

Keysight Technologies

# Improving Usability and Performance in High-Bandwidth Active Oscilloscope Probes

Application Note



## Introduction

If you use high-bandwidth active voltage probes, you may have tried some creative approaches to gain visibility into hard-to-reach nodes in your circuits. You may have attached relatively short wires to the input of your probe so you could reach into a tight probe point and solder them in place. You may have used a long, needle-like pin as the signal input to your probe because you found it easier to see the tip of the probe and successfully apply it to the node of interest. Or you may have attached your probe to a header pin that is conveniently located on the board for just this purpose.

These creative approaches arise frequently in development labs where engineers have a “whatever it takes” attitude to getting their jobs done. If you’re like most creative probe users, you are aware that there is a price to pay – in terms of electrical performance – for relying on these methods to improve probe usability.

This application note will explore three different approaches to high-bandwidth, active-probe architecture. First, it will discuss some of the performance and usability issues with traditional probe architecture. Next, it will explore how some of these issues have been addressed in a modified traditional architecture. Finally, it will take a close look at an innovative probe architecture that effectively eliminates all of the issues found with traditional architecture probes.

This discussion assumes that users of high-bandwidth active probes have three fundamental electrical requirements:

1. You would like the probe to load your circuit as little as possible at all frequencies.
2. You would like the probe to show as accurate a representation of the signal as possible while it is being probed. With an accurate representation of the loading effects on your oscilloscope screen, you can determine the loading and decide if it is an issue.
3. You would like to see the highest possible performance representation of your signal.

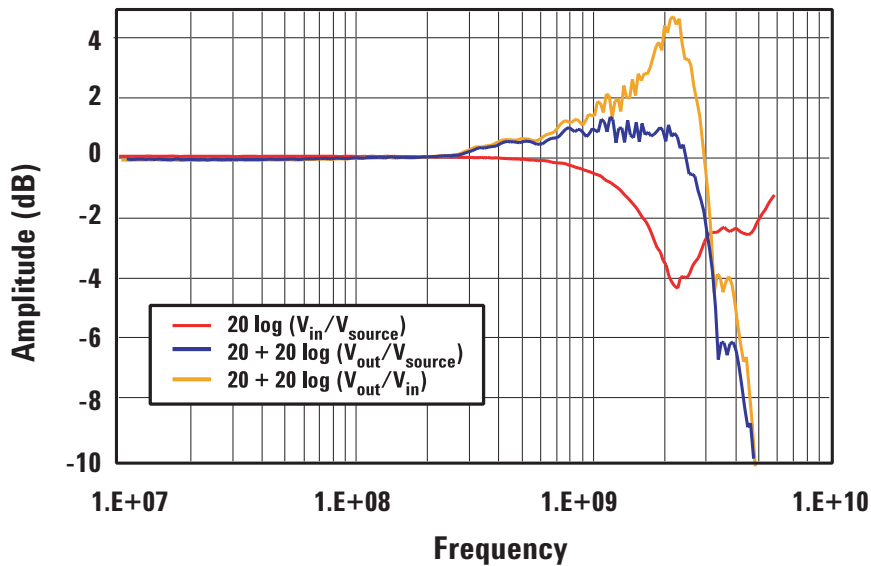


Figure 1. Traditional form factor 4 GHz probe with pin in signal socket and pogo pin in ground.  
Note >+4 dB peaking of  $V_{out}/V_{in}$  and 4 dB attenuation of  $V_{in}$  at 2.25 GHz

## Traditional Active Probes

Traditional oscilloscope probes are designed as “browsers.” These devices are optimized to be held in your hand and moved from point to point for troubleshooting or debugging.

Typically, for single-ended probes, the browser is outfitted with two sockets, one to accept signal-path accessories, and another to accept ground-path accessories. These sockets exist for two reasons. First, accessories wear out and need to be replaced. Second, manufacturers know that you might want to use the probes for activities other than browsing, and the sockets can be used for accessories that enable other use models, including hands-off socketed probing and hands-off soldered-in probing.

Unfortunately, browser designs available on the market today are not necessarily ideal for browsing. To minimize a probe’s input parasitics, manufacturers have designed probes to be as small as possible, allowing a higher-bandwidth transfer response. In a traditional active-probe design, the active electronics are inside the portion of the probe that you hold in your hand. This circuitry can only be made so small – typically ~ 50 mm x 6 mm x 13 mm (2 in x 0.25 in x 0.5 in) – so probes are usually too large to fit into tight spaces, yet too small to be comfortable for hours of probing.

## Achieving the illusive “specified” bandwidth

Manufacturers have used two approaches to building high-bandwidth, single-ended active probes. The first approach is to provide signal- and ground-path sockets that are integrated with the probe. Unfortunately, the parametric inductance and capacitance created by these sockets and the accessories that go in them yields an input impedance resonance. Unless manufacturers take appropriate design measures to prevent resonance in “socketed” probes, which will be discussed later, they will always load the probed signal significantly at some frequency (see Figure 1).

For traditional socketed probes, manufacturers usually try to provide accessories to insert into the signal- and ground-path sockets that are short enough (i.e., low enough inductance) to move the resonant frequency outside the specified bandwidth of the probe.

However, with the socketed probes available on the market today, it is becoming impossible to push the resonance out of band while still providing accessories that are long enough to provide any usability benefit. With accessories inserted in the socket that are

long enough to use, the resonance is almost always within band. Just the socket alone, with no accessories inserted, can produce a significant in-band resonance. Inserting a pin in the signal socket and a pogo in the ground socket will cause even more dramatic in-band fidelity issues, as shown in Figure 1.

Because of this electrical behavior, you can see why probe manufacturers often specify the bandwidth of the probe using a special fixture to maximize the resonance frequency. Typically, the socketed probe's specified bandwidth (defined as the frequency at which  $20 \log (V_{out}/V_{in}) = -3 \text{ dB}$  from DC) is unachievable in any everyday, usable configuration. (The plots in this article were taken using an Keysight Technologies, Inc. 8720ES\* 50 MHz to 20 GHz vector network analyzer.  $V_{a_{source}}$  (Vs) is 0 dB (1 volt) from 50 MHz to 20 GHz and is not shown on the plots.  $V_{in}$  is a plot of the signal while being probed, showing the loading effects of the probe on the signal.  $V_{out}$  is the signal at the  $_{out}$ put of the probe.  $V_{out}/V_{in}$  is the transfer function of the probe.)

The second approach manufacturers use for traditional probes is to replace the signal-path socket with an integrated, fixed pin. Manufacturers do this because it reduces the inductance in the signal path and allows damping resistance to be applied immediately after this short signal pin. In this case, the probe can actually achieve measurements that are of the probe's specified bandwidth. Unfortunately, this design relies on the probe points of interest always being the same fixed distance apart because there is no way to vary the distance between signal and ground. This limitation greatly reduces the usability of the probe. To achieve variable pitch, one manufacturer provides an accessory that appends a socket to the end of the input signal pin. You can insert additional accessories that allow variable span into this socket. All of this metal between the probe and probed point makes the resonance worse, peaking the transfer response by 8 dB (see Figure 2).

## How to make a bad resonance worse

Suppose you decide to add wires or a long, skinny, needle-like accessory into a hard to reach probe point. This is exactly the same as adding inductance in series with the input. The resonance described above always moves down in frequency as the series inductance looking into the input grows. Therefore, these accessories will often serve to move the low-impedance resonance into the frequency spectrum of interest.

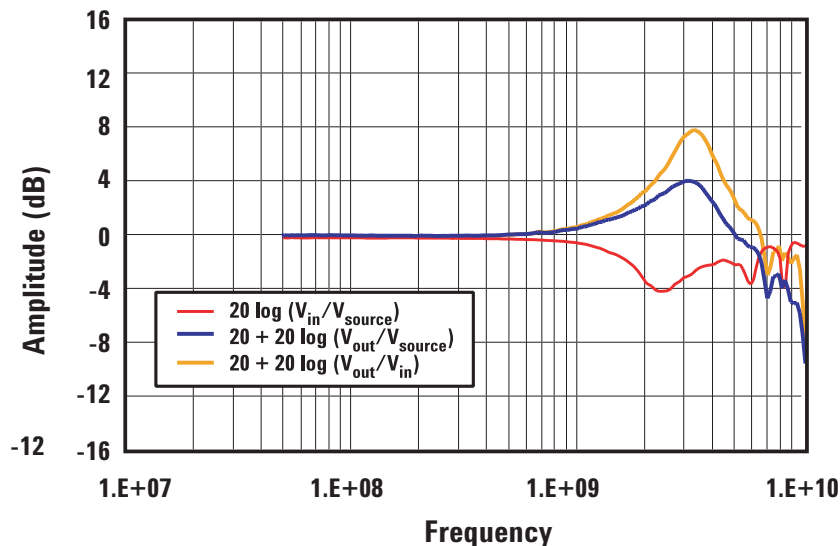


Figure 2. Six GHz "browser" probe equipped with socket accessory. Note +8 dB peaking at 3.3 GHz

\* 8720ES is a discontinued product. The Keysight PNA-L Series of network analyzers (N5230A) are the recommended replacements.

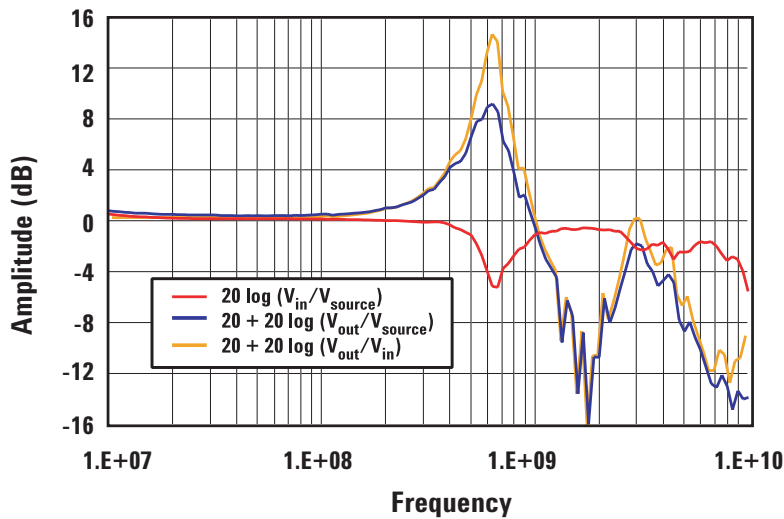


Figure 3. Six GHz "browser" probe equipped with socket accessory and wire accessories. Note +14 dB peaking at 800 MHz

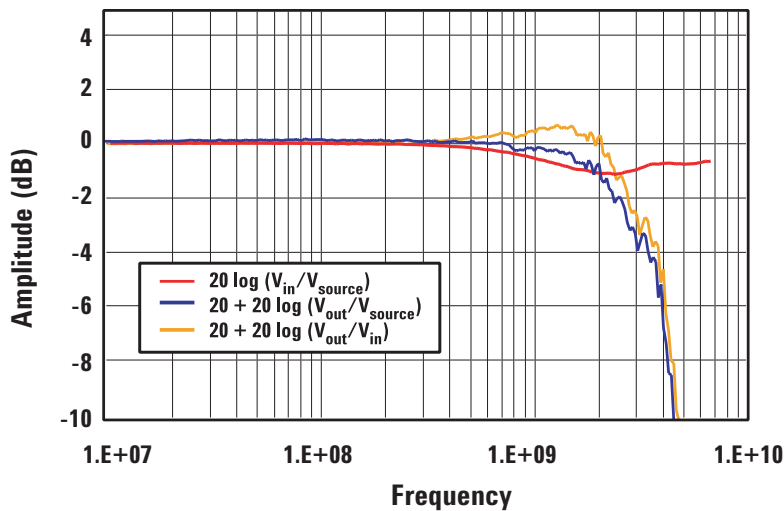


Figure 4. Keysight 1158A 4 GHz probe with damping resistor in signal socket and ground pogo accessory

Unless manufacturers take appropriate design measures to avoid this problem, using these accessories will invariably yield inaccurate measurement results due to the in-band resonance they cause. Figure 3 shows the results when a 51 mm (2 in) wire is used to probe a relatively fast signal.

Though many have used methods like this, the hope is that the representation of the probed signal is accurate enough to do the job. Often, this is not the case.

## The Improved Traditional Probe

As mentioned earlier, traditional single-ended active probes configured with accessories have an in-band resonance, unless the manufacturer has taken appropriate steps to prevent it.

For its 1150 Series of single-ended active probes, Keysight has taken these steps. Accessories for the 1150 Series include a damping resistance placed close to the probe tip so that the minimum impedance at the probed point is guaranteed not to drop below the value of the damping resistor. As shown in Figure 4, the probed signal is only slightly

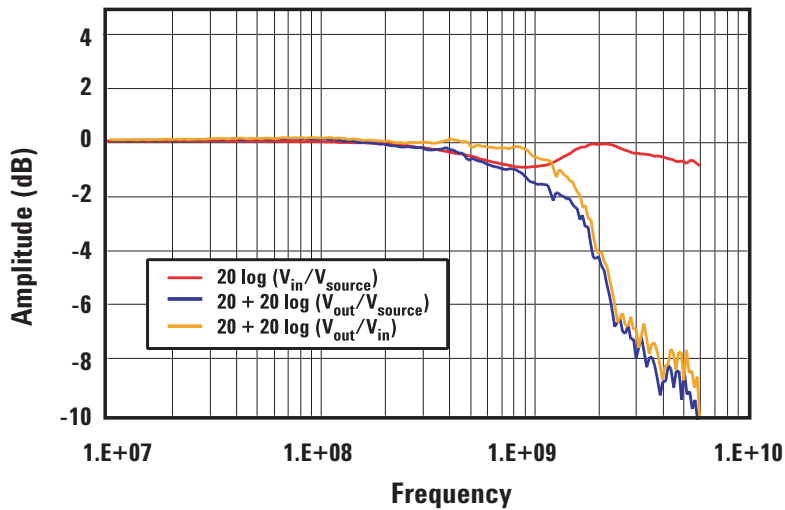


Figure 5. Keysight 1158A probe equipped with properly damped wires

changed when the probe is attached. In addition, the output signal of the probe is an accurate representation of what the probed signal looks like while it is being probed.

When you need to use long wires to get to a particularly hard-to-reach probe point, or when you need to take your hands off the probe to take measurements, Keysight provides damped wire accessories. When you use these accessories, the probed signal is hardly affected, and  $V_{out}$  is a well-behaved, low-pass filtered representation of the input signal, as shown in Figure 5. It is impossible to avoid a significant reduction in bandwidth, but fidelity is maintained with this approach. This is the best result that can be achieved with a product that is optimized for browsing.

## A Probe Optimized for All Use Models

With the introduction of the InfiniiMax probing system for use with the Infiniium Series oscilloscopes, Keysight has made a paradigm shift in active probe architecture. The InfiniiMax system eliminates many of the electrical limitations described earlier.

Keysight has designed a mainframe architecture for the Infiniium Series oscilloscopes that is optimized for all probe use models. The InfiniiMax probing system incorporates a high-performance RF connector between the probe head and the probe amplifier, so you can choose a high-performance probe head that is optimized for your particular type of measurement. Properly damped accessories are provided for you to use with each type of probe head.

To illustrate how this architecture strikes a balance between performance and usability, let's look at various use models and the performance you can achieve with each one.

### Browsing single-ended signals

The single-ended probe head is optimized for one of the most common uses for active probes, browsing single-ended signals. Traditionally, browsers come equipped with sockets for both signal and ground that accept 0.64 mm (0.025 in) square pins or 0.84 mm (0.033 in) round pins so that accessories can be inserted in the tips. The Keysight browser has a signal-path socket that is much shorter and smaller in diameter than sockets in traditional probes. Instead of a ground-path socket, this probe has a ground collar and pogo-pin accessory. A resistor tip accessory has the appropriate resistance for damping the input parasitics of the browser. The signal pin is angled, so when you rotate the ground collar, you vary the span between the signal pin and the ground pogo

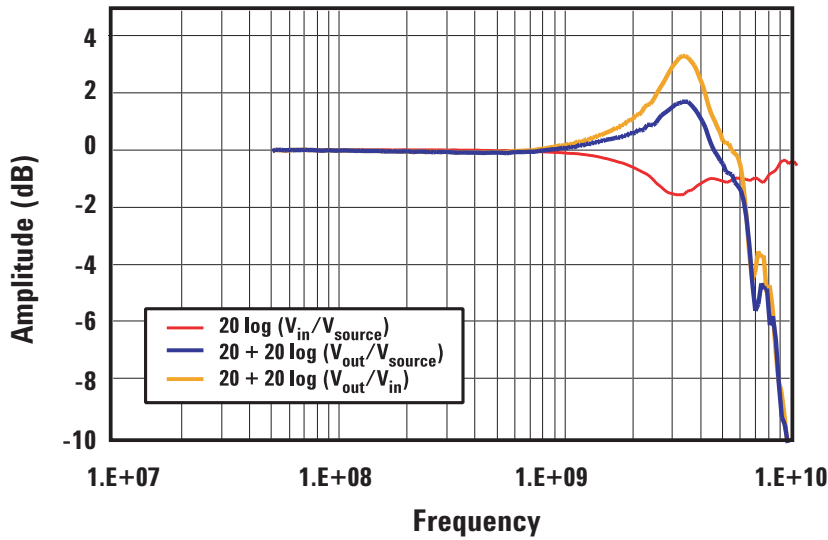


Figure 6a. Six GHz probe with fixed pin and pogo ground accessory. Even a stubby fixed pin causes +3 dB peaking at ~ 3.5 GHz

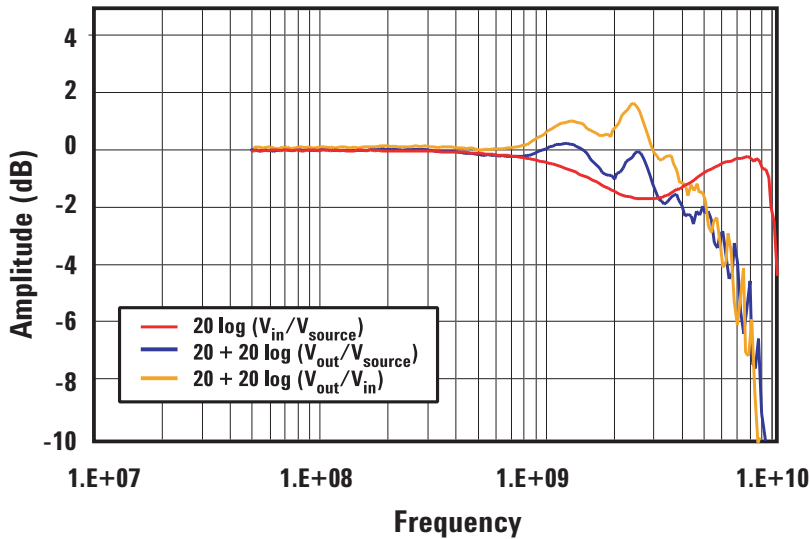


Figure 6b. InfiniiMax single-ended browser probe head with damped signal pin and pogo ground accessory

pin. These features allow the browser to achieve excellent measurement fidelity and bandwidth, while still providing variable span so that the probe is much more usable than a probe with fixed span.

Figures 6a and 6b compare a traditional 6 GHz probe that is optimized for browsing with a fixed metal pin in the signal path and a pogo pin in the ground, and the single-ended browser probe head and properly damped resistor pin in the InfiniiMax architecture.

The Keysight browser is designed to be as small as possible to minimize input parasitics. Because there is minimal circuitry inside the browser, it is smaller than most of the traditional probes on the market. This design allows you to squeeze the browser into very tight places to reach nodes that are difficult to probe. However, this probe is too small to use for hours and hours of browsing, which is exactly how many engineers use their probes. To solve this problem, the probe comes with a pencil-shaped accessory that the browser fits into. This accessory is much easier to hold for long periods.

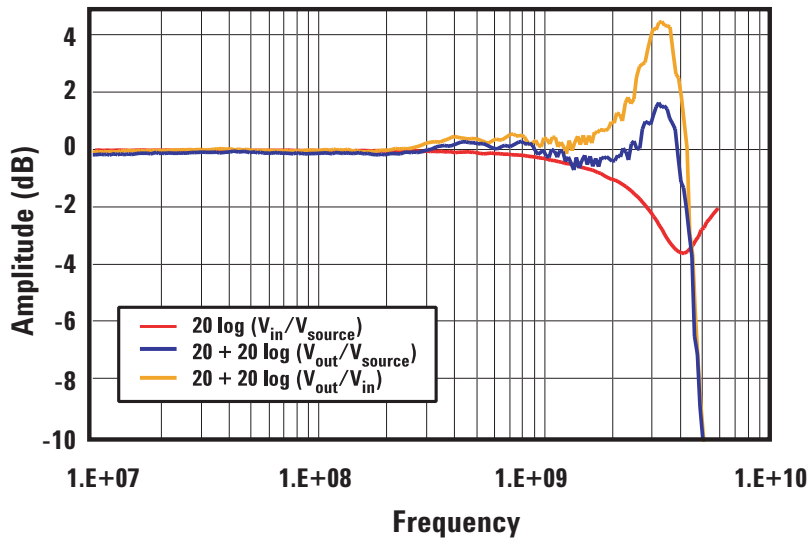


Figure 7a. Three and one-half GHz differential probe equipped with accessories for varying span. Added accessories cause resonant input and peaked transfer response

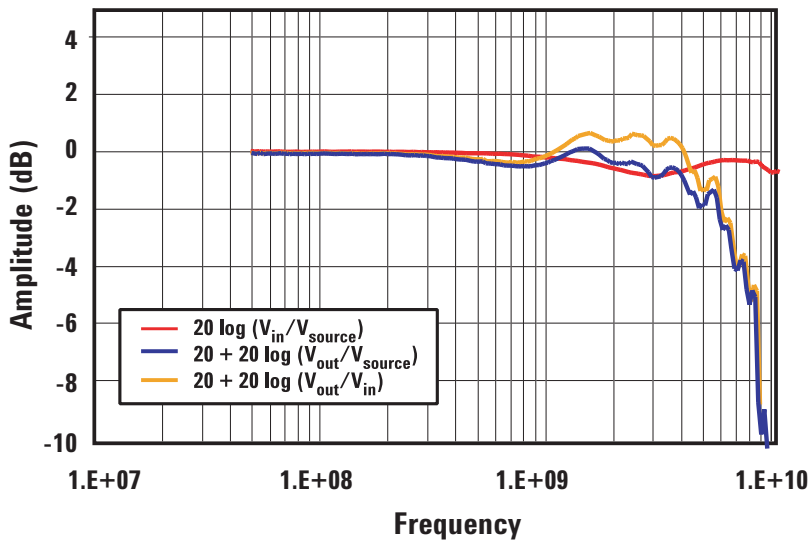


Figure 7b. InfiniiMax differential browser probe head with damped signal pins. Response is flat and  $V_{out}$  tracks  $V_{in}$

## Browsing differential or single-ended signals

This flexible InfiniiMax architecture allows you to make either differential or single-ended measurements. Like the single-ended browser, the differential browser probe head is equipped with miniature sockets that are only as large as is necessary to take the custom damping resistor input pin provided. Note that the differential probe head comes equipped with variable span and z-axis compliance. This means that you are not required to add accessories that increase inductance (such as pogo pins) at the input to configure the probe so that it is usable.

Note the dramatic difference in response of this probe relative to a traditional differential probe outfitted with accessories to achieve variable span (see Figures 7a and 7b). Unfortunately, the traditional differential probe does not offer any spring action in the signal pin, which would improve usability when you make contact on both signals.

It is important to note that a differential probe is the best tool to use for any high-speed probing. A differential probe provides inherently better common mode rejection and bandwidth than a single-ended probe offers. Though there are single-ended probes



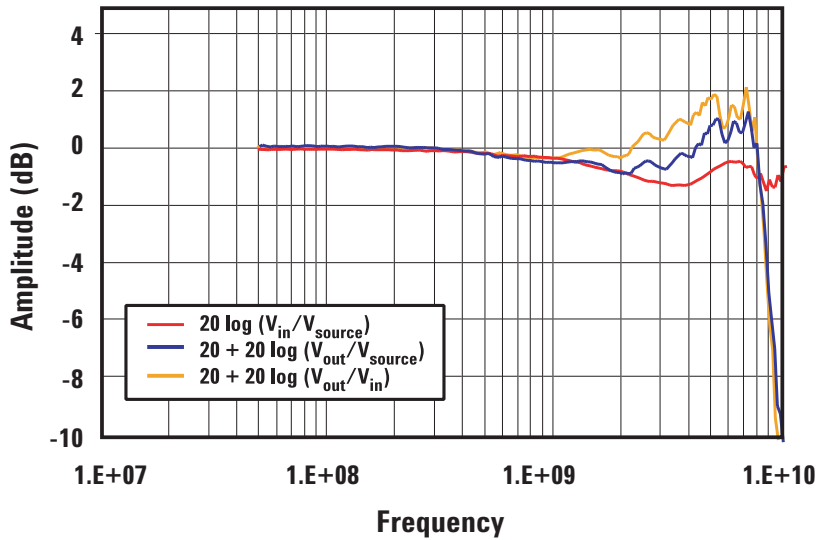


Figure 8. InfiniiMax differential socketed probe head.  $V_{out}$  tracks  $V_{in}$  and is relatively flat. Note bandwidth is  $> 8$  GHz

on the market that feature a very high specified bandwidth, the bandwidth is usually specified using no accessories in the inputs and a special fixture to minimize the input parasitics. A differential probe is not as sensitive to the input parasitics, as long as they are balanced. This allows you more choices in very high-bandwidth connections to your circuit. The InfiniiMax differential browser features 12 GHz of bandwidth, even with its variable span and z-axis compliance capabilities.

### Measuring differential or single-ended signals using a hands-off, socketed connection

Traditionally, to make a hands-off measurement, you insert wire accessories into the long sockets in the probe. Often these accessories are equipped with sockets that are to be attached to the probe point via a 0.64 mm (0.025 in) square header pin. Figure 3 shows the dramatically resonant and overpeaked response of a 6 GHz probe equipped with undamped socketed wires. This approach is clearly not useful for making measurements on any signals with signal content above about 400 MHz.

To make a similar measurement with the InfiniiMax probe, the socketed differential probe head is connected to the probe point through short axial lead resistors – instead of header pins – yielding markedly better fidelity and much higher bandwidth (see Figure 8). This is one of the most dramatic examples contrasting this innovative probe architecture and traditional architectures.

### Measuring differential or single-ended signals using a hands-off, solder-in connection

The InfiniiMax solder-in differential probe head only differs from the socketed version in that Keysight has removed the sockets from the probe tip and replaced them with miniature axial lead resistors. The leads on these resistors are ideal for soldering onto small package leads and vias on the circuit under test. The usability advantages in this probe head are similar to the socketed version described above.

It is important to point out another usability advantage that this probe and the socketed version share, and that is size. Often it is important to squeeze your probe into very tight spaces to get to a difficult-to-reach probe point. For example, probing the leads on a RAM in a DIMM package when the package is inserted in its socket is impossible using traditional probes. Because the browser probe heads can be removed and replaced with

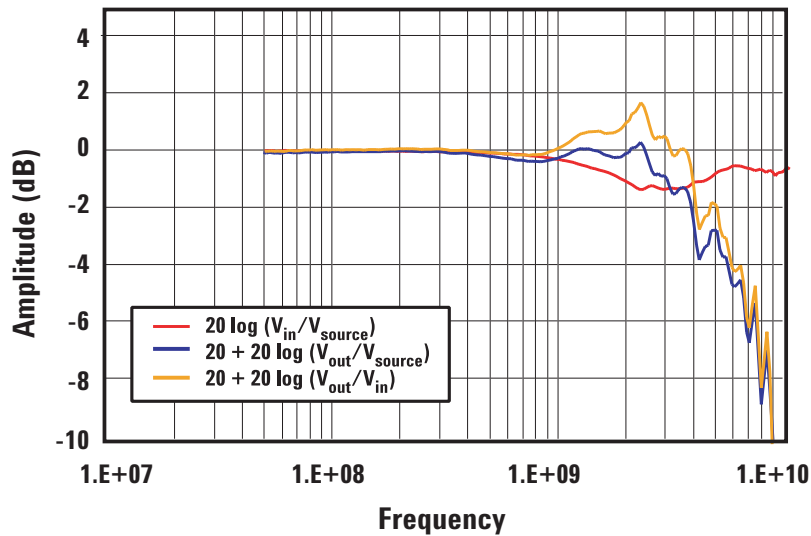


Figure 9. InfiniiMax single-ended solder-in probe head. Bandwidth is ~ 5 GHz

these tiny probe heads (6.4 mm x 12.7 mm x 2.5 mm (0.25 in x 0.5 in x 0.1 in)), getting into tight spaces is significantly easier. To use a traditional browser probe, you have to attach long wire accessories that decrease both the performance and the fidelity of the measurement.

## Measuring single-ended signals using a hands-off, solder-in connection

To squeeze into even tighter spaces, a single-ended solder-in probe head is provided with this new system. The probe tip end of the probe head is remarkably small (3.8 mm x 12.7 mm x 2.5 mm (0.15 in x 0.5 in x 0.1 in)). This probe head achieves excellent measurement performance and fidelity, as shown in Figure 9. The performance of this measurement is much higher than when it is made with the damped-wire accessories included with a traditional single-ended active probe.

Notice the difference in measurement performance between the single-ended (Figure 9) and the differential solder-in probe head (Figure 8). This straightforward comparison dramatically illustrates the performance differences between differential and single-ended probes. The single-ended version is included because it delivers the minimum size available for making high-bandwidth measurements. However, for the absolute highest-bandwidth measurements, the differential version is recommended.

## Summary

Keysight's InfiniiMax probe architecture addresses serious deficiencies found in traditional high-bandwidth probes. Traditional browser probe architectures are optimized for browsing only, but are too large to fit into very tight places and too small to be comfortable for extended periods of use. Additionally, to use a browser probe for anything other than browsing, accessories must be added that compromise performance and fidelity.

The InfiniiMax probe architecture offers interchangeable probe heads that are optimized for a variety of uses, including browsing in tight places, browsing for extended periods of time, hands-off socketed probing, and hands-off soldered-in probing. For all of these use models, this architecture offers the highest-bandwidth and highest-fidelity measurements available. Additionally, InfiniiMax provides unmatched ability to make high-performance measurements at the hardest-to-reach probe points due to the small size of some of the probe heads. Finally, this system has the flexibility to be used for

either differential or single-ended measurements.

## Glossary

**Bandwidth** – the frequency at which the magnitude of the frequency response is equal to  $-3$  db (or  $.707$ ) relative to the magnitude at DC.

**Common mode rejection** – for circuits that perform the function  $\text{input1} - \text{input 2}$ , common mode components of  $\text{input1}$  and  $\text{input2}$  do not produce an output. **Damping** – a way of reducing the oscillations introduced into a measurement.

**Differential signal** – a method of electronic signaling using two conductors where the signal on one conductor is equal and opposite to the signal on the other conductor.

**Frequency response** –  $v_o(s)/v_i(s)$ , where  $v_o(s)$  is the output signal as a function of frequency and  $v_i(s)$  is the input signal as a function of frequency.

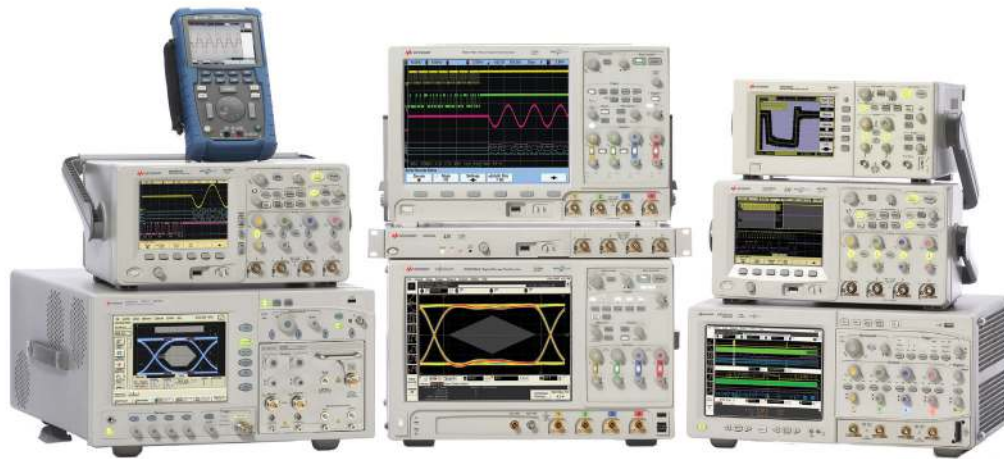
**Parasitics** – parasitic inductance, which is usually a function of the length of the conductor, and parasitic capacitance, which is usually a function of the volume of the conductor and its proximity to ground.

**Single-ended signal** – a method of electronic signaling using one signal conductor and a common ground conductor. Nominally, the common ground conductor has no signal on it and the signal conductor moves relative to the ground conductor.

**Z-axis compliance** – spring-loaded compliance in the direction in which force is applied, pushing the probe against a probe point. Also known as “pogoing”, this compliance eliminates z-axis positional mismatch between signal and ground pins in single-ended probes, or signal and signal pins in differential probes.

## Related Literature

Publication Title	Publication Type	Publication Number
Keysight Infiniium DSO/DSA 90000A Series	Data sheet	5989-7819EN
Keysight Oscilloscope Probes and Accessories	Selection guide	5989-6162EN
Extending the Range of Keysight InfiniiMax Probes	Application note	5989-7587EN
Eight Hints for Better Scope Probing	Application note	5989-7894EN
Restoring Confidence in Your High-Bandwidth Probe Measurements	Application note 1419-01	5988-7951EN
Performance Comparison of Differential and Single-Ended Active	Application note 1419-03	5988-8006EN
Understanding Oscilloscope Frequency Response and Its Effect on Rise-Time Accuracy	Application note 1420	5988-8008EN
The Truth About the Fidelity of High-Bandwidth Voltage Probes	Application note 1404	5988-6515EN



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This document was formally known as Application Note 1419-02

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