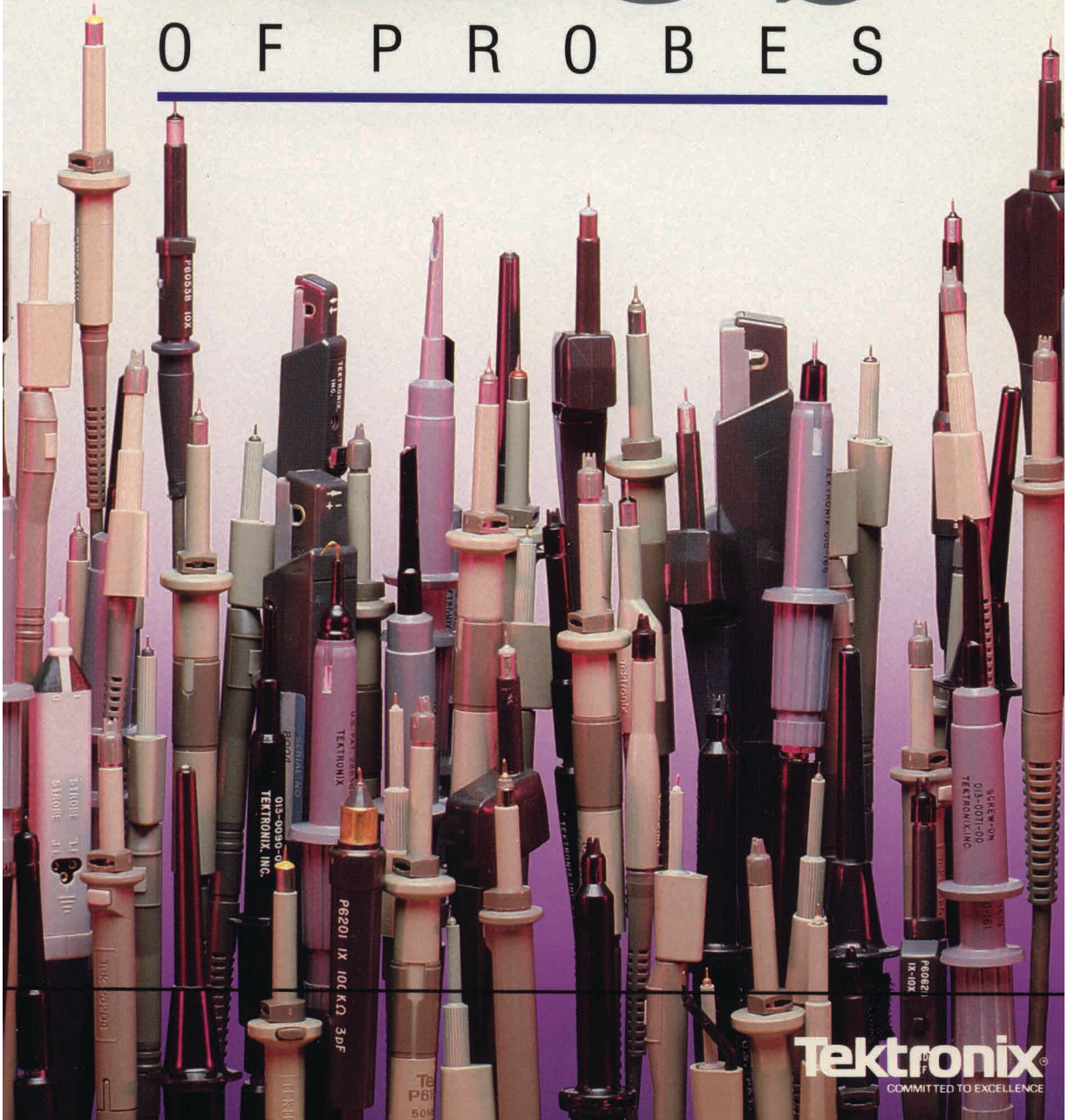


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# ABC's

O F P R O B E S

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**Tektronix**  
COMMITTED TO EXCELLENCE

## FOREWORD TO THE SECOND EDITION:

This edition has been updated, revised and expanded to make **The ABC's of Probes** a more useful tool for both the beginning student in electronics, and the advanced user of sophisticated scopes and test equipment.

This booklet has been expanded to include a Probe to Scope Cross-Reference for all current Tektronix probes, scopes, plug-in amplifiers and test equipment.

Tektronix is constantly adding new probes, scopes and test equipment to their product line, therefore it may be advisable to verify your selection by consulting the current Tektronix Catalog, or Accessories Selection Guide for up-to-the-minute information.

Of course, your local Tektronix Sales office is within easy reach by phone, or, if you prefer, call toll free, 1-800-426-2200, Ext. 510 for ordering or product information.

The signal acquisition probe is **The Vital Link** between the scope and your measurement.

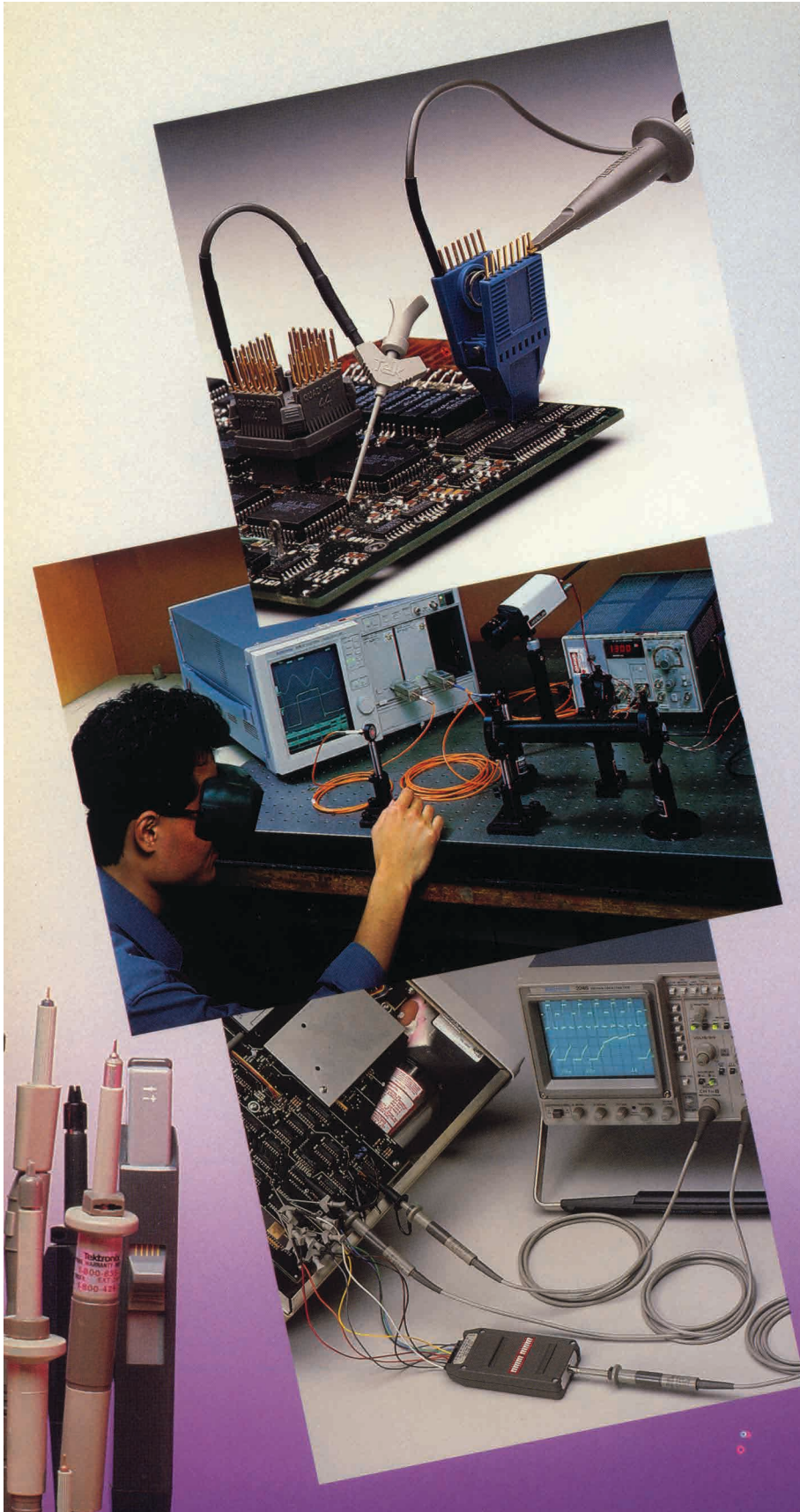
By understanding the concepts involved, you will be able to select the correct probe for your application.

By understanding the correct way to use probes, you will gain confidence in your measurement results.

And by being able to recognize probing problems, you will be able to avoid them.

That is what the second edition of **The ABC's of Probes** is all about.

Written by:  
Les Hurlock and  
Measurement and  
Accessory Products Division,  
Tektronix



# TEK SCOPES AND VERTICAL AMPLIFIERS TO TEK PROBES CROSS-REFERENCE

## A PROBE FOR VIRTUALLY EVERY APPLICATION

Tek offers many probes for your different probe requirements. The probes highlighted on this guide are those normally shipped with the scope. For non-highlighted probes, the scope bandwidth may be limited by the probe shown. Use scope's bandwidth and probe specification chart to determine overall probe/scope bandwidth.

### RECOMMENDED PROBES

	PASSIVE 1X	PASSIVE 10X	PASSIVE 1X/10X	Low-Z	HIGH VOLT. 100X	HIGH VOLT. 1000X	ACTIVE		PASSIVE 1X	PASSIVE 10X	PASSIVE 1X/10X	Low-Z	HIGH VOLT. 100X	HIGH VOLT. 1000X	ACTIVE
<b>11000 SERIES</b>								<b>22XX SERIES</b>							
11201/A	P6101A	P6134C	P6063B		P6009		P6204	2201	P6101A	P6103	P6119		P6007	P6015	
11A32	P6101A	P6134C	P6063B		P6009		P6204	2205	P6101A	P6103	P6119		P6007	P6015	
11A33		P6135						2210	P6101A	P6103	P6119		P6009 Opt. 14	P6015	
11A34	P6101A	P6134C	P6063B		P6009		P6204	2211	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
11A52		P6156*2		P6156*2			P6204	2213	P6101A	P6122	P6119		P6009 Opt. 14	P6015	
11A71		P6156*2		P6156*2			P6204	2213A	P6101A	P6122	P6119		P6009 Opt. 14	P6015	
11A72		P6156*2		P6156*2			P6204	2214	P6101A	P6103	P6119		P6007	P6015	
SD20/22/24/26	P6150	P6150		P6150				2215	P6101A	P6122	P6119		P6009 Opt. 14	P6015	
<b>7000 SERIES</b>								<b>46X SERIES</b>							
7A13		P6055						2215A	P6101A	P6122	P6119		P6009 Opt. 14	P6015	
7A15A	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1	2220	P6101A	P6109 Opt. 01	P6119		P6009 Opt. 14	P6015	
7A16A	P6101A	P6106A	P6063B		P6009	P6015	P6202A*1	2221	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7A18/A	P6101A	P6105A	P6062B		P6009		P6202A*1	2224	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7A19		P6156*2		P6156*2			P6201*1	2225	P6101A	P6103	P6119		P6009 Opt. 14	P6015	
7A22		P6055						2230	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7A24		P6156*2		P6156*2			P6201*1	2232	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7A26	P6101A	P6106A	P6063B		P6009		P6202A*1	2235/A	P6101A	P6109 Opt. 01	P6119		P6009 Opt. 14	P6015	
7A29/P		P6156*2		P6156*2			P6201*1	2235L	P6101A	P6122	P6119		P6009	P6015	
7A42	P6101A	P6131	P6063B		P6009		P6202A*1	2236/A	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7D15	P6101A	P6106A	P6063B					2245/A	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
7D20	P6101A	P6105A	P6053B					2246/A	P6101A	P6109 Opt. 01	P6062B		P6009	P6015	
<b>5000 SERIES</b>								<b>300 SERIES</b>							
5A14N	P6101A	P6102A	P6062B		P6007	P6015		434	P6101A	P6105A	P6062B		P6007	P6015	P6202A*1
5A15N	P6101A	P6102A	P6062B		P6007			455	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5A18	P6101A	P6102A	P6062B		P6007			464	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5A21N		P6055						464M	P6101A	P6104A	P6062B		P6009	P6015	P6202A*1
5A22N		P6055						465	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5A26		P6055						465B	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5A38N	P6101A	P6105A	P6062B		P6009			465M	P6101A	P6104A	P6062B		P6009	P6015	P6201*1
5A45	P6101A	P6105A	P6062B		P6009	P6015		466	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5A48	P6101A	P6105A	P6062B		P6009	P6015		468	P6101A	P6105A	P6062B		P6009	P6015	P6202A*1
5D10	P6101A	P6105A	P6062B		P6007	P6015		475/A	P6101A	P6106A	P6063B		P6009	P6015	P6201A*1
<b>SPECIAL</b>								<b>TM500/5000 SERIES</b>							
2815	P6101A	P6103	P6119		P6009 Opt. 14			AM 502		P6055					
<b>24XX SERIES</b>								<b>220X SERIES</b>							
2430/A/M	P6101A	P6133 Opt. 25	P6063B		P6009	P6015	P6202A*1	T201/202	P6115	P6103	P6119				
2431L	P6101A	P6136 Opt. 25	P6063B		P6009	P6015	P6201A*1	<b>TM500/5000 SERIES</b>							
2432/A/M	P6101A	P6137	P6063B		P6009	P6015	P6201A*1	DC 503A	P6101A	P6125					
2440/M	P6101A	P6137	P6063B		P6009	P6015	P6201A*1	DC504A/5004	P6101A	P6125					
2445	P6101A	P6131	P6063B		P6009	P6015	P6202A*1	DC509/5009	P6101A	P6125					
2445A	P6101A	P6133 Opt. 25	P6063B		P6009	P6015	P6202A*1	DC510/5010	P6101A	P6125					
2445B	P6101A	P6133 Opt. 25	P6063B		P6009	P6015	P6202A*1	DC 505/A	P6101A	P6108A					
2455A/B	P6101A	P6136 Opt. 25	P6063B		P6009	P6015	P6202A*1	DC 508/A	P6101A	P6125					
2465	P6101A	P6131 Opt. 25	P6063B		P6009	P6015	P6201*1	SC 501, 2, 3	P6101A	P6102A	P6062B		P6007	P6015	
2465A	P6101A	P6136 Opt. 25	P6063B		P6009	P6015	P6201*1	SC 504	P6101A	P6108A	P6062B		P6009	P6015	
2465B	P6101A	P6137	P6063B		P6009	P6015	P6201*1	SI5010		P6156*2		P6156*2			P6202A*1
2467	P6101A	P6136 Opt. 25	P6063B		P6009	P6015	P6201*1								
2467B	P6101A	P6137	P6063B		P6009	P6015	P6201*1								
<b>23XX SERIES</b>															
2335	P6101A	P6108A	P6119		P6009 Opt. 14	P6015									
2336	P6101A	P6108A	P6119		P6009 Opt. 14	P6015									
2336YA	P6101A	P6108A	P6119		P6009 Opt. 14	P6015									
2337	P6101A	P6108A	P6119		P6009 Opt. 14	P6015									

### SPECIFICATION SUMMARY

MODEL	ATTEN	LGTH**4	LOADING		B/W	MAX V	COMP.	R/O**5
			INPUT R M OHM	INPUT C pF				
P6007	100X	6 ft.	10	2.2	25	1.5 kV	15-55	N
P6009	100X	9 ft.	10	2.5	120	1.5 kV	15-47	Y
P6009 Opt. 14	100X	9 ft.	10	2.5	120	1.5 kV	15-47	N
P6015	1000X	10 ft.	100	3.0	75	20 kV	12-47	N
P6053B	10X	6 ft.	10	12.5	200	500	15-24	Y
P6055	10X	3.5 ft.	1	10	60	500	20-47	Y
P6062B	10X 1X	6 ft.	10 1	14.0 105.0	100 7	500 500	15-47 N/A	Y
P6063B	10X 1X	6 ft.	10 1	14.0 105.0	200 6	500 500	15-24 N/A	Y
P6101A	1X	2 m	1	54.0	15	500	N/A	N
P6101A Opt. 01	1X	1 m	1	32.0	34	500	N/A	N
P6102A	10X	2 m	10	13.2	60	500	36-55	Y
P6103	10X	2 m	10	13.2	50	500	15-35	N
P6104A	10X	1 m	10	11.2	100	500	15-35	Y
P6105A	10X	2 m	10	11.2	100	500	15-35	Y
P6106A	10X	2 m	10	11.2	250	500	15-35	Y
P6107A	10X	2 m	10	13.0	100	500	20-51	Y
P6108A	10X	2 m	10	11.2	100	500	15-35	N
P6109	10X	2 m	10	13.2	150	500	15-35	Y
P6109 Opt. 01	10X	1.5 m	10	11.8	150	500	15-35	Y
P6115	1X	1.5 m	1	64.0	5	42	ANY	N
P6119	10X 1X	2 m	10 1	15.3 120	100 8	500 350	15-35 N/A	N
P6122	10X	1.5 m	10	11.0	100	500	15-35	N
P6125	5X	1.5 m	5	20.0	250	250	15-33	N
P6130	10X	2 m	10	13.2	250	500	15-35	Y
P6131	10X	1.3 m	10	10.8	300	500	14-18	Y
P6133	10X	2 m	10	12.7	150	500	10-25	Y
P6133 Opt. 25	10X	1.3 m	10	11.4	150	500	10-25	Y
P6134C	10X	1.5 m	10	10.5	400	500	12-18	Y
P6135	10X	1.5 m	1	11.3	150	500	14-17	Y
P6136	10X	1.3 m	10	10.8	350	500	12-18	Y
P6136 Opt. 25	10X	1.3 m	10	10.8	350	500	12-18	Y
P6137	10X	1.5 m	10	10.8	400	500	12-18	Y
P6148A	10X	2 m	10	13	50	500	20-51	Y
P6149A	10X	2 m	10	13.0	50	50	20-51	N
P6150*3	10X 1X	1 m	500 ohm 50 ohm	0.15 N/A	9 GHz 3 GHz	12 42	50 ohm N/A	N
P6156	10X	1.5 m	500 ohm	1.0	3.5 GHz	15	50 ohm	Y
P6156 Opt. 25	100X	1.5 m	5K ohm	1.1	3.0 GHz	50	50 ohm	Y
P6156 Opt. 26	20X	1.5 m	1k ohm	1.0	3.5 GHz	22	50 ohm	Y
P6156 Opt. 27	1X	1.5 m	50 ohm	N/A	1.5 GHz	42	N/A	Y
P6201	100X 10X 1X	6 ft.	1 1 100K ohm	1.5 1.5 3	1.1 GHz 1.1 GHz 1.1 GHz	200 200 100	50 ohm 50 ohm 50 ohm	Y
P6202A	100X 10X	2 m	10 10	2 2	500 500	200 200	50 ohm 50 ohm	Y
P6204	10X	1.5 m	10	1.9	1 GHz	40	50 ohm	Y

\*\*3 Uses an SMA Male Connector instead of BNC connector.

\*\*4 Other optional cable lengths are available for most probes listed. For additional information refer to the Tektronix Product Catalog or contact your local sales representative.

\*\*5 R/O = Readout.

\*1 The P6201 and P6202A active probes require probe power, which is normally supplied by the scope (either standard or optional to the scope). If probe power is unavailable, an 1101A power supply may be used to supply probe power.

\*2 The P6156 is standard with 10X attenuation. Other attenuations are available. Order Option 25 for 100X, Option 26 for 20X, Option 27 for 1X attenuation, or Option 28 which includes one each 1X, 10X, 20X, and 100X attenuation tips.



# 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 three parts, **Understanding Probes, Selecting Probes, and Advanced Probing Techniques.**

The first part 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.

A Probe to Scope cross-reference has been added to help you select the correct probe for your Tektronix scope or plug-in amplifier.

The third part features advanced probing techniques. We show problems encountered in probing high speed and complex circuitry, how to recognize them, and most importantly, how to avoid them.

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:

## **Tektronix, Inc.**

Jack Murdock Park  
P.O. Box 3500  
Vancouver, WA 98668

Attention: Measurement and Accessory Products Division Marketing

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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 15 picofarad (15pF), which is the typical scope input capacitance plus the stray capacitance of the hookup wire.

### 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.

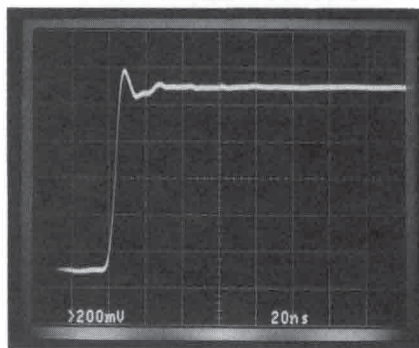


Figure 1-1

Figure 1-1 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 nSec.

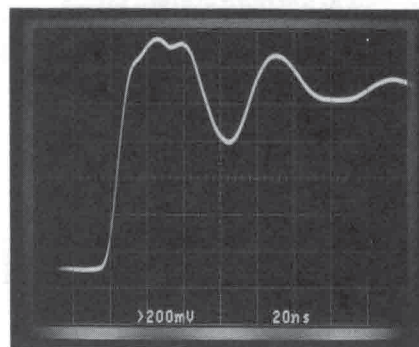


Figure 1-2

Figure 1-2 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.

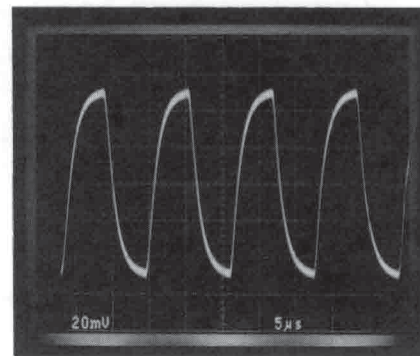


Figure 1-3

Figure 1-3 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 1-4.)

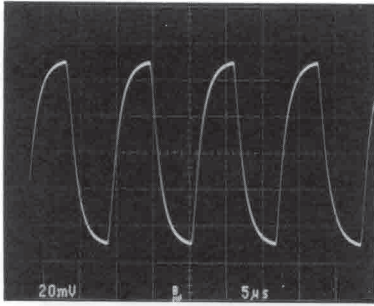


Figure 1-4

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 1-5)

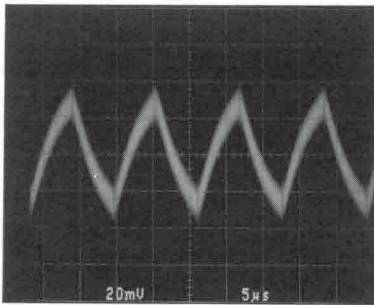


Figure 1-5

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 minimize loading.** 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 p-p maximum. The standard 10X passive probe provides 400V p-p 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 effect 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 1-6 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 1-7.

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

Figure 1-8 shows the equivalent circuit of the generator and probe, applying 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.

Curves showing typical input impedance vs frequency, or typical Xp and Rp vs frequency are included in most Tektronix probe instruction manuals. Figure 1-9A shows the typical input impedance and phase relationship vs frequency of the Tektronix P6203 Active Probe. Note that the 10 KΩ input impedance is maintained to almost 10 MHz by careful design of the associated resistive, capacitive and inductive elements.

Figure 1-9B shows a plot of Xp and Rp vs frequency for a typical 10 MΩ

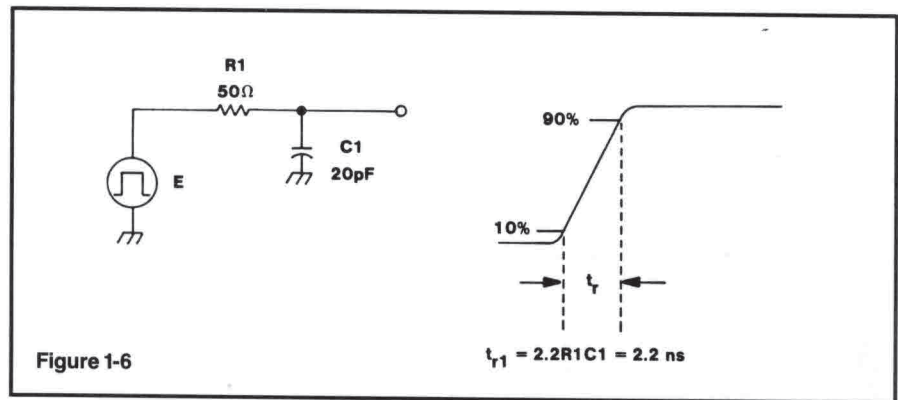


Figure 1-6

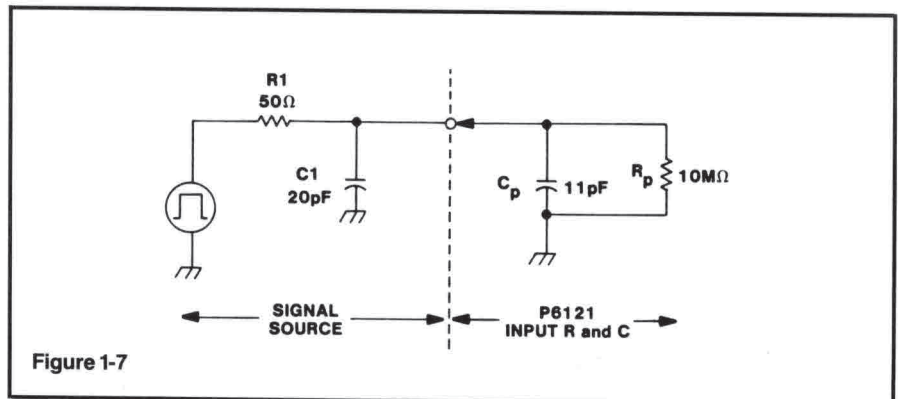


Figure 1-7

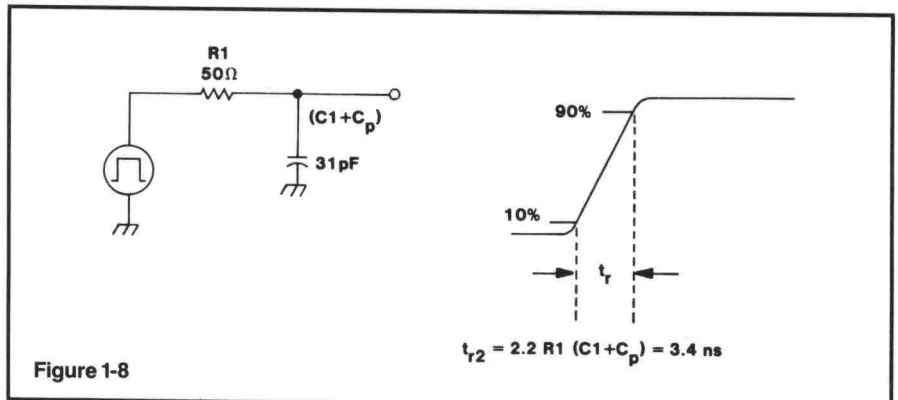


Figure 1-8

passive probe. The dotted line (Xp) shows capacitive reactance vs frequency. The total loading is again offset by careful design of the associated R, C and L elements.

If you do not have ready access to the information and need a worst-case guide to probe loading, use the following formula:

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

- Xp = Capacitive reactance (ohms)
- F = Operating frequency
- C = Probe tip capacitance (marked on the 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 (by simple divider action), and even on the operation of the circuit itself.

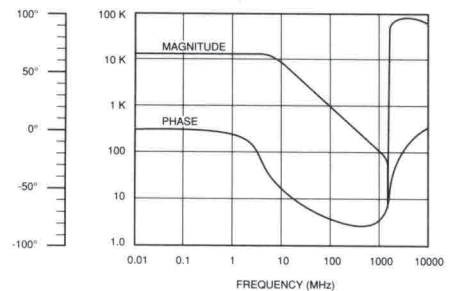


Figure 1-9A. Typical Input Impedance vs Frequency for the Tektronix P6203 Active Probe

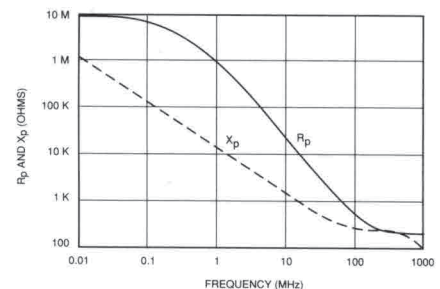


Figure 1-9B. Xp and Rp vs Frequency for a Typical 10 MΩ Passive Probe



**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.

**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 1-10 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 rise-time and transit-time 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.

**Bias-Offset Probes.** A Bias/Offset probe is a special kind of Low Z design with the capability of providing a variable bias or offset voltage at the probe tip.

Bias/Offset probes like the Tektronix P6230 or P6231 are useful for probing high speed ECL circuitry, where resistive loading could upset the operating point. These special probes are fully described in Part 3; under Advanced Probing Techniques.

**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.

Active probes are discussed under "How to Select the Best Probe" (page 20), but in general, they provide low resistance loading (10M ohm) with very low capacitive loading (1 to 2 pF). They do have trade-offs in terms of limited dynamic range, but under the right conditions, do indeed offer the best of both worlds.

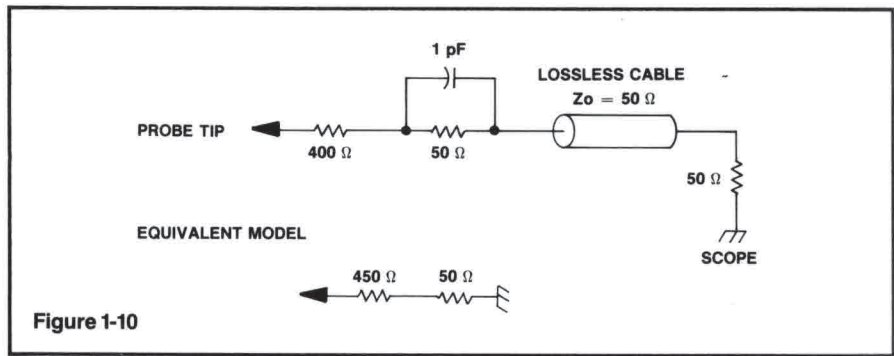


Figure 1-10

**Bandwidth.** Bandwidth is the point on an amplitude versus frequency curve where the measurement system is down 3dB from a starting (reference) level. Figure 1-11 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 1-12 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.

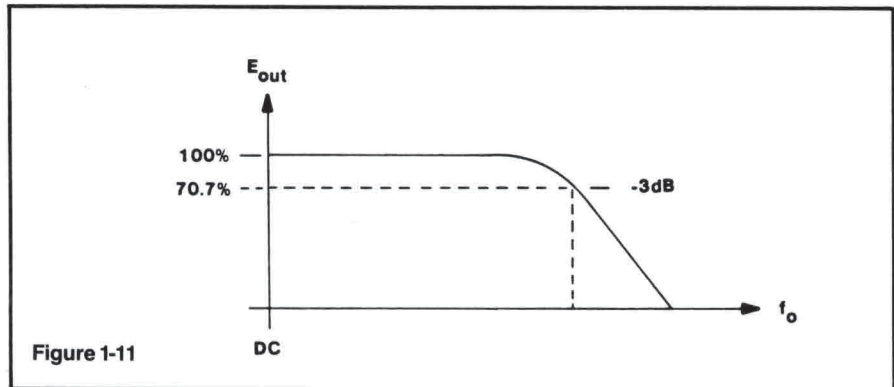


Figure 1-11

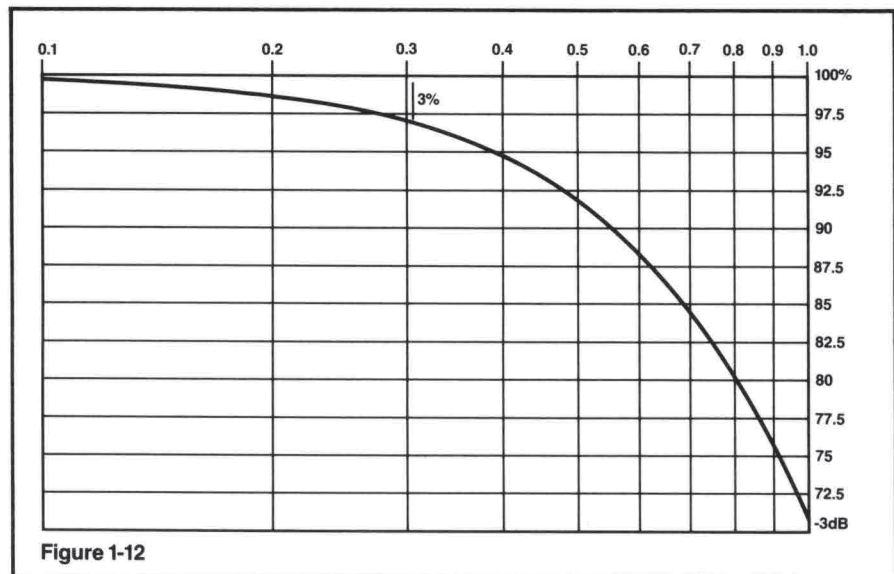


Figure 1-12

SCOPE	BW (1 M $\Omega$ input)	PROBE	BW	SYSTEM
2235	100	P6109	150	100
2245A	100	P6109	150	100
2246A	100	P6109	150	100
2445B	150	P6133	150	150
		Opt 25		
485	350	P6106A	250	250
2465B	400	P6137	400	400
2467B	400	P6137	400	400

Figure 1-13

**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:

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

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

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 aberrations, 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.**

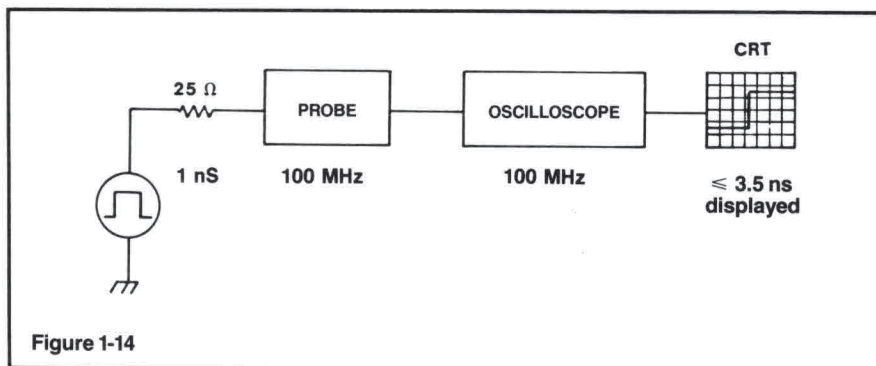


Figure 1-14

Figure 1-14 shows an equivalent circuit of a typical setup. The displayed risetime should be a 3.5 nSec or faster.

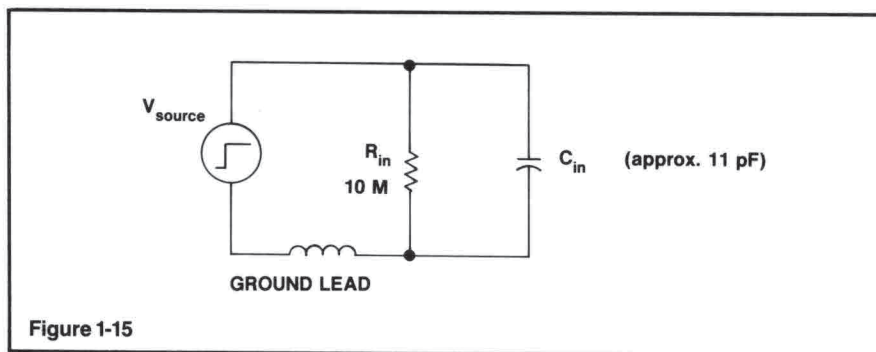


Figure 1-15

Figure 1-15 shows an equivalent circuit of a typical passive probe connected to a source.

However, not all probe/scope systems can follow this general rule. Refer to the sidebar, "Scope Bandwidth at the Probe Tip?"

Figure 1-13 shows examples of Tektronix scopes and their recommended passive probes.

**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 1-14).

### Scope Bandwidth at the Probe Tip ?

Most manufacturers of general-purpose oscilloscopes that include standard accessory probes in the package, promise and deliver the advertised scope bandwidth **at the probe tip.**

For example, the Tektronix 2465B 400 MHz Portable Oscilloscope and its standard accessory P6137 Passive Probes deliver 400 MHz (-3db) at the probe tip.

However, not all high performance scopes can offer this feature, even when used with their recommended passive probes. For example, the Tektronix 11A32 400 MHz plug-in has a system bandwidth of 300 MHz when used with its recommended P6134 passive probe. This is simply because even the highest impedance passive probes are limited to about 300 to 350 MHz, while still meeting their other specifications.

It is important to note that the above performance is only obtainable under strictly controlled, and industry recognized conditions; which states that the signal must originate from a 50  $\Omega$  back-terminated source (25  $\Omega$ ), and that the probe must be connected to the source by means of a probe tip to BNC (for other) adaptor.

This method ensures the shortest ground path and necessary low impedance to drive the probe's input capacitance, and to provide the specified bandwidth at the signal acquisition point, the probe tip.

Real-world signals rarely originate from 25  $\Omega$  sources, so less than optimum transient response and bandwidth should be expected when measuring higher impedance circuits.

## 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 indirect 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, compact or subminiature probe configurations.

Figure 1-15 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. 1-16A, B and C show the effect of a 12-inch ground lead when used on various bandwidth scopes.

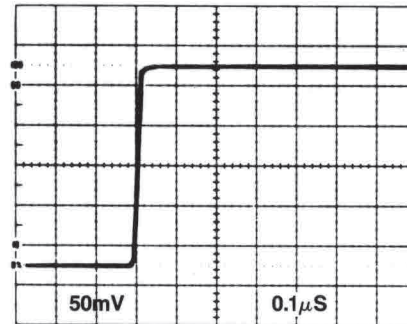


Figure 1-16A

Scope BW = 15MHz  
Ground lead 12 inches

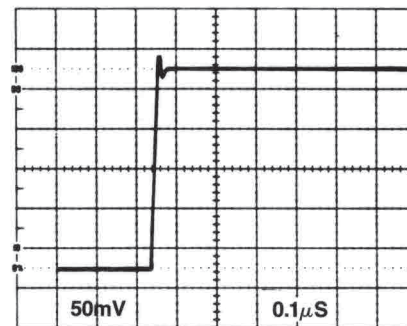


Figure 1-16B

Scope BW = 50MHz  
Ground lead 12 inches

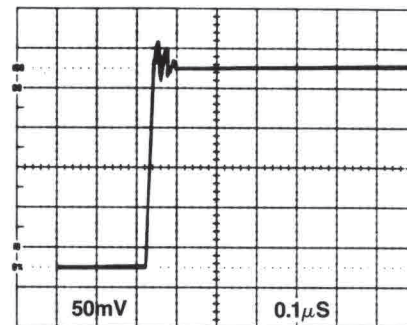


Figure 1-16C

Scope BW = 100MHz  
Ground lead 12 inches

In Figure 1-16A, the display on the 15MHz scope looks OK because the ringing aberrations are beyond the passband of the instrument and are greatly attenuated. Figs. 1-16B and C 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.

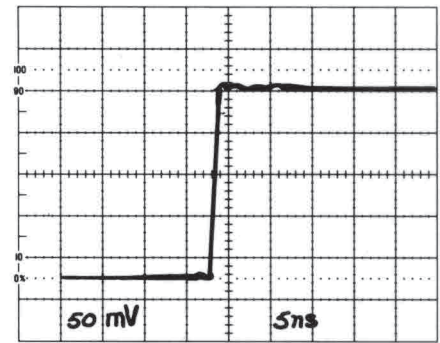


Figure 1-17A

50 ohm Source/Cable/2465B/50 ohm input

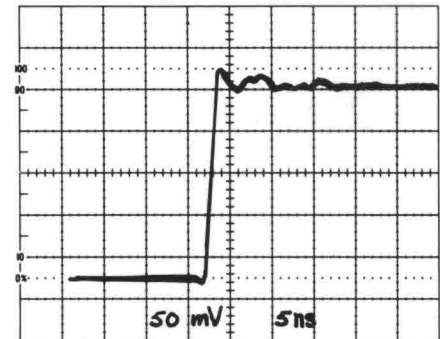


Figure 1-17B

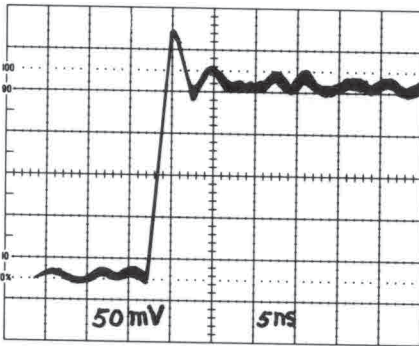
P6137-BNC/Probe Adaptor Tr = < 1nS

Figs. 1-17A through F 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 (400 MHz) scope with a matching P6137 probe.

Fig. 1-17A shows the input pulse under the most optimum conditions when using 50 ohm coax cable. Scope: the Tektronix 2465B with 50 ohm input and 50 ohm cable from a 50 ohm source. Displayed risetime is < 1 nSec.

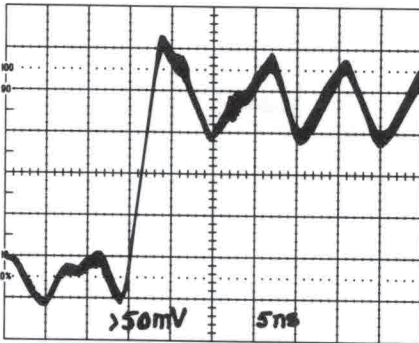
Fig. 1-17B shows the same signal when using the scope-probe combination under the most optimum conditions. A BNC to probe adaptor or an in-circuit test jack provides a coaxial ground that surrounds the probe ground ring. This system provides the shortest probe ground connection available. Displayed risetime is < 1 nSec.

Figures 1-17C through E show the effects of longer ground leads on the displayed signal. Fig. 1-17C shows the effect of a short semi-flexible ground connection, called a "Z" lead. Finally, Fig. 1-17F shows what happens when no probe ground lead is used.



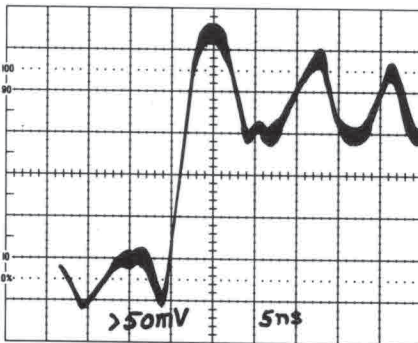
**Figure 1-17C**

P6137 - Probe/Z Ground Tr = 1.5 nS



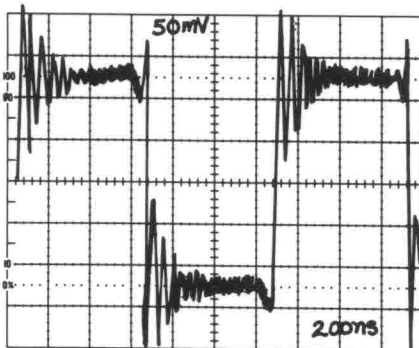
**Figure 1-17D**

P6137 - Probe/3" Gnd Lead Tr = 4 nS



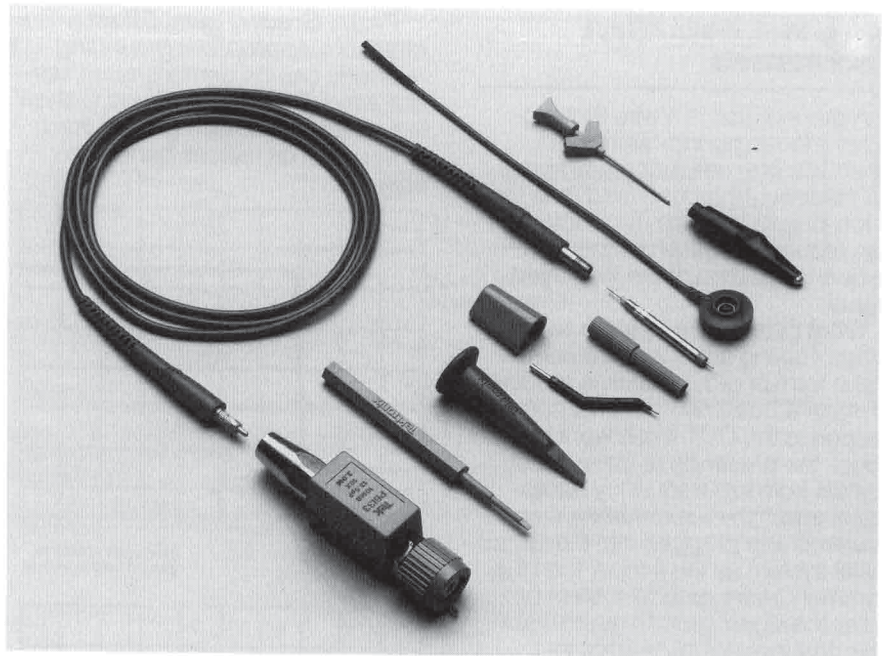
**Figure 1-17E**

P6137 - Probe/6" Gnd Lead Tr = 4 nS



**Figure 1-17F**

No Ground Lead



Typical probe & accessories package.

## 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.

## 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:

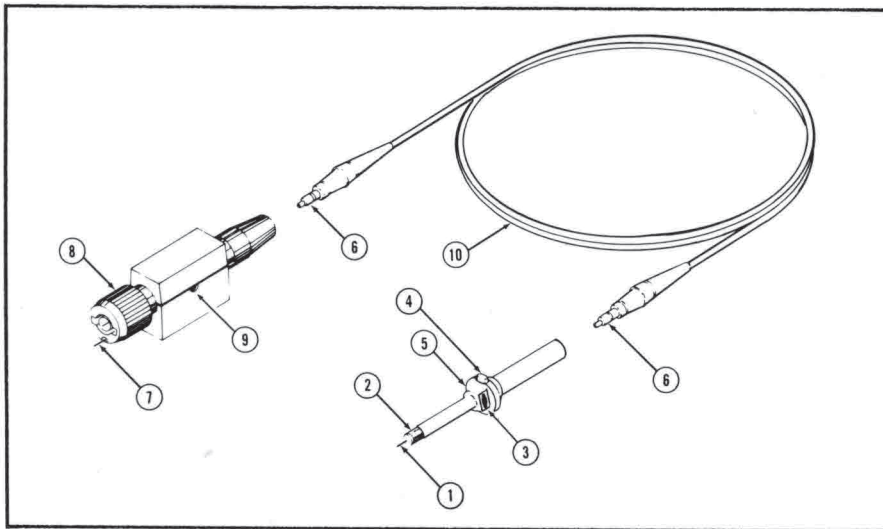
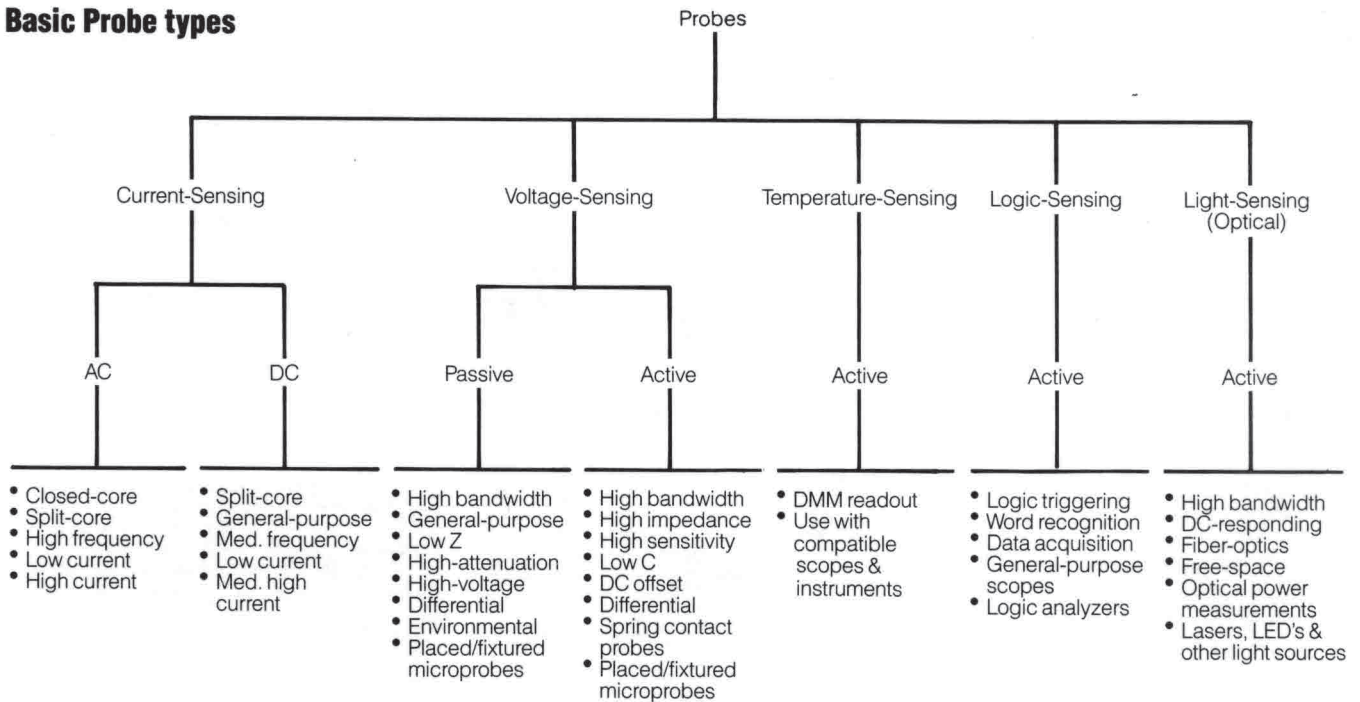
- Ruggedness
- Relatively low cost
- Wide dynamic range (therefore, less liable to electrical damage).
- Simplicity (which makes them easy to use and calibrate).
- Fast risetime.

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)

## Basic Probe types



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, 1.3 meters, 1.5 meters, 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.

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.

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.)

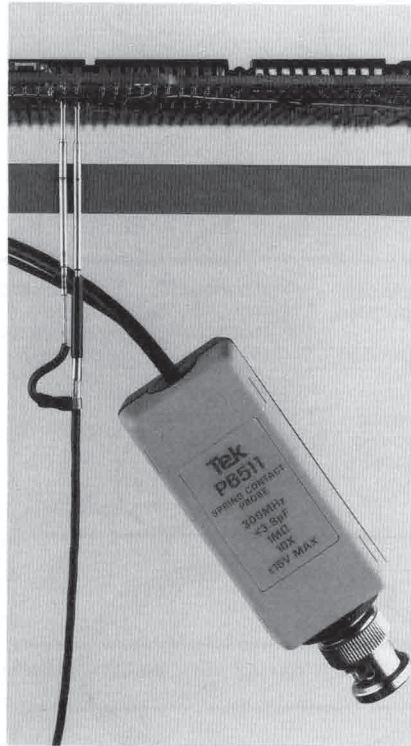
A differential probe (one probe with two inputs, such as the Tektronix P6046) provides maximum CMRR at high frequencies.

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 heat-generating items.

## Spring Contact Probes

A unique form of signal acquisition device called a Spring Contact Probe, is specially designed for bed-of-nails mounting and high speed testing of circuit boards at the component level.



**Figure 1-18.** Cross-section of bed-of-nails fixture with the Tektronix P6511 mounted. The spring contact on the left is a ground connection.

Most spring contact designs merely provide a connection from the test point to the measuring equipment via  $50\Omega$  or other types of cables. The resulting loading severely limits high frequency performance and makes this basic type of spring contact design suitable only for making low frequency measurements.

On the other hand, the Tektronix P6511, P6513, P6515 and P6517 Spring Contact Probes are real probes, with low capacitive and resistive loading, similar in operation to Tektronix active probes.

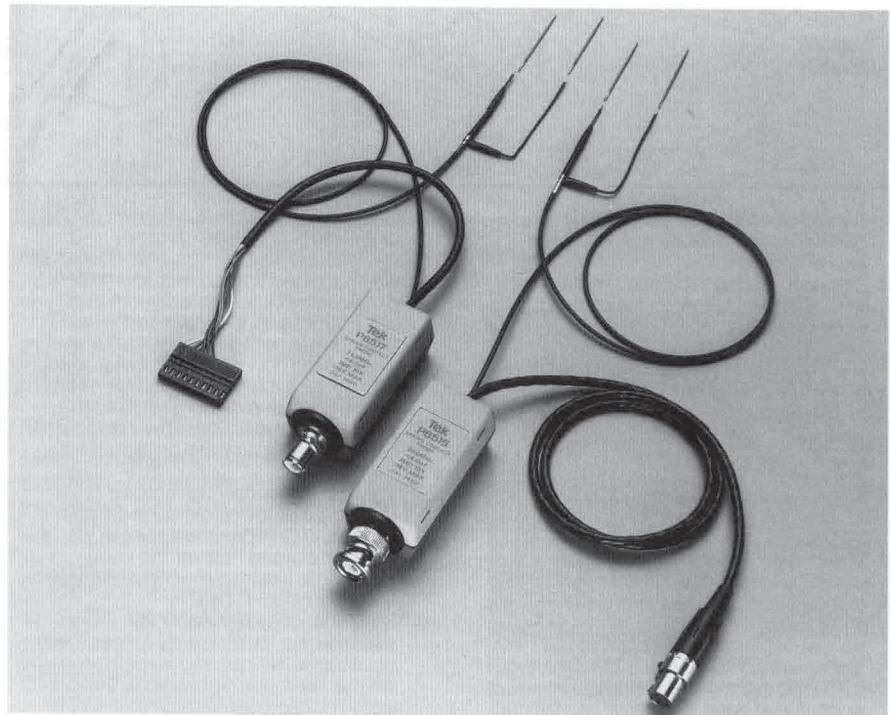
The P6511 and P6515 are designed for high speed functional testing in the 100 mil bed-of-nails environment, and have 300 MHz bandwidth and  $1\text{ M}\Omega$ ,  $< 3.8\text{ pF}$  input impedance.

The smaller P6515 and P6517 probes provide another breakthrough in spring-loaded contact probe design by enabling high speed functional testing in the 50 mil center-spacing environment.

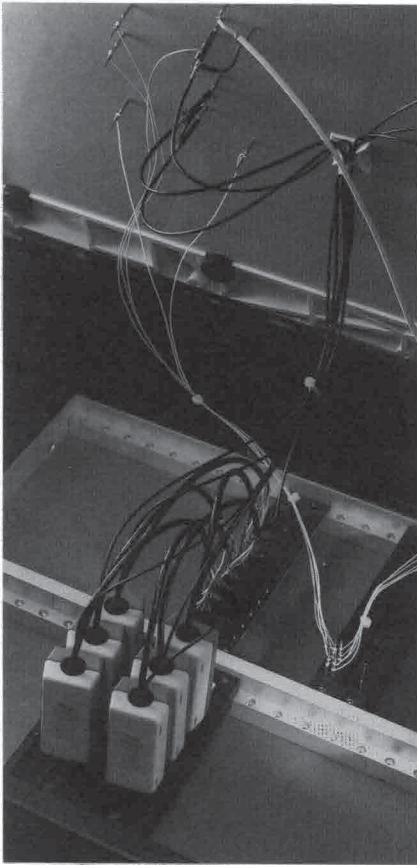
These two probes have 250 MHz bandwidth and  $1\text{ M}\Omega$ ,  $< 4\text{ pF}$  input impedance.

The Tektronix P651X Series probes incorporate a very small hybrid microcircuit right at the probe tip, and a buffer amplifier/line driver in a small enclosure at the end of the probe cable.

Figure 1-18 shows a cross-section of a bed-of-nails fixture with the Tektronix P6511 mounted. Figure 1-19 shows a closeup of the 50 mil center P6515 and P6517 probes. Ground



**Figure 1-19.** Tektronix P6515 and P6517 Spring Contact Probes for 50 mil center spacing.



**Figure 1-20.** Tektronix P6513 and P6517 Spring Contact Probes installed in a test fixture.

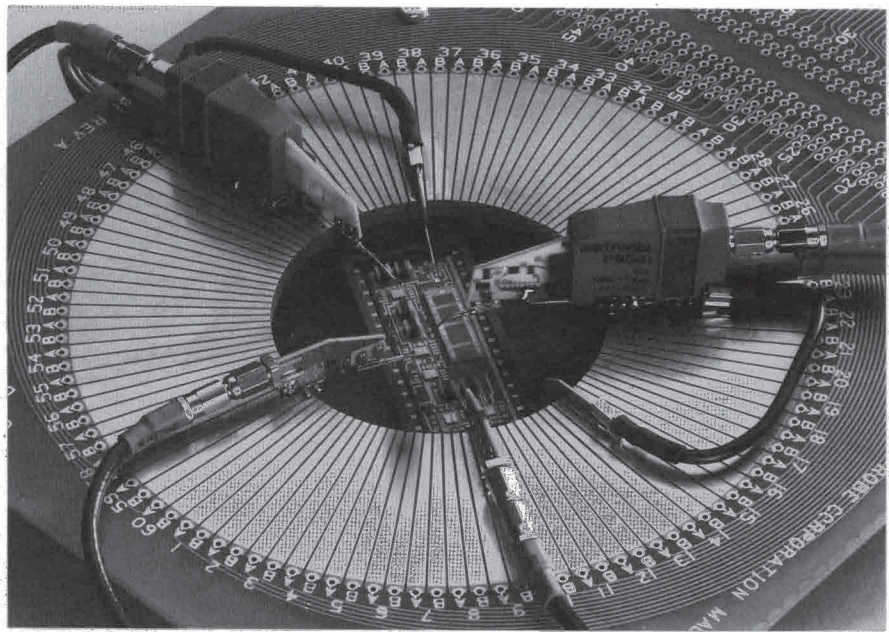
connections are also shown.

Tektronix P651X Series Spring Contact Probes utilize standard spring contact receptacles, enabling 100 mil center spacings (50 mil for the P6515, P6517).

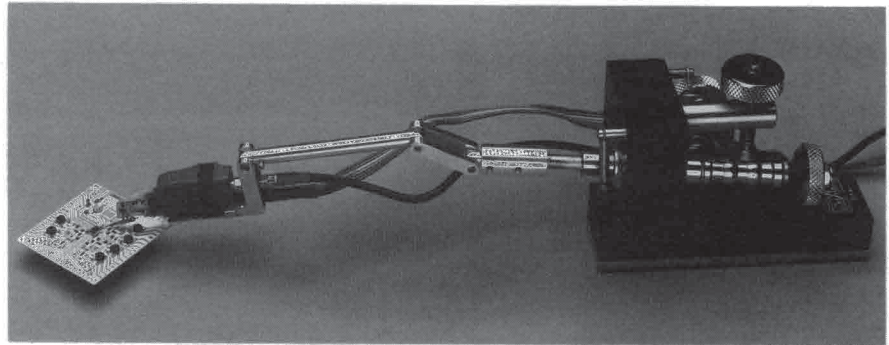
Crown contact tips are provided. Other point styles are available from Q.A. Technology, for 100 mil center types, and from Everett/Charles, for 50 mil center types. The two most popular are the cone, which centers itself in plated-through holes, and the crown, which provides multiple contacts on solder pads.

All probes can be moved from one fixture to the next, leaving only the contact receptacle behind. This protects your investment in the probes when old fixtures are replaced by new ones.

The P6511 and P6515 include a standard BNC connector for direct connection to 50Ω scope or other measuring device inputs, and a DIN power connector that mates with the Tektronix 1102 Power Supply (or equivalent).



**Figure 1-21.** Tektronix P6501 and P6507 Microprobes mounted on a test fixture.



**Figure 1-22.** The Tektronix P6501 FET Microprobe mounted on a micropositioner.

The P6513 and P6517 are used with quick-change fixtures, like those used on the TSI 8150. These have a push-on BNC and a Berg (harmonica) power connector. Either type power connector can be replaced with your own preferred types.

Figure 1-20 shows an installation of P6513 (100 mil center) and P6517 (50 mil center) probes. These two probes feature the Berg power connector and the push-on BNC signal connection.

The Tektronix P651X Series Spring Contact Probes provide a breakthrough in dynamic high speed testing of circuit boards at the component level during production testing. They provide minimum capacitive and resistive loading, while interfacing with standard 50Ω input systems.

### Placed/Fixtured Microprobes

A new generation of signal acquisition and signal injection devices called "Microprobes" are specially designed for card (circuit board) mounting.

Because of their small size, many probes can be placed side by side or in a circle.

Figure 1-21 shows a combination of Tektronix P6501 and P6507 Microprobes mounted on a test fixture for production testing.

The P6501 is an active (FET) signal acquisition probe with an input loading of 1 MΩ and <1.8 pF. It has a bandwidth of DC to 750 MHz.

The P6507 is a passive, 50Ω microprobe, primarily designed for high speed signal injection. It is also ideal for time domain reflectometry (TDR) when used with a sampling system TDR unit, and can be used as a signal acquisition probe, if the 50Ω loading does not present a problem.

Either probe can be mounted on a micro-positioner for precise positioning of the probe tip, as shown in figure 1-22.

## Optical To Electrical Converters

Optical to electrical converters are optical probes that allow the user to acquire optical signals and convert them to electrical signals for convenient analysis and display on an oscilloscope.

The Tektronix P6701/P6702 optical to electrical (O/E) converter probes interface directly with Tektronix scopes equipped with the TEKPROBE™ interface, or any other scope when used with the Tektronix 1103. TEKPROBE™ Interface Power Supply. Use of the 11000 Series scope's TEKPROBE™ interface allows the scope to supply power to the probe, automatically determine and display the proper scale factor (in milliwatts of optical power), and set the input termination to the required 50Ω.

A scope-controlled calibrated offset of 0 to 1 mW is also available through the interface.

The conversion is linear, DC coupled, calibrated, and of high bandwidth.

The P6701/P6702 provides a means of analog analysis of optical signals in the wavelength range of 450 to 1050 nm, with signal bandwidth from DC to 700 MHz (P6701), and 1000 to 1700 nm, with signal bandwidth from DC to 500 MHz (P6702), thus combining the functions of an optical power meter with the high speed analog waveform analysis capability of an oscilloscope in one instrument.

Figure 1-23 shows the P6701 and P6702 optical to electrical converters with standard SMA fiber-optic connectors. Optional FC and ST connectors are also available.

**Typical Applications.** These optical signal acquisition probes can be used to study devices which produce or modulate light, such as LEDs, diode lasers, electro-optic modulators, optical waveguides etc.

In experiments where light is either a by-product, or is used as a probe, the P6701 and P6702 provide a calibrated means of acquiring, displaying and analyzing this optical radiation. acquiring, displaying and analyzing this optical radiation.

Product/system development engineers can use these probes to develop fiber optic control networks. Optical memory systems, LANs

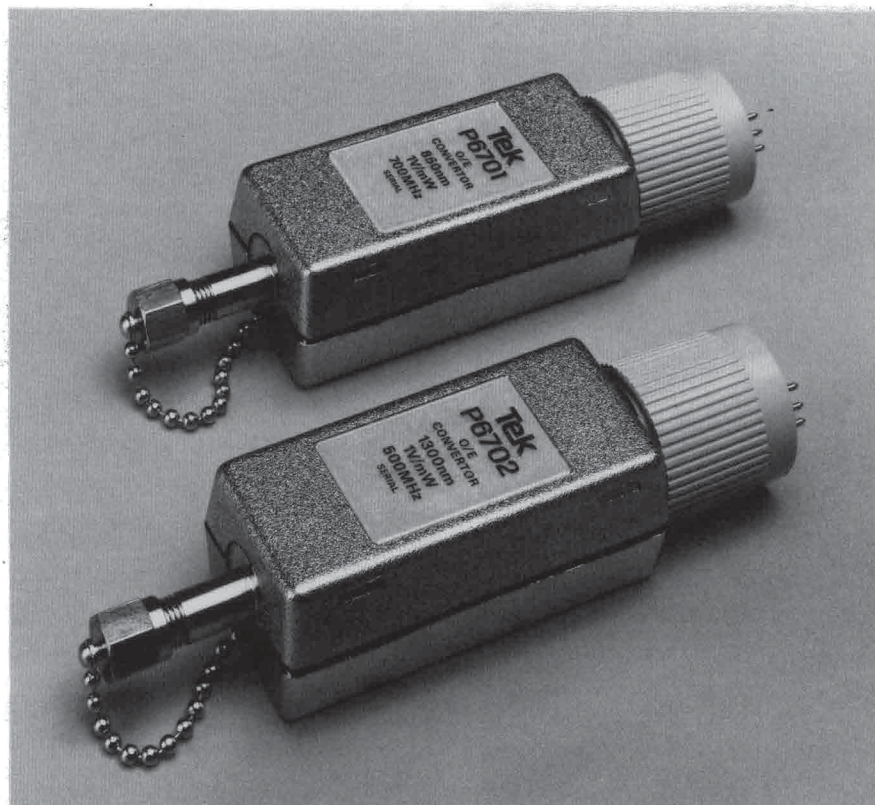


Figure 1-23. Tektronix P6701 and P6702 Optical to Electrical Converters.

(local area networks), medical laser equipment, and high speed, secure, fiber optic or free-space laser communications systems are some additional examples of development applications of these O/E devices.

In the area of manufacturing of electro-optic components and systems, these probes can be used for quality control, such as measuring risetime and output power level of LEDs.

**The Optical Input System.** Primary input is via fiber optic cable and SMA fiber optic connector to either the P6701 or P6702, depending upon the wavelength of the observed signal carrier. Other connectors available are FC or ST.

For free-space applications, the P6751 Spatial Input Head functions with either the P6701 or P6702 to facilitate acquisition of radiated light from free-standing devices such as, lasers, LEDs, flash lights (strobe lights) etc. The P6751 can be adjusted to optimize the amount of optical energy sampled and delivered to the P6701/P6702.

Also available are a series of fiber optic jumper cables for interfacing the P6751, P6701 and P6702 with other industry standard optical fiber connectors.

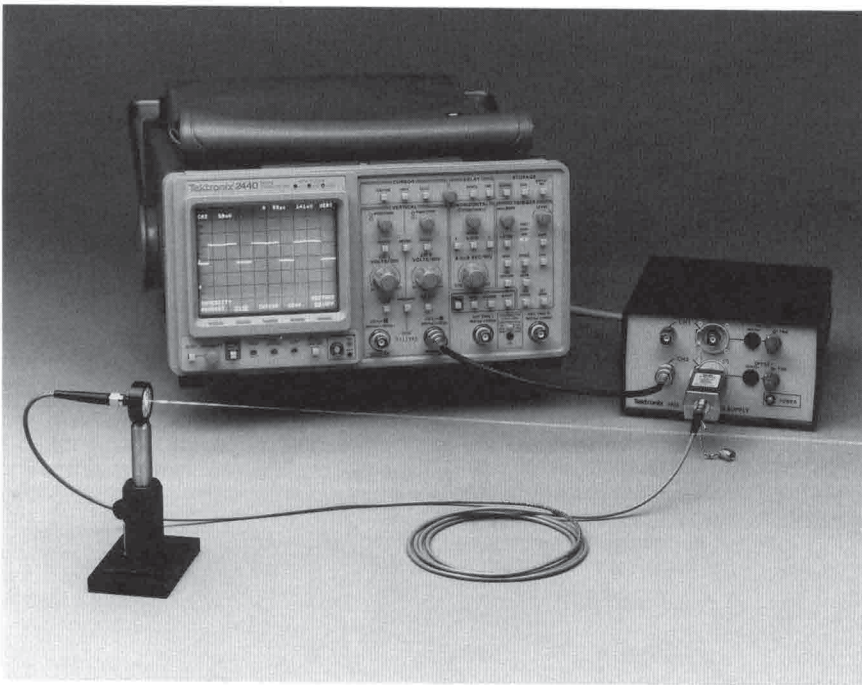
### Using the P6701, P6702 with General Purpose and High Performance Oscilloscopes.

As previously mentioned, the P6701 and P6702 O/E probes are equipped with the TEKPROBE™ interface for direct connection to Tektronix 11000 Series scopes. This interface provides power for the probe, automatically sets the scale factor in milliwatts (mW), and sets the input termination to 50Ω. A scope-controlled offset of 0 to 1 mW is also available through this interface.

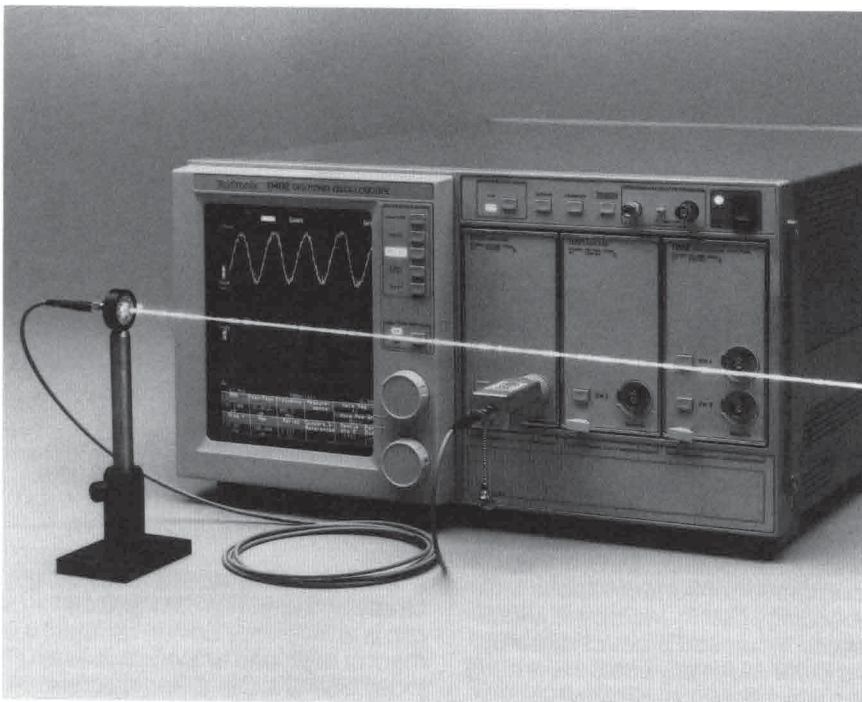
Maximum linear optical input power is 1 mW without offset. 2 mW with maximum offset.

The P6701 and P6702 can also be used with any scope that has the required bandwidth and features needed for your application, when it is used with the 1103 TEKPROBE™ Interface Power Supply. The scope should also have a 50Ω input provision, or use a 50Ω feed-through termination on 1 MΩ input systems.





**Figure 1-24.** Set-up for acquiring free-space optical signals with a portable oscilloscope. The P6751 Spatial Input Head, coupled to the P6701 O/E Converter, is interfaced to the Tektronix 2440 Digital oscilloscope via the 1103 TEKPROBE™ Interface Power Supply.



**Figure 1-24A.** The P6751 Spatial Input head, coupled to the P6701 O/E converter, is interfaced directly with the Tektronix 11402 scope to sample, scale, analyze and display the self-modulation of a HeNe laser.

Figure 1-24 shows the P6701 being used with the P6751 Spatial Input Head to acquire free-space optical signals. The Tektronix 2440, 300 MHz, dual trace, digitizing scope is used in conjunction with the 1103 TEKPROBE™ Interface Power Supply to display and analyze dynamic optical information. The 2440 can also provide signal averaging for low level, noisy signals, and X-Y capability for easy characterization of light emitting devices.

The 1103 TEKPROBE™ Interface Power Supply provides two channels of signal acquisition, supplies operating power to the P6701/P6702, and provides adjustable offset with on/off switches. Signal level (into 50Ω) is 1 V per mW of optical power, ± 12% at DC (specified at 850 nm for P6701, at 1300 nm for P6702).

In use, the P6701/P6702 is connected to the 1103 and the output is connected via 50Ω coax to the 50Ω terminated input of your scope. Assuming a dual-channel scope, up to two channels of optical and electrical signals can be measured, such as, LED optical power versus input current or voltage as a function of time (Y-T), or the same, or other devices can be characterized by using your scope in the X-Y mode to plot optical output versus forward voltage, or optical power versus input current.

Ask your Tektronix sales engineer about the P6701/P6702 Optical to Electrical Converters and their many applications.

Figure 1-24A shows the P6751 Spatial Input Head accessing radiation from a HeNe laser. The P6701 O/E Converter is directly connected to the input of the 11402, 1GHz Digitizing Oscilloscope.

## Word Recognizer Probes

Word recognizer probes are designed to generate a trigger pulse in response to specific logic states, rather than on analog signal levels. By only responding to a specific word, the device produces an output signal to trigger the scope externally (EXT Trigger) to produce a coherent display of the observed logic states.

The Tektronix P6408 is a 16 channel word recognizer/trigger probe for use with analog and digital storage scopes.

The trigger word is manually programmed via 16 miniature DIP switches on the probe pod, with HI, LO, and DON'T CARE recognition capabilities.

The P6408 leads are connected to the DUT (device under test) via TEK SMT Grabber Clips (see Surface Mount Device Interconnects). The grabber clips allow access to high-density circuitry, with lead spacing down to 50 mils.

The P6408 is an active probe and derives its operating power from the DUT (+ 5 V at 100 mA max.).

The P6408 includes a P6109, 10X, passive probe to couple the output of the probe pod to the 1 M $\Omega$  trigger input of an oscilloscope. This presents a low C load to the probe pod and delivers a fast rise trigger pulse to the scope's external trigger input.

### Typical Applications.

- Troubleshooting timing problems between an MPU and disc drive.
- Troubleshooting memory systems
- Used whenever a specific binary word is used to implement a function
- Simplifies digital design and troubleshooting

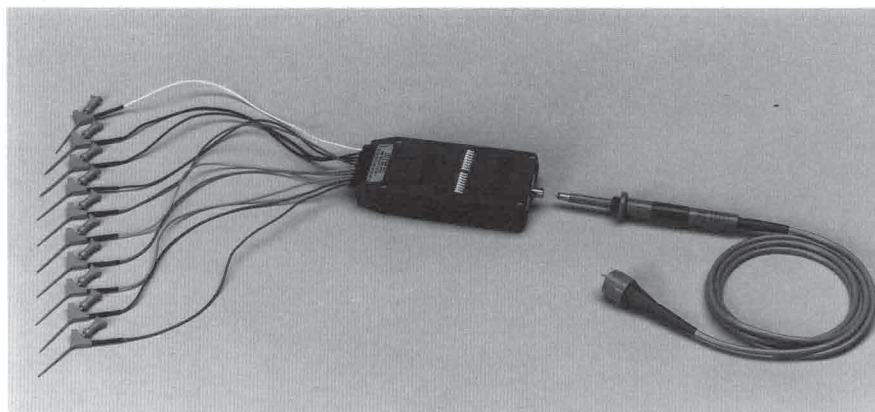


Figure 1-25. Tektronix P6408 Word Recognizer/Trigger Probe. Shown with the included P6109, 10X Passive Probe.

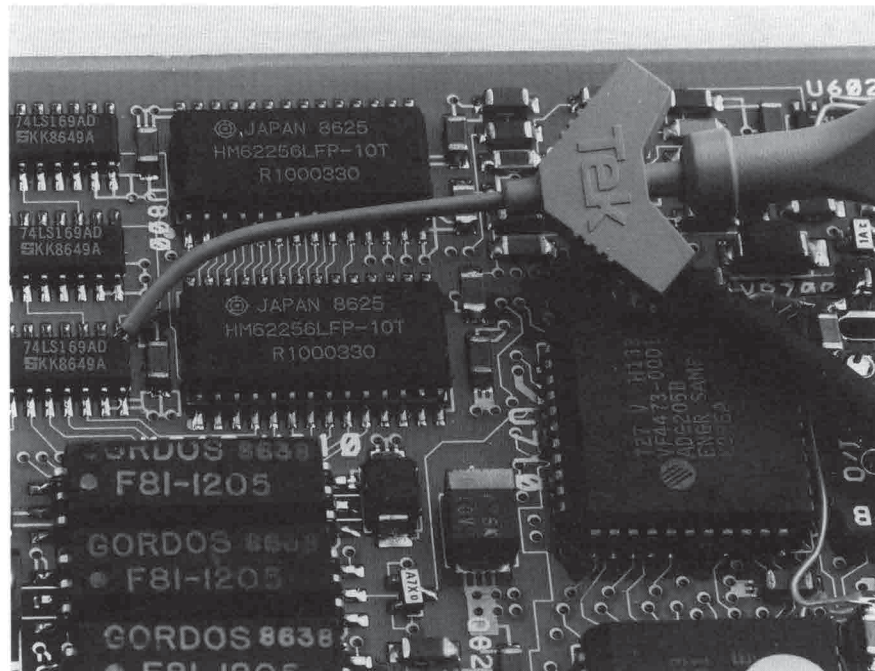


Figure 1-26. The SMT Grabber Clip accessing a component on a high-density circuit board.

## Surface Mount Device Interconnects

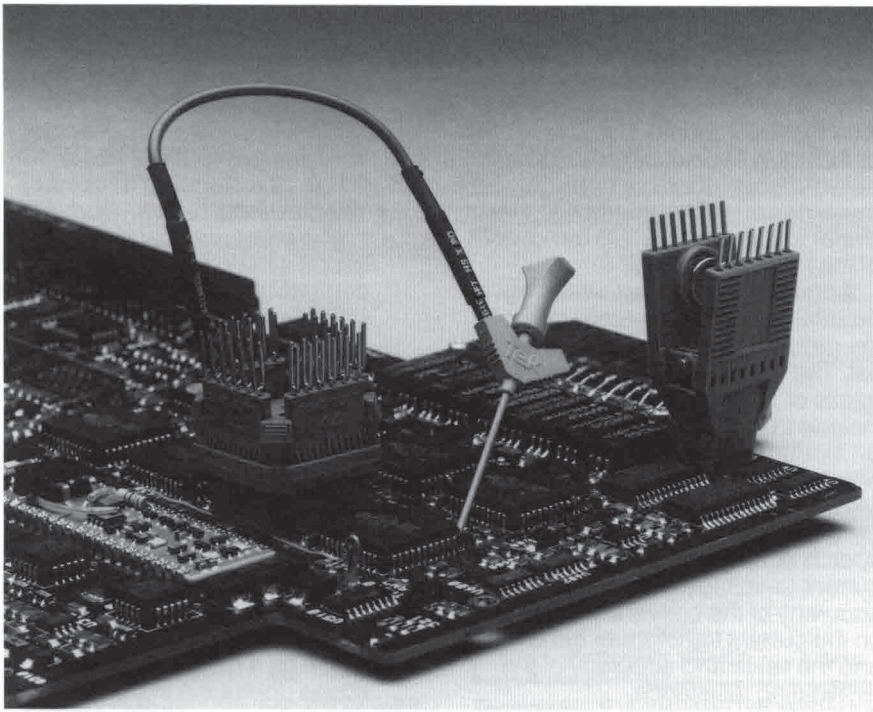
A rapidly growing area in Electronic Circuit Boards (ECB) is the incorporation of Surface Mount Technology (SMT). Increased circuit density, increased product reliability, and lower assembly costs are among the many benefits of this new technological trend. Troubleshooting and device interconnection however, have become more difficult due to decreased device size, tighter lead spacing, and increased ECB densities.

These requirements have influenced the design of the following SMT devices, however, remember that most Tektronix probes come with a variety of interconnect devices as standard accessories, including retractable and straight tips, and various grounding choices.

The following interconnects will complement and enhance the usefulness of your probe and enable you to access signals in high-density areas.

**SMT (Surface Mount Technology) Grabber Clips.** The SMT grabber clip is an interface device for attachment of logic and analog probes to today's SMD's, DIP's, and discrete components with maximum lead diameters of 0.095" and stackable on lead centers of 0.050" (50 mils). Dual sided 0.025" lead contacts allow this grabber to be used in multiple signal insertion/acquisition.

Figure 1-26 shows a SMT grabber clip accessing a component on a high-density board. The semi-rigid tip can be bent to clear obstructions.



**Figure 1-27.** PLCC Quad Clip (left) and SOIC Clip (right). Also shown is the SMT Grabber Clip.

**PLCC (Plastic Leaded Chip Carriers) Quad Clips.** The snap-ring design allows for quick and easy interconnection to all four sides of Plastic Leaded Chip Carriers (PLCC) with “J” leads on 50 mil centers. Test contacts are gold plated beryllium copper to provide low contact resistance.

A PLCC Quad Clip is shown on the left in figure 1-27.

**SOIC (Small Outline Integrated Circuits) Clips.** SOIC clips provide hands-free testing of onboard Small Outline Integrated Circuits (SOIC).

These clips are compatible with gull wing and “J” leads on 50 mil centers. They feature gold plated beryllium copper contacts with glass-filled nylon insulation. Upper contact pins are square, 0.025” (0.64 mm).

Figure 1-27 shows a combination of PLCC and SOIC clips on a circuit board.

### Active Probes.

Active voltage measuring probes employ active elements in the probe body and termination box to acquire and process signals from the circuit under test. They may be hand-held or used with circuit board to probe tip adaptors for best waveform fidelity, or they may be specially fixtured.

Spring contact probes, covered earlier, are designed for bed-of-nails mounting and high speed testing of circuit boards at the component level. These are true active probes, and represent the state-of-the-art in miniaturization and performance. The smaller versions of the P651 X family allow mounting on 50 mil (1.27mm) centers.

Probe card types [Microprobes] can be used for probing micro-electronic devices, hybrid circuits, surface mounted packages, and integrated circuits at the water level.

Differential active probes are used for probing computer back planes and for accessing small signals in the presence of high frequency common mode voltages. They provide a greater than 10:1 improvement in high frequency common mode rejection compared to the best passive differential probe-pair systems.

The first active probes employed vacuum tubes as the active element, and were generally known as cathode follower [CF] probes.

This type has long since been replaced by probes employing semiconductors and are used as source followers in active Bipolar probes.

More commonly, field effect transistors, or FET's are used.

Today, active probes are also referred to as FET probes.

All active probes require a source of power for their operation. Power is either obtained from an external power supply, or from the scope itself.

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.

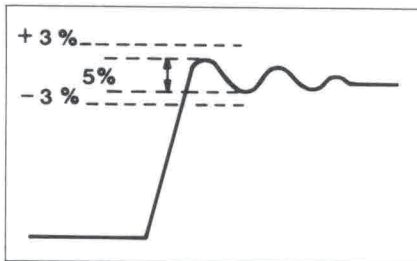
## How to interpret probe specifications

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 32.

**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% p-p 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.



**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 band-

width at the probe tip. These probes will not degrade the upper 3 dB bandwidth spec of the scope with which they are compatible. The rise-time formula (square root of the sum of the squares) that usually applies to active probes does not apply to these passive voltage probes. (Refer to Sidebar, "Scope Bandwidth at the Probe Tip?" Page 6)

**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.

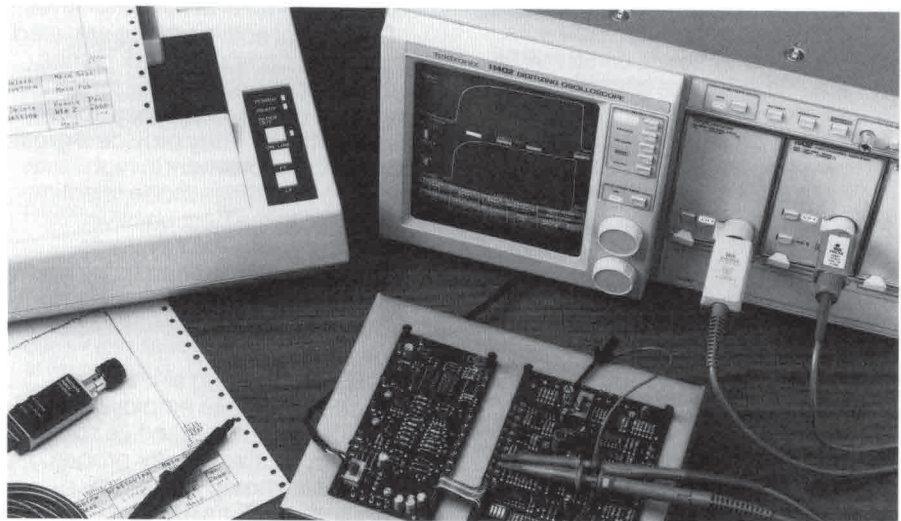
Current probes that work with dedicated amplifiers (such as the Tektronix A6302/AM503) read directly in amps/div, and specify attenuator accuracy as a percentage of the current/division setting. This specification is similar to scope attenuator specs.

The following bandwidth guidelines make probe selection a little easier:

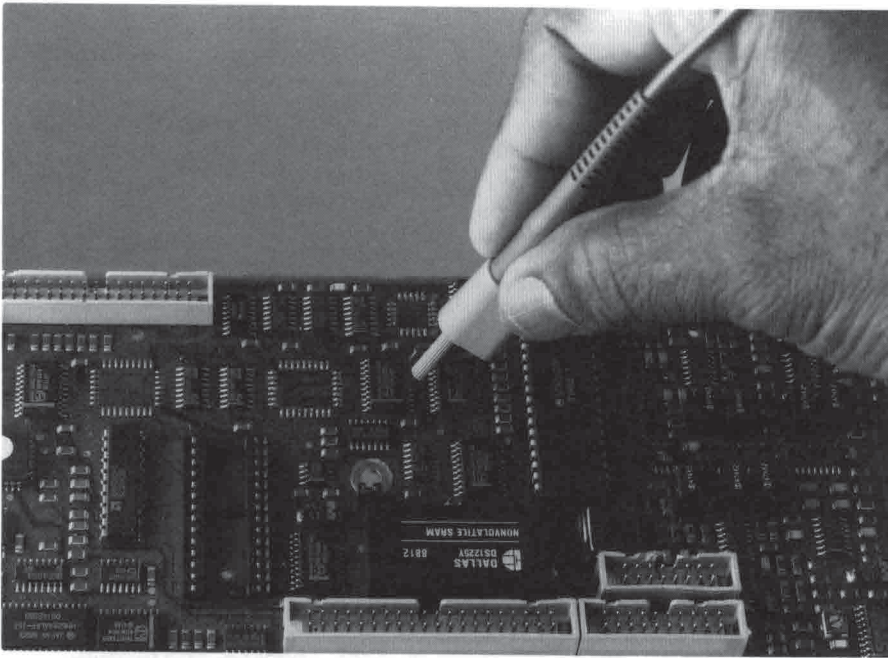
- Choose a probe that has a bandwidth spec equal to or higher than the scope's bandwidth spec. For example, the Tektronix 2335 100MHz Dual Trace Portable Oscilloscope in-

cludes, as standard accessories, two P6108A 10X probes, also specified at 100MHz. The Tektronix 2465B 400MHz Four Channel Portable Oscilloscope includes the 400MHz P6137 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 19.) 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.



**Figure 1-28.** Making risetime measurements with the 11402 Digitizing Oscilloscope and P6134 Passive and P6203 Active Probes.



**Figure 1-29.** Probing SMT circuitry with the P6130 Subminiature Passive Voltage Probe.

**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 3.)

**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 is approximately related to bandwidth by the factor 0.35. (See Bandwidth, page 6.)

**Ringings.** 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  $0.707 = \text{RMS}$ .

**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 or 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 20.)

## 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 30mm.
- 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 p-p risetime, 5.8nSec; pulse width, 1  $\mu$ Sec. 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 3.) 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.

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 5.)

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  $\pm 0.6V$  to  $\pm 60V$ . 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  $\pm 0.6V$  and the maximum non-destructive input is  $\pm 100V$  (or  $\pm 200V$  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  $\pm 3\%$ .

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,  $\pm 4\%$  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:

$$\frac{\text{transit time}}{\text{seconds}} \times 360^\circ = \text{phase shift degrees}$$

(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 rise-time) 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 8).

### 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 "compact and 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 requirements 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 bulk 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, compact 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.

Fitting mid-way between the miniature and sub-miniature types in tip and ground ring size, the compact series probes provide greater tip strength than that of the smaller sub-miniature series.

The compact probe configuration is well suited for manufacturing test operations—where durability and performance are of prime importance.

ECB to Probe Tip Adaptors are available for all three tip configurations.

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. 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



## Characteristics

	Attenuation	Accuracy	Input Resistance	Input Capacitance			Probe Rise Time	Aberrations	Bandwidth	Nominal Cable Length (ft)	Maximum Dc Voltage	Derated Above	Derated to @ Frequency	Compensation Range (pF)
				3½ ft	6 ft	9 ft								
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	Adjustable	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**

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.

Refer to the "Probe to Scope Cross-Reference" at the front of this Booklet for the correct combinations for your measurement needs.

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 p-p 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.

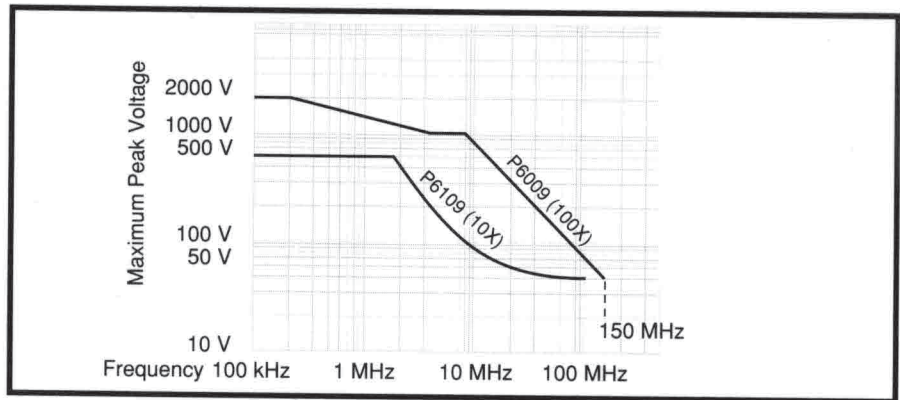
#### For maximum sensitivity applications:

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.

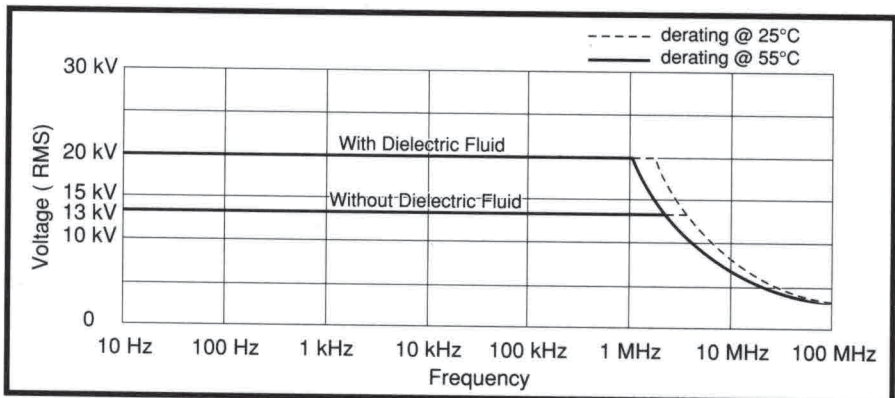
2 For high frequency use, choose an active probe (FET) with a 1X sensitivity. These will provide high sensitivity, low capacitive loading and wide bandwidth (up to 900MHz). Trade-offs are their price and narrow dynamic range.

#### For minimum circuit loading at high frequencies:

1 Select a passive 50 ohm type probe providing about 1 pF



Tektronix P6109 (10X) and P6009 (100X) Voltage Derating vs Frequency



Tektronix P6015 (1000X) Voltage Derating vs Frequency

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. (Refer to Table 1 and the "Voltage Derating vs Frequency" graphs.)

#### 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 33, 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 applying Ohm's 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.

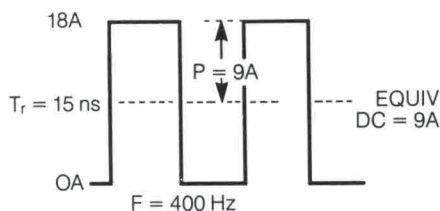
Current probes are classified as either AC responding (AC) or AC and DC responding (DC), and are either a fixed core or split-core configuration, as described under **Types of Probes**. We need to know a lot more about the total signal being measured when selecting a current probe. This will become evident 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
Continuous Wave (CW)	Sensitivity: Scope @ 10 mV/div	1 mA/div to 5 A/div	10 mA/div to 50 A/div
	Accuracy 3%		
Pulse, single-shot or low rep rate	Bandwidth	Dc to 50 MHz	Dc to 15 MHz
	Risetime	7 ns	23 ns
DC + Peak AC	Max Ac Current CW	40 A p-p	200 A p-p
	Derated above	20 kHz	20kHz
Continuous Wave (CW)	2.5 A @ 10 MHz		12 A @ 10 MHz
	Maximum Current Peak Not to Exceed A-S product	50A	500A
Pulse. Amp-Second product	A-S Product	100 × 10 <sup>-6</sup>	10,000 × 10 <sup>-6</sup>
	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 Susceptibility	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 p-p 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 p-p 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. Tr 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.

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

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:

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

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 34-36.

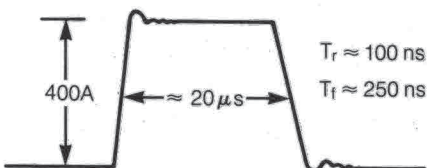
Fill out either the worksheet for continuous wave (cw) applications, or the worksheet for single-shot applications plus the common worksheet for all current measurement applications.

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 25 in conjunction with the manufacturers specs (Table 2) you can make a quick selection of the current probe for your application.

## 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.

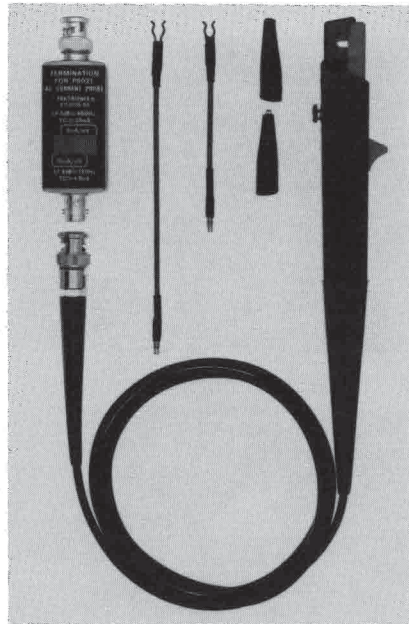


Figure 2-3. P6021 Current Probe and termination.

**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 contaminants 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 over 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.

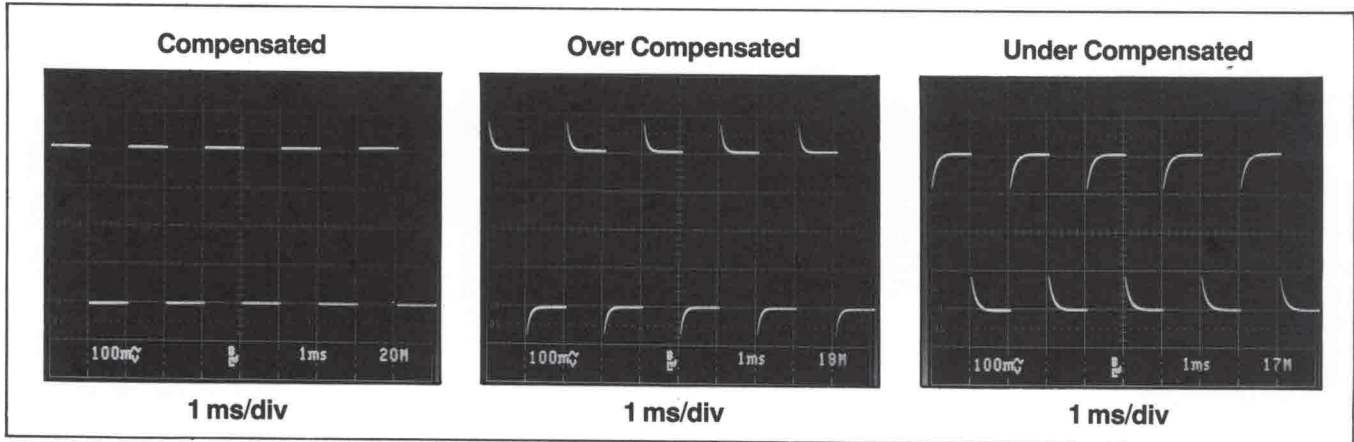
#### "Cleaning the Current Probe:

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.

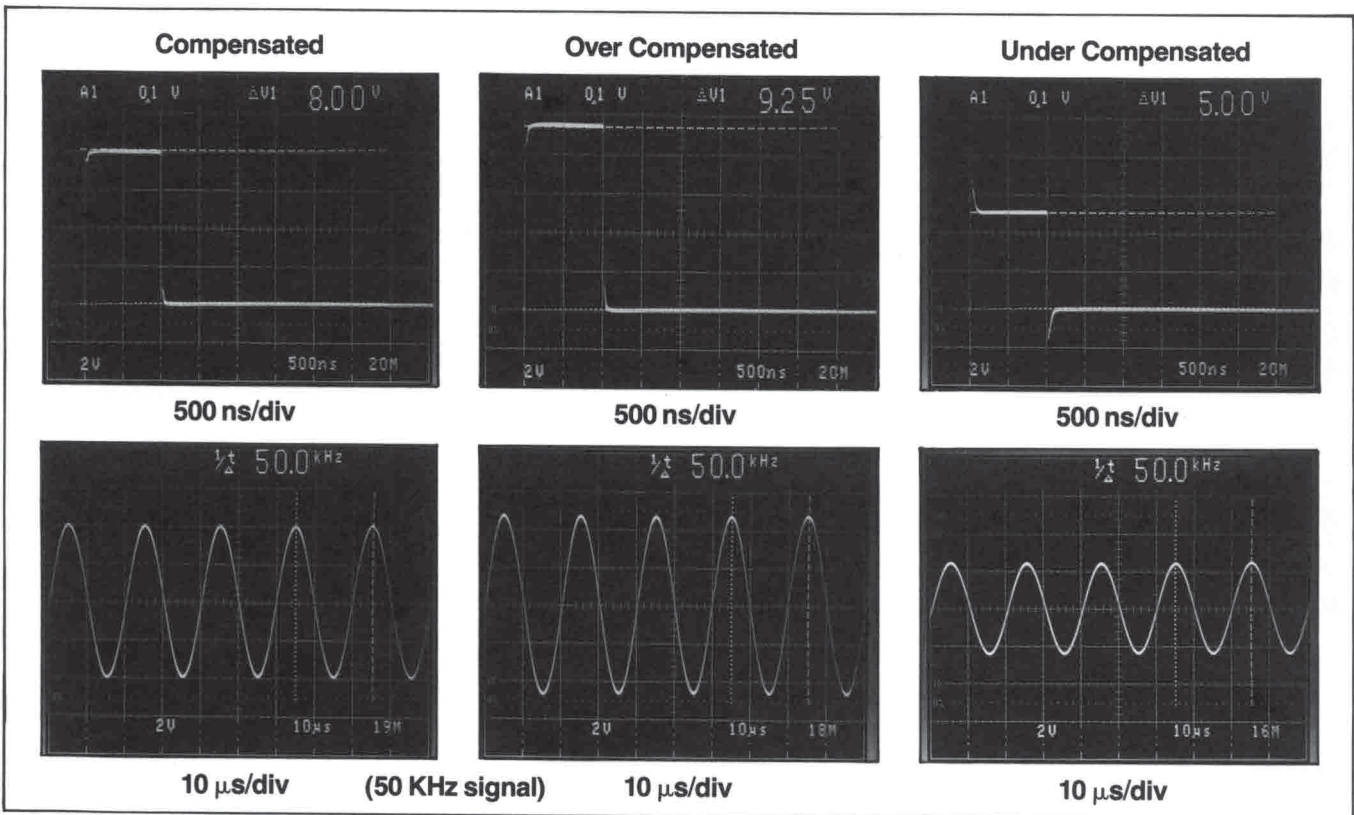
While cleaning the probe, make a visual check of the probe parts. Look for any excessive wear of the slide parts which might cause improper operation later on. Dirty or worn mating surfaces between the transformer and the lid will degrade low-frequency response. Clean these surfaces if necessary.

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

## Effects of Probe Compensation



**Figure 2-1.** Shows the display associated with correctly and incorrectly compensated probes.



**Figure 2-2.** 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.

### 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-metallic alignment tool to turn the compensation adjust until the tops and bottoms of the square-wave are flat.

### 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 cir-

cuit 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.

**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 Mfgs. 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 = $\frac{A - \mu s \text{ Prod.}}{A \text{ Peak}}$	Amp-Second Product (A-S Product)	20 μs 400 × 20 = 8000 A-μs	10000 A-μs	A6303/AM503
4. What is the risetime/falltime?	Risetime	≈ 100 ns	23 ns	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 Mfgs. 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	NO		A6303/AM503
Am I measuring current through a bare wire? Is it 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	

**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 2445B and 2465B, 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.).

# PART III: ADVANCED PROBING TECHNIQUES

## INTRODUCTION:

In Part III we will examine some of the more advanced probing techniques associated with accessing high frequency and complex signals, such as fast ECL, waveforms offset from ground, and true differential signals.

Most of the techniques to be described follow recommended practices outlined throughout this Booklet, and to a large extent involve proper grounding techniques.

Workers in the audio and relatively low frequency fields may wonder what all the fuss is about, and may comment "I don't have any of these problems," or "I can't see any difference when I use different ground lead lengths, or even when I leave the ground lead completely off?"

In order to see aberrations caused by poor grounding techniques, two conditions must exist:

1. The scope system bandwidth must be great enough to handle the high frequency content existing at the probe tip.
2. The input signal must contain enough high frequency information (fast risetime) in order to cause ringing and aberrations due to poor grounding techniques.

To illustrate these points, a 20 MHz scope was used to access a 1.7 nS pulse by using a standard passive probe with a 6" ground lead.

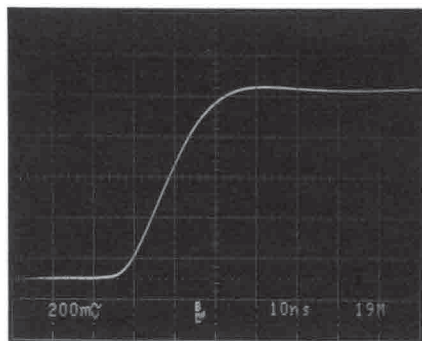
NOTE: A fast scope can be made into a slow scope simply by pushing the Bandwidth Limit (B/W Limit) button?

We used a 350 MHz scope with a 20 MHz B/W Limit function.

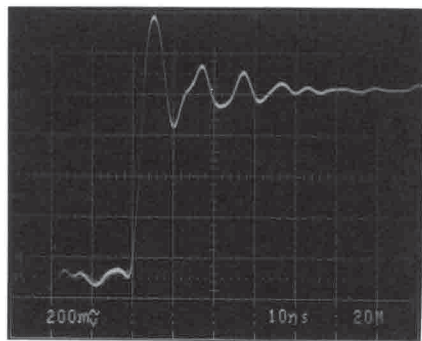
Figure 3-1 shows the resultant clean displayed pulse with a risetime of about 20 nS (17.5 MHz).

This display does not represent conditions actually existing at the probe tip, because the 20 MHz measurement system cannot "see" what's really happening.

Figure 3-2 shows what the probe tip signal really looks like when a 350 MHz scope is used under the same conditions (B/W Limit off).



**Figure 3-1.** Resultant clean, but incorrect display caused by inadequate scope system bandwidth.



**Figure 3-2.** The same input signal as shown in figure 3-1, but accessed by a 350 MHz system bandwidth scope (same 6" ground lead).

The observed risetime has improved to about 2 nS, but we have serious problems with ringing and aberrations, caused by incorrect grounding techniques.

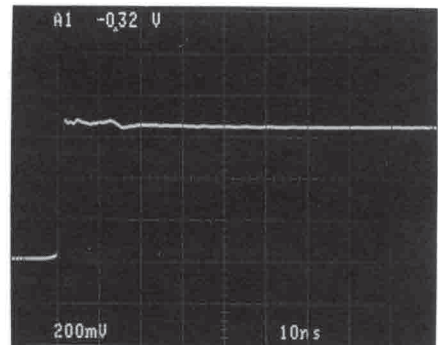
The problem can now be seen because the scope system bandwidth is great enough to pass and display all the frequency content existing at the probe tip.

To further stress the points about high frequency content and scope system bandwidth, let's assume an input pulse with a risetime of about 20 nS. If the signal is accessed by the same probe /6" ground lead /350 MHz system, it would look very much like the display in figure 3-1.

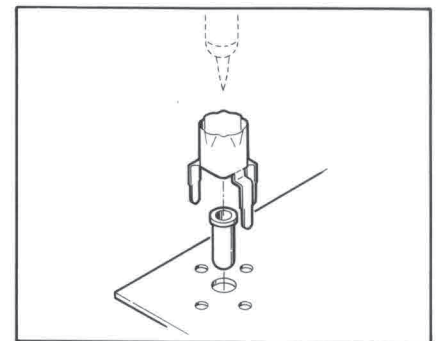
There would be no frequency content higher than 17.5 MHz (20 nS Tr). The 6" ground lead would not ring, and would therefore be the correct choice for accessing this relatively slow signal.

In the following sections we discuss how to recognize signal acquisition problems, and how to avoid them.

Techniques for probing ECL, high speed 50  $\Omega$  environments, and accessing true differential signals are also discussed.



**Figure 3-3.** 1 nS Tr pulse accessed via an ECB to Probe Tip Adaptor (test point)



**Figure 3-4.** Typical ECB to Probe Tip Adaptor installation

**Probe Ground Lead Effects.** In Part I we discussed the basic need for probe grounding, and showed several different ways of looking at the effects of correct, and incorrect probe grounding.

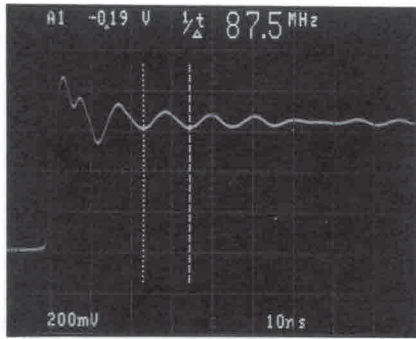
In this section, we will expand upon these techniques and show how to identify problem areas.

When a probe (high Z, low Z, passive or active) is connected to the circuit under test via an ECB to Probe Tip Adaptor (test point), the coaxial environment existing at the probe tip is extended through the adaptor to the signal pick-off point, and to the ECB ground plane (or device ground).

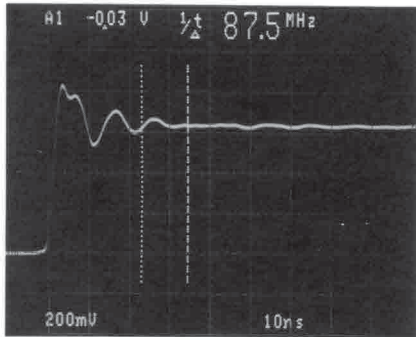
Figure 3-3 shows what a typical 1 nS Tr pulse looks like when a suitable probe is connected to the circuit via an ECB to Probe Tip Adaptor.

Figure 3-4 shows a typical ECB to Probe Tip Adaptor (test point) installation.

These test points are available in three sizes to accept miniature, compact or sub-miniature series probes.



**Figure 3-5.** Effect of a 6" ground lead on a 1 nS Tr input step.



**Figure 3-7.** The same setup as in figure 3-5, except that the probe cable has been repositioned, and a hand has been placed over part of the probe cable.

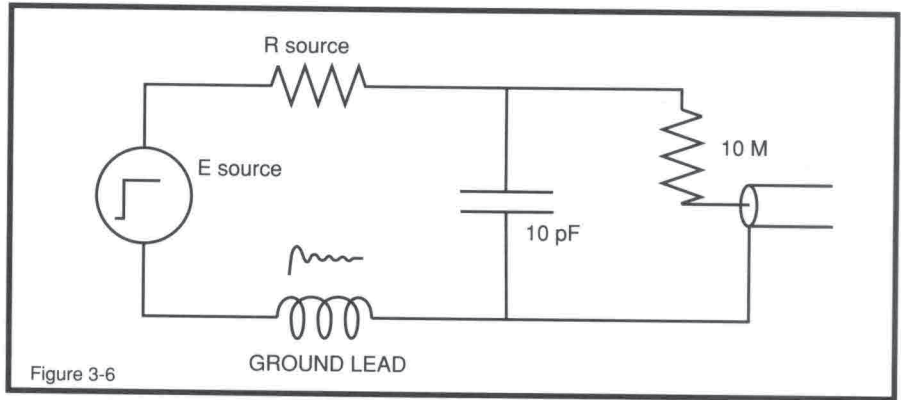
If a flexible ground lead is used in place of the ECB to Probe Tip Adaptor, the 1 nS Tr input step (with high frequency content up to 350 MHz) will cause the ground lead to ring at a frequency determined by the ground lead inductance and the probe tip and source capacitance.

Figure 3-5 shows the effect of using a 6" ground lead to make the ground connection.

The ring frequency for the 6" ground lead/probe tip C combination is 87.5 MHz. This signal is injected in series with the wanted signal and appears at the probe tip, as shown in figure 3-6.

Unfortunately, the problem is not this simple.

The probe's coaxial environment has been disrupted at the signal acquisition point by ground lead inductance, and is no longer correctly terminated (for high speed signal acquisition).



**Figure 3-6.** Equivalent circuit, ground lead inductance (excess inductance).

**Figure 3-6.** Equivalent circuit, ground lead inductance (excess inductance).

This abrupt transition leaves the probe's outer shield susceptible to ring frequency injection (the ground lead inductance is in series with the outer braid).

The now unterminated probe cable system develops reflections, which intermix with the ring frequency and the signal to produce a multitude of problems and unpredictable results.

Herein lies the key to the identification of ground lead problems.

Figure 3-7 shows exactly the same setup as in figure 3-5, except that the probe cable has been moved, and a hand has been placed over part of the probe cable.

**KEY:** If touching or moving the probe cable produces changes in the display, you have a probe grounding problem.

A correctly grounded (terminated) probe should be completely insensitive to cable positioning or touch.

**Ground Lead Length.** All things being equal, the shortest ground lead produces the highest ring frequency.

If the lead is very short, the ring frequency might be high enough to be outside the passband of the scope, and/or the input frequency content may not be high enough to stimulate the ground lead's resonant circuit.

In all cases, the shortest ground lead should be used, consistent with the need for probe mobility.

If possible, use 3" or shorter ground leads, such as the Low Impedance Contact (Z Lead). These are supplied with the Tektronix P613X and P623X family of probes.

One final note. The correct probe grounding method depends on the signal's high frequency content, the scope system bandwidth, and the need for mobility between test points.

A 12" ground lead may be perfect for many lower frequency applications. It will provide you with extra mobility, and nothing will be gained by using shorter leads.

If in doubt, apply the cable touch test outlined previously.

#### **Ground Loop Noise Injection.**

Another form of signal distortion can be caused by signal injection into the grounding system.

This can be caused by unwanted current flow in the ground loop existing between the common scope and test circuit power line grounds, and the probe ground lead and cable.

Normally, all these points are, or should be at zero volts, and no ground current will flow.

However, if the scope and test circuit are on different building system grounds, there could be small voltage differences, or noise on one of the building ground systems.

The resulting current flow (at line frequency or noise frequency) will develop a voltage drop across the probe cable's outer shield, and be injected into the scope in series with the desired signal.

#### **Inductive Pickup in Ground Loops.**

Noise can enter a common ground system by induction into long 50 Ω signal acquisition cables, or into standard probe cables.

Proximity to power lines or other current-carrying conductors can induce current flow in the probe's outer cable, or in standard 50 Ω coax. The circuit is completed through the building system common ground.

### Prevention of Ground Loop Noise Problems.

Keep all signal acquisition probes and/or cables away from sources of potential interference.

Verify the integrity of the building system ground.

If the problem persists, open the ground loop:

1. By using a Ground Isolation Monitor like the Tektronix A6901.
2. By using a power line isolation transformer on either the test circuit or on the scope.
3. By using an Isolation Amplifier like the Tektronix A6902B.
4. By using differential probes (see Differential Measurements).

NOTE: Never defeat the safety 3-wire ground system on either the scope or on the test circuit.

Do not "float" the scope, except by using an approved isolation transformer, or preferably, by using the Tektronix A6901 Ground Isolation Monitor.

The A6901 automatically reconnects the ground if scope ground voltages exceed  $\pm 40$  V.

**Induced Noise in Probe Ground Leads.** The typical probe ground lead resembles a single-turn loop antenna when it is connected to the test circuit.

The relatively low impedance of the test circuit can couple any induced voltages into the probe, as shown in figure 3-8.

High speed logic circuits can produce significant electro-magnetic (radiated) noise at close quarters.

If the probe ground lead is positioned too close to certain areas on the board, interference signals could be picked up by the loop antenna formed by the probe ground lead, and mix with the probe tip signal.

Question: Is this what my signal really looks like?

Moving the probe ground lead around will help identify the problem.

If the **noise level** changes, you have a ground lead induced noise problem.

A more positive way of identification is to disconnect the probe from the signal source and clip the ground lead to the probe tip.

Now use the probe/ground lead as a loop antenna and search the board for radiated noise.

Figure 3-9 shows what can be found on a logic board, **with the probe tip shorted to the ground lead.**

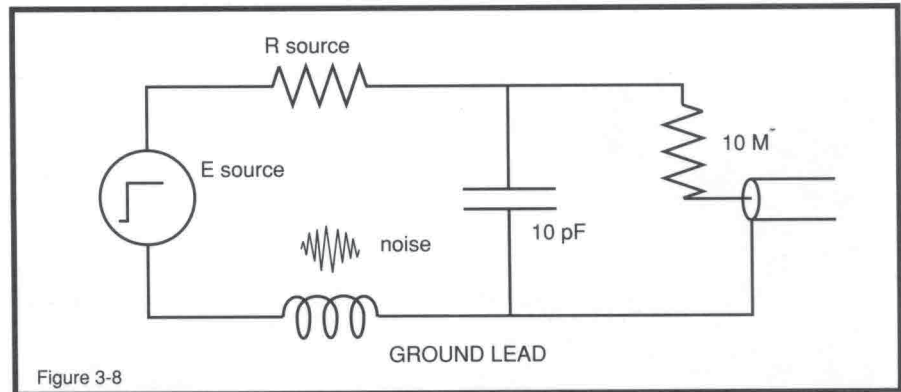


Figure 3-8. Equivalent Circuit. Ground Lead Induced Noise.

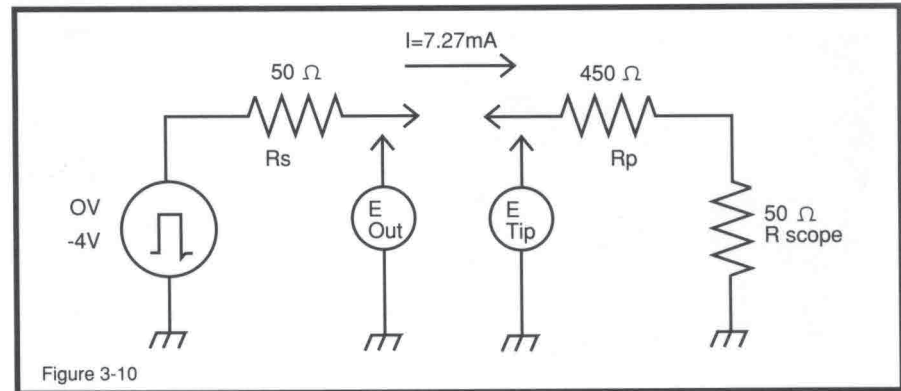


Figure 3-10. Low Z 10X 500  $\Omega$  probe connected to a 50  $\Omega$  source.

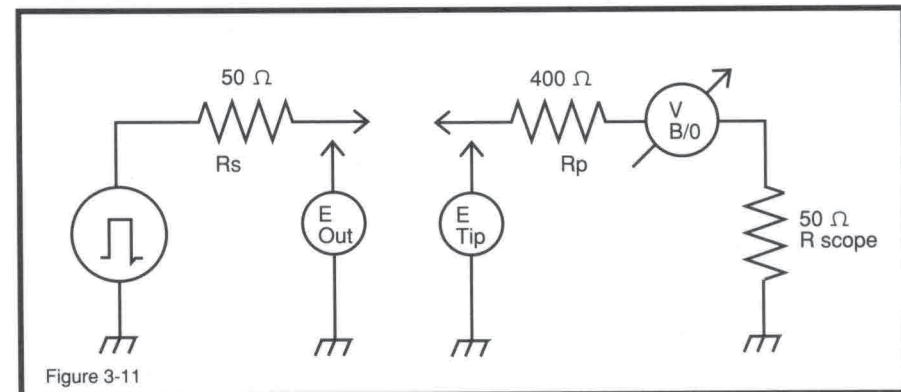


Figure 3-11. A 450  $\Omega$  Bias/Offset probe connected to a 50  $\Omega$  source.

This is radiated noise, induced in the single-turn loop and fed to the probe tip.

The significance of any induced or injected noise increases with reduced working signal levels, because the signal to noise ratio will be degraded. This is especially true with ECL, where signal levels are 1 V or less.

Prevention: If possible, use an ECB to Probe Tip Adaptor (test point). If not, use a Z Lead or short flexible ground lead.

Also, bunch the ground lead together to make the loop area as small as possible.

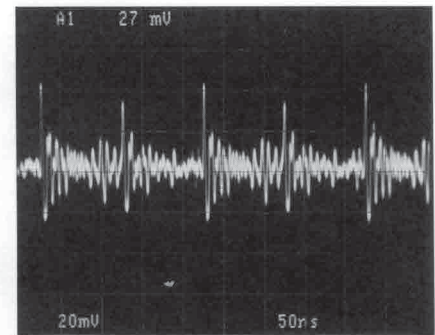


Figure 3-9. Induced noise in the probe ground loop (tip shorted to the ground clip).



**Bias Offset Probes.** A Bias/Offset probe is a special kind of Low Z design with the capability of providing a variable bias or offset voltage at the probe tip.

Bias/Offset probes like the Tektronix P6230 and P6231 are useful for probing high speed ECL circuitry, where resistive loading could upset the operating point.

They are also useful for probing higher amplitude signals (up to  $\pm 5$  V), where resistive loading could affect the DC level at some point on the waveform.

Bias/Offset probes are designed with a tip resistance of  $450 \Omega$  (10X). When these probes are connected into a  $50 \Omega$  environment, this loading results in a 10% reduction in peak to peak source amplitude. This round-figure loading is more convenient to handle than that produced by a standard  $500 \Omega$  (10 X) Low Z probe, which would work out at 9.09% under the same conditions.

It is important to note that bias/offset probes always present a  $450 \Omega$  resistive load to the source, regardless of the bias/offset voltage selected.

The difference between bias/offset and standard Low Z probes lies in their ability to null current flow **at some specific and selectable point** on the input waveform (within  $\pm 5$  V).

To see how bias/offset probes work, let's take a typical  $10 \times 500 \Omega$  Low Z probe and connect it in the circuit shown in figure 3-10.

By taking a current flow approach we find that at one point on the waveform the source voltage is  $-4$  V, therefore the load current will be;

$$I = ER = 4/R_s + R_p + R_{scope} = 4/550 = 7.27 \text{ mA.}$$

Therefore the voltage drop across the  $50 \Omega$  source resistance ( $R_s$ ) will be;

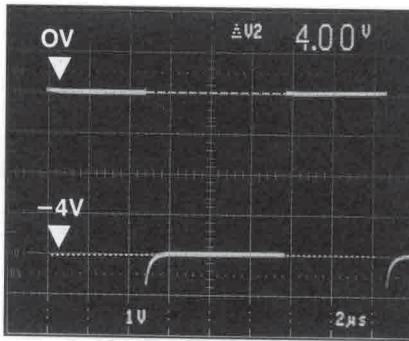
$$E = IR = 7.27 \times 10^{-3} \times 50 = 0.363 \text{ V}$$

And the measured pulse amplitude will be  $-4 - 0.363 = 3.637$  V (E dut), or about 9% down from its unloaded state.

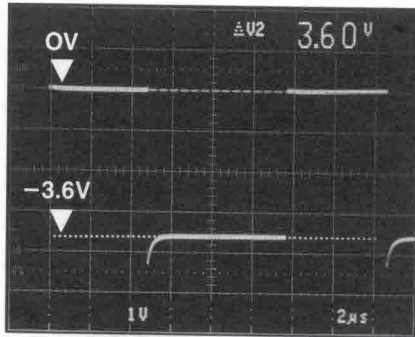
If we substitute the  $500 \Omega$  Low Z probe with a  $450 \Omega$  bias/offset probe, the circuit will look like figure 3-11.

With the bias/offset adjusted for 0 V, the effect on the circuit will be similar to a  $500 \Omega$  Low Z probe, except for the small resistive change.

Figure 3-12 shows the source waveform acquired by a  $10 \text{ M}\Omega$  probe.



**Figure 3-12.** Unloaded negative-going 4 V pulse acquired by a  $10 \text{ M}\Omega$  probe.



**Figure 3-13.** Effect of connecting a  $450 \Omega$  Bias/Offset probe (offset = 0 V). Minus level has been reduced by 10%.

Figure 3-13 shows the effect on the waveform when the  $450 \Omega$  probe is added.

As expected, the pulse amplitude has reduced from  $-4$  V to  $3.60$  V, or exactly 10% down.

Figure 3-14 shows the effect of adjusting the offset to  $-4$  V. The  $-4$  V bias opposes the signal at the  $-4$  V level and results in zero current flow, and the source is effectively unloaded **at this point**.

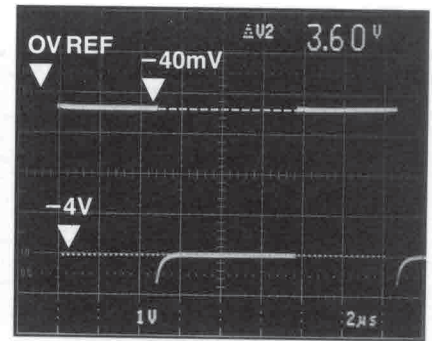
However, when the signal returns to ground level, there is a  $4$  V differential between the top of the pulse and the bias/offset source. Current will flow, and Ohms Law will dictate that the top of the pulse will go negative by  $-40$  mV (10%).

Sometimes it is desirable to adjust the offset mid-way between the peak to peak excursions. This distributes the effect of resistive loading between the two voltage swings.

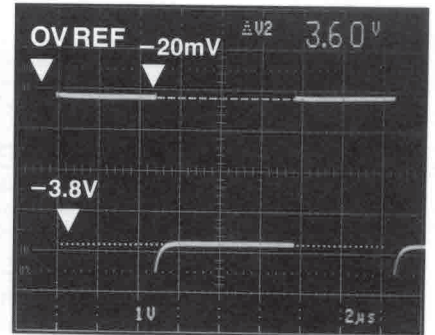
Figure 3-15 shows the effect of adjusting the bias/offset to  $-2$  V. Current flow will be the same for both signal swings, and they will be equally down by 5%, for a total of 10%.

Summary:

1. Bias/Offset probes can be adjusted (within  $\pm 5$  V) to provide zero resistive (effective) loading at one selected point on the input waveform.



**Figure 3-14.** Bias/Offset adjusted for  $-4$  V. Signal current at the  $-4$  V level is zero. Current flow at ground level is maximum. Peak to peak amplitude remains the same (10% down).



**Figure 3-15.** Bias/Offset adjusted for  $-2$  V. Load current distributed between the negative and positive-going swings. Peak to peak amplitude remains the same (10% down).

2. Bias/Offset probes can be used to simulate the effect of pull-up or pull-down voltages (within  $\pm 5$  V) on the circuit under test (voltage source impedance is  $450 \Omega$ ).
3. Bias/Offset probes always present a total resistive load of  $450 \Omega$ , and reduce the peak to peak amplitude of  $50 \Omega$  sources by 10%.
4. For simplicity, we have ignored the effects of capacitive loading. Typically, Bias/Offset probes have less than  $2 \text{ pF}$  tip C. Bias/Offset probes like the Tektronix P6230 or P6231 have bandwidths to  $1.5 \text{ GHz}$ ,  $450 \Omega$  input R, and  $1.3 \text{ pF}$  (P6230), or  $1.6 \text{ pF}$  (P6231) input C. They provide offset voltages of  $\pm 5$  V DC, and function with  $1 \text{ M}\Omega$  or  $50 \Omega$  input systems (P6231,  $50 \Omega$  only). The P6230 obtains operating power, either from the scope itself, or from the Tektronix 1101A or 1102 Power Supply. The P6231 is designed to operate with the Tektronix 11000 Series scopes, and obtains operating power and bias/offset from the scope. Offset is selectable from the mainframe touch screen.

### Differential Probing Techniques.

Accessing small signals elevated from ground, either at an AC level or a combination of AC and DC, requires the use of differential probes and a differential amplifier system.

One of the problems associated with differential measurements is the maintenance of high common mode rejection ratio (CMRR) at high common mode frequencies.

Poor common mode performance allows a significant portion of the common (elevated) voltage to appear across the differential probe's inputs. If the common mode voltage is pure DC, the result may only be a displayed baseline shift. However, if the common mode voltage is AC, or a combination of AC and DC, a significant portion may appear across the differential input and will mix with the desired signal.

Figure 3-16 shows the basic items necessary to make a differential measurement.

In this example two similar but un-matched passive probes are used. The probe ground leads are usually either removed or clipped together. They are **never** connected to the elevated DUT (device under test).

CMRR depends upon accurate matching of the probe-pair's electrical characteristics, including cable length. System CMRR can be no better than the differential amplifier's specifications, and in all cases, CMRR degrades as a function of frequency.

Figure 3-17 shows a simplified diagram of a DUT with a pulsed output of 1 V p-p floating on a 5 V p-p 20 MHz sinewave.

CMRR at 20 MHz is a poor 10:1 because of the un-matched probes.

Observed signal. (referred to probe input) = 1 V p-p pulse + (5 V p-p sine/10) = 1 V p-p pulse + 0.5 V p-p sine.

Figure 3-18a shows what the displayed waveform might look like under the conditions shown in figure 3-17.

In comparison, figures 3-18b and 3-18c show what the displayed signal might look like at CMRR's of 100:1 and 1000:1.

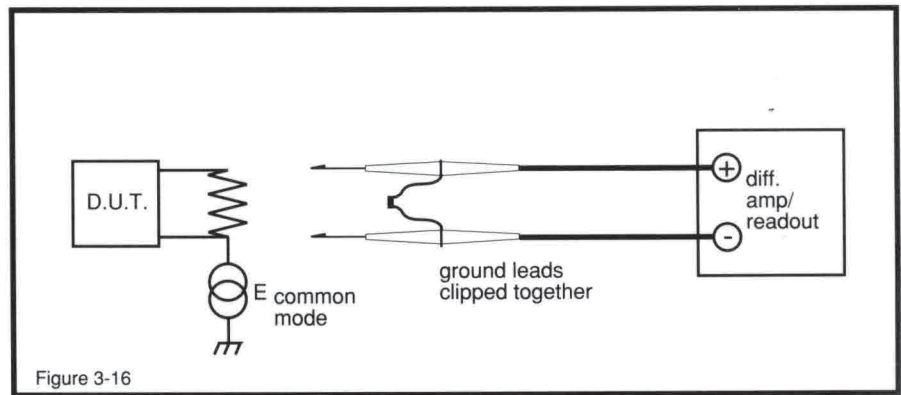


Figure 3-16

Figure 3-16. Basic connections to a device under test to make a differential measurement.

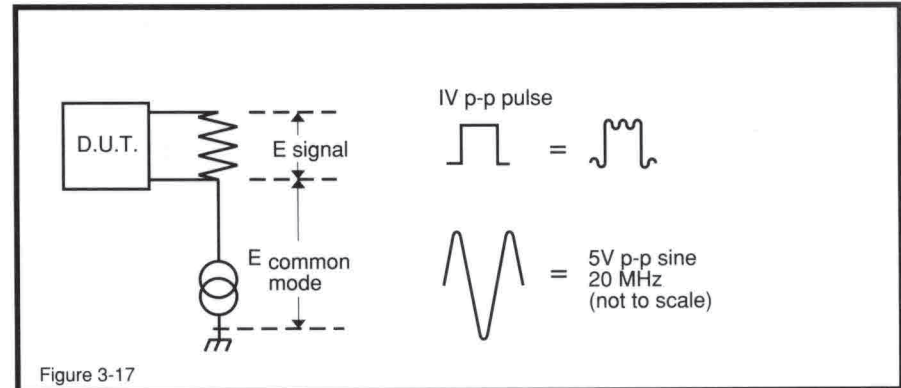


Figure 3-17

Figure 3-17. Simplified diagram. Elevated DUT. Common mode rejection is 10:1 at 20 MHz.

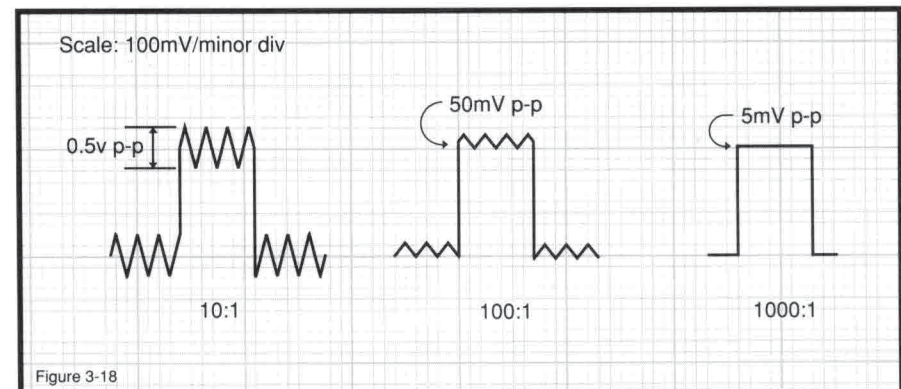
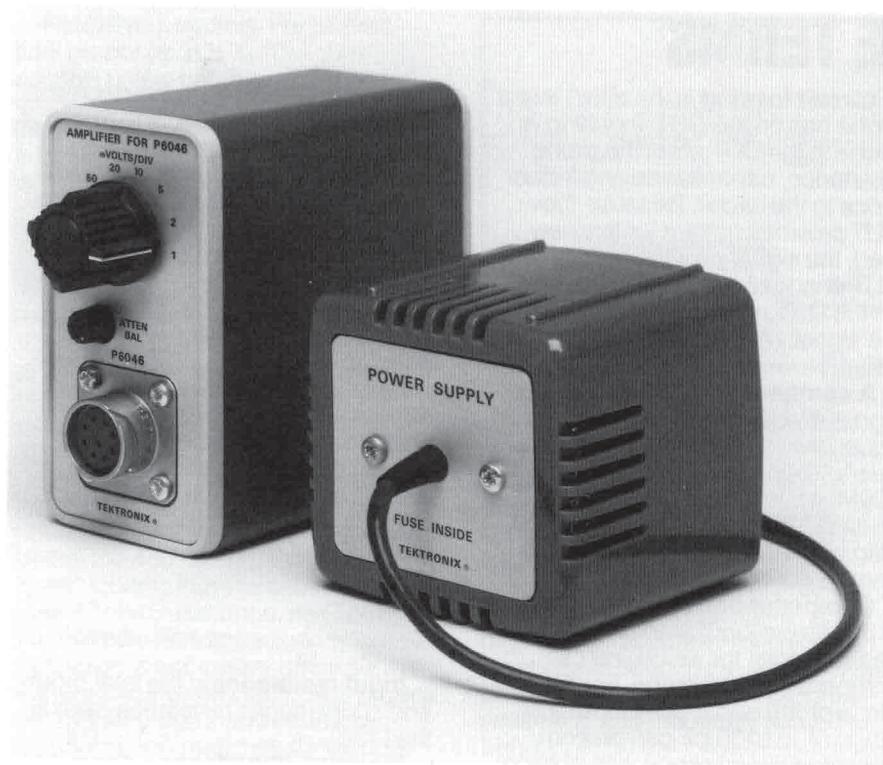


Figure 3-18

Figures 3-18, a, b and c. Displayed waveforms from the circuit shown in figure 3-17 at CMRR's of 10:1, 100:1 and 1000:1.



**Figure 3-19.** P6046 Active Differential Probe System.

**Differential Probe Types.** There are two general types of differential probes. Passive Matched Pairs and Active One-Piece Differential Probes.

The Tektronix P6055 and P6135 passive matched probe-pairs provide a 100:1 CMRR at 20 MHz when used with appropriate differential amplifiers, and can provide CMRR's of up to 20,000:1 at low frequencies. (P6135, 10,000:1; P6055, 20,000:1)

**Active Differential Probes.**

Passive probes impose a limit on CMRR at high frequencies because of the physical and electrical characteristics, and the separation from the differential amplifier.

This barrier is overcome by moving the differential amplifier out to the probe tips on an active differential probe. Now lead lengths and electrical parameters can be accurately controlled to produce superior high frequency CMRR performance.

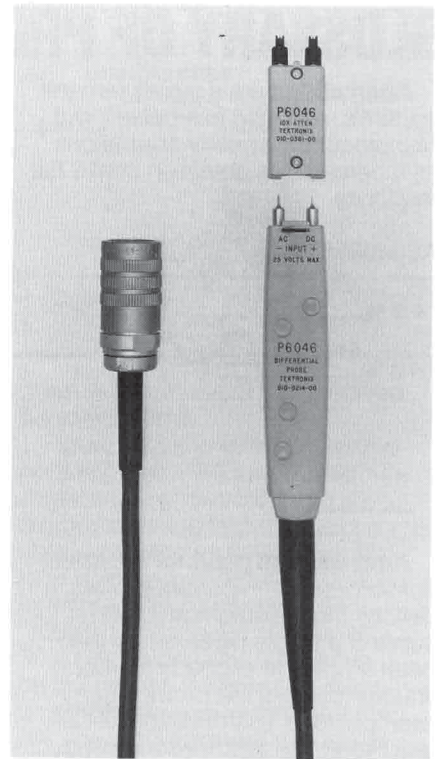
The Tektronix P6046 Active Differential Probe houses dual input FET's, a differential amplifier, and a line driver in the probe body. A 10X dual attenuator can be used to extend the basic operating range of the system, and various probe tips can be used to access variously spaced test points.

At the scope end, a power supply and a calibrated Volts/div switch provides ranges of 1 to 200 mV/div when the scope sensitivity is set to 10mV/div.

Because differential signal processing is performed at the probe tip, common mode rejection can be as high as 1000:1 at 50 MHz. Contrast this with 100:1 at 20 MHz for the best passive probe-pair performance. (see figure 3-18).

The P6046 system is compatible with a wide range of scopes and measuring devices with single-ended 1 MΩ inputs. No external differential amplifiers are required.

**Common Mode Linear Dynamic Range.** Linear Dynamic Range figures are unique to active probes, and refer to the maximum voltage swing (DC + Peak AC) between ground and the probe tip before some degree of non-linearity manifests itself.



In the case of differential active probes this parameter is called Common Mode Linear Dynamic Range, and specifies the maximum voltage of the probe inputs from ground (DC + Peak AC) before **signal** non-linearity manifests itself.

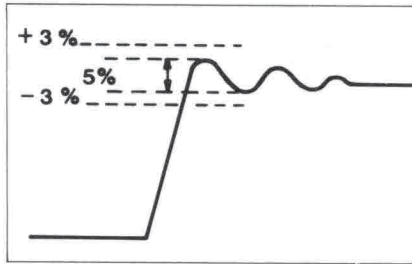
The P6046 can access signals that are elevated up to ± 5 V from ground (DC + Peak AC) at 1X, and up to ± 50 V with the 10X attenuator.

When the above limits are observed, differential signal linearity is taken care of by common-sense use of the Volts/div. control to keep the differential signal amplitude within the screen height.

# GLOSSARY OF PROBE TERMS

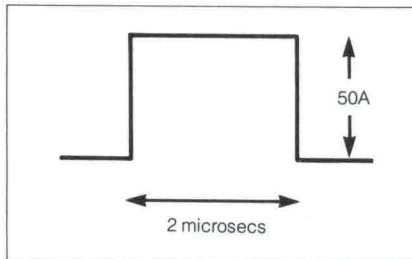
**Aberrations** are a measurement system's response to a pulse input. Manufacturers specify aberrations as a percentage deviation from a flat response.

Aberration



**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 of the probe. For example for a Tektronix A6302 Current Probe, the amp-second product is  $100 \times 10^{-6}$  AS., the maximum CW current is 40 A p-p (14 A rms), and the maximum peak is 50A. In this case, the maximum line is 2 microseconds:

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



**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.

**Dynamic Range** is the useful operating range of an active device in plus or minus volts before an unacceptable degree of non-linearity manifests itself.

Linear dynamic range figures usually apply to active probes, and specify the maximum plus or minus voltage swing at the probe tip before vertical non-linearity (compression) exceeds a certain value, such as 3%.

**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 sine wave 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-off 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 (0V) 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 (150N P6056)	↓

**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)		

**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)	<ul style="list-style-type: none"> <li>• If your signals are between 100mV and 400V peak to peak; choose a 10X probe.</li> <li>• If they are less than 100mV, choose a 1X probe.</li> <li>• If they are greater than 400V, choose a 100X or 1000X probe.</li> </ul>		
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).		

**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 precedence.		
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.		

**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 Mfgs. spec. sheets)	
			Probe Spec. ( $\geq$ 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.				

**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 Mfgs. 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. $A - \mu s \text{ product} = A \times \mu s$ or $\text{Width } \mu s = \frac{A - \mu s \text{ Prod.}}{A \text{ Peak}}$	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.				

**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 Mfgs. 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 it 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.			





# 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.
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Probe and accessory packages are described in detail in the Tektronix Accessories Selection Guide. It covers the entire product line and supplements 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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P.O. Box 1700  
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**Europe, Africa, Middle East**

Tektronix Europe B.V.  
P.O. Box 406  
2130AK Hoofddorp  
The Netherlands  
Phone: (2503) 15644  
Telex: 74876/74886

**Canada**

Tektronix Canada Inc.  
P.O. Box 6500  
Barrie, Ontario L4M 4V3  
Phone: (705) 737-2700

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