, a bias-offset type, or an active (Fet) probe.		
What capacitive loading can my circuit tolerate? (capacitive reactance Xc)	Capacitive loading Probe.	Capacitive loading becomes the major factor at high frequencies. (See "How Probes Affect Your Measurements" page 4)	For general purpose work, choose a passive 10X probe. For high frequency and fast risetime observation, choose a probe with the lowest input C. Either a 50Ω type or an active (Fet) probe.		
Are my signals referenced to ground? If not, I may need differential probes	Elevated, Isolated Differential. CMRR	True differential measurement capability requires either a differential probe or a true differential amplifier with specially matched probes.	Do not "float" your scope. Use differential probe pairs with scope differential amplifier, or differential probes with standard (single ended) inputs. Or special isolation amplifier (A6902B).		

TEK SUPPORT

Tektronix incorporated in 1946 and since then has grown to be the world's largest manufacturer of oscilloscopes and matching probes. Included in Tek's broad product offering are voltage probes, active and passive probes, high voltage probes, low impedance/high frequency probes and differential probes.

Tek probes are UL 1244 listed, electrically tested to meet advertised specifications and tested for environmental stability, including such factors as humidity, altitude, vibration, shock and temperature.

Probe support features to be aware of, in addition, include:

- One-year warranty from date of purchase.
- Compatible accessory packages, including tips, adaptors, connectors and tools.
- Long-term product support.
- Probe exchange program.
- Worldwide sales and service.

Probe and accessory packages are described in detail in the Tektronix Accessories Selection Guide. It covers the entire product line and supplments material contained herein, with criteria for matching specific probes to your application. For a copy, contact your local Tektronix Sales Engineer.

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