

Side-by-Side Comparison of Agilent and Tektronix Probing Measurements on High-Speed Signals

Application Note 1491

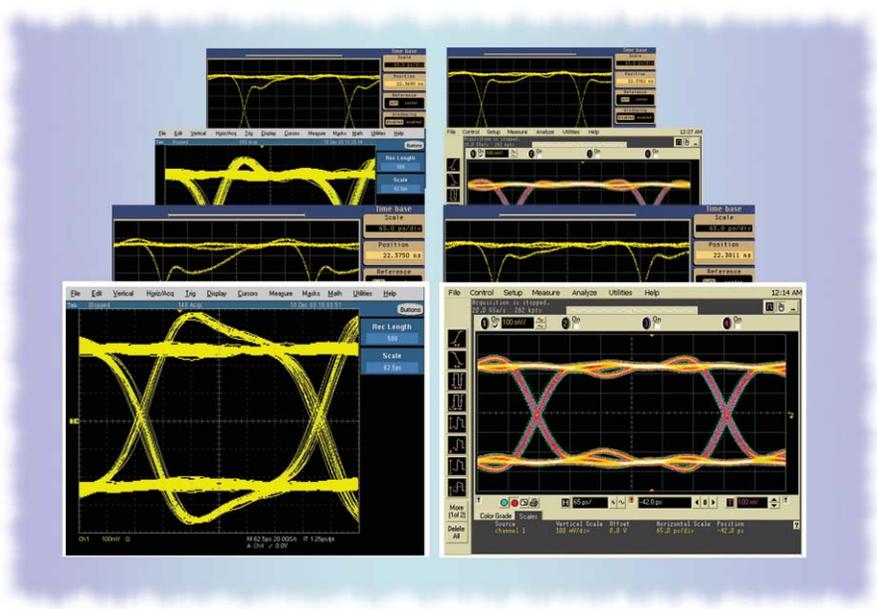


Table of Contents	
Introduction	1
Test Methodology	2
Side-By-Side Probing Measurements on a 50 ps Edge-Speed Signal	3
Browser connection	3
Solder-in connection	5
Side-By-Side Probing Measurements on a 100 ps Edge-Speed Signal	6
Browser connection	6
Solder-in connection	8
Should You Measure “What was” or “What is”?	9
Different Probe Specification Methodologies	10
Conclusion	11
Glossary	12
High-Performance Infiniium Oscilloscopes and Probes	13
Support, Services, and Assistance ..	14

Introduction

When you make signal-integrity measurements on high-speed signals, the oscilloscope and probe you use can have a big impact on the accuracy of your measurements. You may want to compare scopes and probing systems made by different manufacturers to find the best ones for your application. When you do so, it is important to reference test techniques that provide true comparisons of similar probe-type connections that also include effects of probe loading.

In this application note, we demonstrate a methodology for accurately comparing oscilloscope measurements on high-speed signals using Tektronix, Inc. and Agilent 6 GHz bandwidth real-time oscilloscopes and differential active probing solutions. We document results of side-by-side tests on signals with 50 ps and 100 ps edge speeds (10% to 90%), and we discuss differences in Agilent and Tektronix test philosophies and probe specification techniques that should be important to high-speed digital designers.

Test Methodology

We used an Agilent 8133A pulse/pattern generator to produce a 2.5 Gb/s serial data test signal with edge speeds of approximately 50 ps (10% to 90%). Accurately digitizing signals this fast is beyond the measurement capability of the 6 GHz measurement systems we tested, and measurement results actually show the response of the scope as opposed to showing the actual signal. But it may be constructive to look at the response of a measurement system when it encounters an out-of-band signal, especially since real-time scopes are sometimes used in an attempt to measure some characteristics of very high-speed signals.

In addition to testing this very high-speed signal, we fed this signal through a low-pass filter to generate edge speeds of approximately 100 ps, which is about the fastest signal speed that real-time scopes with 6 GHz bandwidth can measure with reasonable accuracy. We constructed a 50 Ω differential microstrip test fixture that allowed us to probe the differential signal under test. We did not tune these tests to showcase the Agilent equipment's strengths or to highlight the Tektronix equipment's weaknesses. As a matter of fact, we used a test setup similar to one used by Tektronix in a recently published white paper and video, with one important difference: *When we performed our tests, we were careful to compare similar probe connections using real-time sampling so we would get a valid comparison of the solutions from each manufacturer. We also captured loaded as well as unloaded signals using a high-bandwidth sampling scope for reference.*

We captured the following signals for comparison:

1. Unloaded (not probed) signal captured by an Agilent 54750 20 GHz sampling oscilloscope
2. Loaded/probed signal captured by an Agilent 54750 20 GHz sampling oscilloscope
3. Measured signal captured by Tektronix and Agilent 6 GHz real-time oscilloscopes and differential active probes with various connections/probe heads

Figure 1a shows a block diagram of the test setup, and Figure 1b shows an actual loaded test using the Tektronix TDS6604/P7350 with a browser connection to the specially designed 50 Ω differential microstrip board. The sampling oscilloscope provides precision 50 Ω terminations for the test fixture and measures the loaded and unloaded signals with repetitive high-bandwidth sampling for reference comparisons.

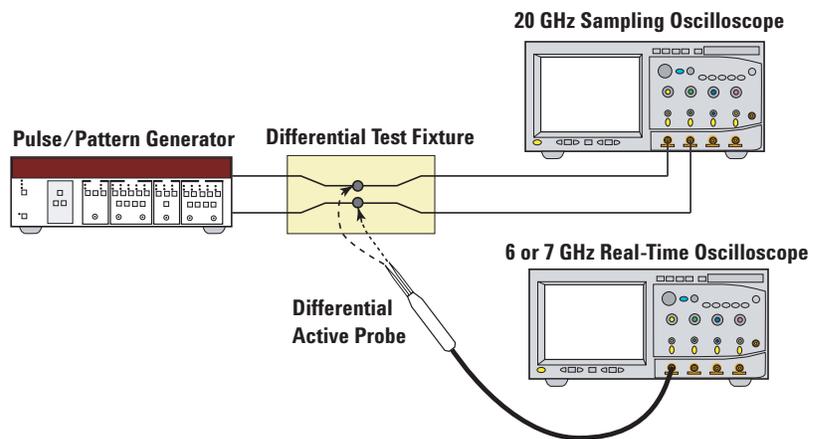


Figure 1a. Block diagram of test setup.

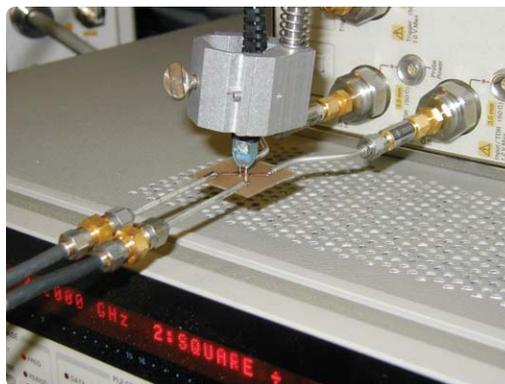


Figure 1b. Test setup with probe attached to test fixture using probe stand holder.

Side-By-Side Probing Measurements on a 50 ps Edge-Speed Signal

Figure 2 shows the eye-diagram of the output of the Agilent 8133A pulse/pattern generator (fed through the 50 Ω differential test fixture) with a very flat response as captured by the Agilent 54750 sampling oscilloscope with approximate edge speeds of 50 ps (10% to 90%). *This signal was captured before any probes were connected to the test fixture.*

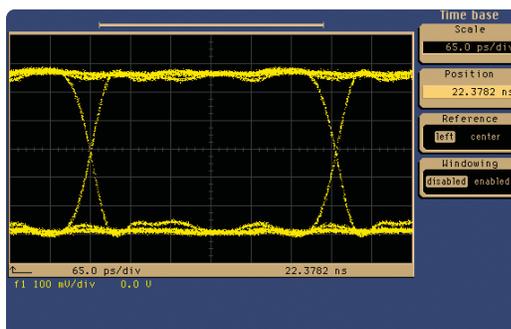


Figure 2. Unloaded 50 ps edge-speed input test signal as measured by a high-bandwidth sampling oscilloscope.

We tested the 50 ps edge-speed signal using a browser connection and a solder-in connection with both Tektronix and Agilent 6 GHz scopes and differential active probing solutions.

Browser connection

Figure 3 shows the test signal at the probe tips during probing with the Tektronix P7350 differential active probe, but captured with a high-bandwidth sampling oscilloscope connected in parallel. As you can see, the waveform does not exhibit an ideal flat response because of probe loading. Figure 4 shows the measured response of

this signal using the Tektronix TDS6604/P7350 with the browser connection. The Tektronix P7350 differential active probe exhibits a very peaked response and does not accurately show what is at the probe tips (Figure 3). The excessive loading and peaking is caused by the inherent parasitic capacitance and inductance of the probe. Some people in the oscilloscope industry may claim that this waveform (Figure 4) more accurately shows what “was” at the test points on the test fixture before the probe was applied (Figure 2). We will discuss this issue in the section

titled “Should you measure ‘what was’ or ‘what is?’” on page 9.

We did not use the Tektronix browser probe-tip “saver” when we performed this test. In our experience, this adapter causes even more loading and excessive peaking (overshoot). Although the probe-tip saver enhances usability and helps to keep the fixed and non-user-replaceable probe tips from bending and breaking, we recommend you avoid using this probing accessory on high-speed signals when signal-integrity measurements are important.

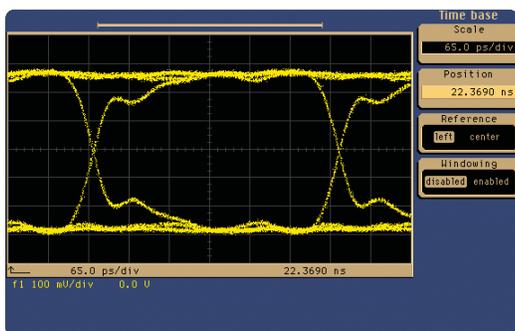


Figure 3. Loaded/probed 50 ps edge-speed signal using Tektronix P7350 browser connection as measured by a high-bandwidth sampling oscilloscope.

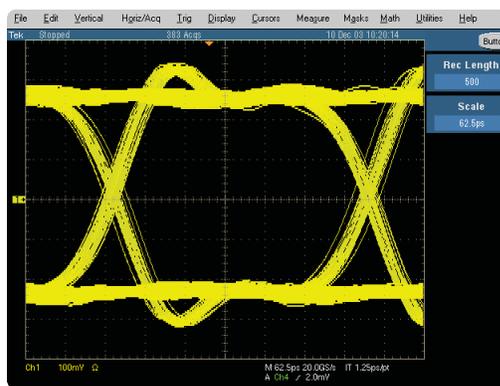


Figure 4. Measured response of 50 ps edge-speed signal using Tektronix P7350 browser connection.

Side-By-Side Probing Measurements on a 50 ps Edge-Speed Signal

Figure 5 shows the 50 ps edge-speed input signal as it is being probed by Agilent's 1134A InfiniiMax differential active probe with a browser connection. Notice that Agilent's probe also loads the signal, but to a lesser degree than the Tektronix probe. Figure 6 shows the measured response using the Agilent 54855A oscilloscope with the 1134A InfiniiMax browser connection. With this probe connection, we see a very flat response that more closely approximates the original unprobed input signal (Figure 2). But the unprobed signal is *not* what we should be comparing to the measured response. We should compare the measured response (Figure 6) to the actual signal at the probe tips (Figure 5), as we will explain on page 9.

The Agilent browser probe exhibits some peaking due to parasitics, but the peaking is not as severe as the peaking caused by the Tektronix probe. Unfortunately, these parasitics, and their measured behavior, are unavoidable when using high-bandwidth browser-type probes that also exhibit good usability characteristics. The measured response shown in Figure 6 is the best you can get with a browser-type probe.

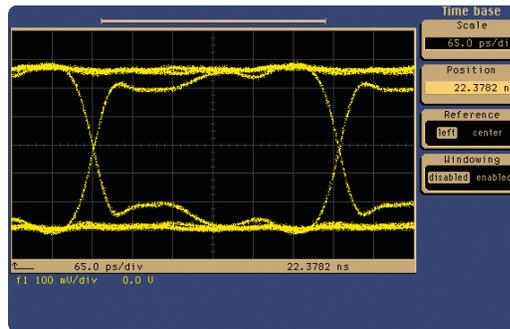


Figure 5. Loaded/probed 50 ps edge-speed signal using Agilent 1134A with browser connection as measured by a high-bandwidth sampling oscilloscope.

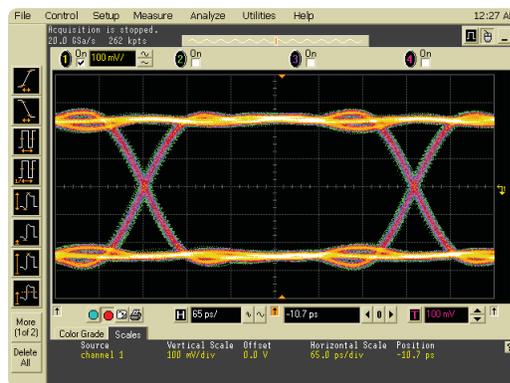


Figure 6. Measured response of 50 ps edge-speed signal using Agilent 1134A with browser connection.

Side-By-Side Probing Measurements on a 50 ps Edge-Speed Signal

Solder-in connection

Figure 7 shows the same test on the 50 ps edge-speed signal, but now using Tektronix' recommended solder-in connection. This solder-in connection was established using a Tektronix supplied solder-in adapter with damping resistors trimmed as short as possible and then soldered onto the differential test fixture. Notice the significant loading on the input signal. Figure 8 shows the measured response using this test setup. The edge speeds are reduced significantly due to the reduced bandwidth limitation of this connection, and the measured

response also exhibits excessive peaking. Whether you compare this measured response (Figure 8) to the original unloaded/unprobed input signal (Figure 2) or to the loaded/probed signal (Figure 7), which is a more meaningful comparison, it is a poor approximation of the signal under test.

Figure 9 shows loading effects on the 50 ps edge-speed signal when we probed with Agilent's 1134A InfiniiMax solder-in probe head. Again, there is some loading, but much less than that exhibited by the Tektronix probing solutions. Figure 10 shows the measured

response using the Agilent solder-in probe head. Notice that this response is a very good approximation of the actual signal at the probe tips (Figure 9), given the 6 GHz scope/probe system bandwidth limitation. Using Agilent's 54855A oscilloscope with the 1134A InfiniiMax solder-in probe head provides the highest-fidelity active probing measurements in the industry today. This combination (54855A oscilloscope/1134A InfiniiMax solder-in probe head) is as good as it gets for real-time high-bandwidth oscilloscope measurements using active probes!

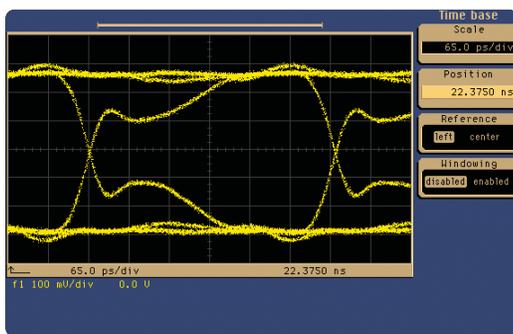


Figure 7. Loaded/probed 50 ps edge-speed signal using Tektronix P7350 with solder-in connection as measured by a high-bandwidth sampling oscilloscope.

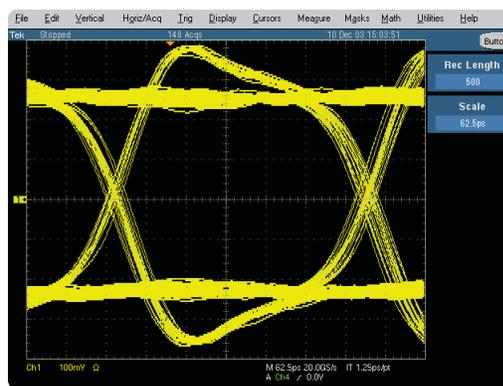


Figure 8. Measured response of 50 ps edge-speed signal using Tektronix P7250 with solder-in connection.

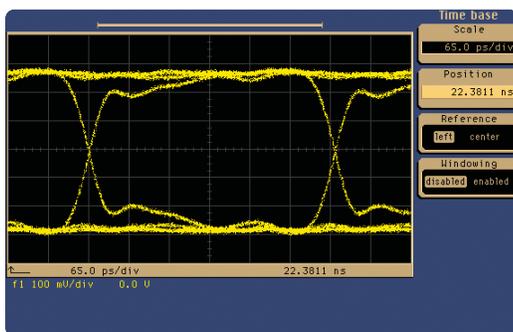


Figure 9. Loaded/probed 50 ps edge-speed signal using Agilent's 1134A InfiniiMax solder-in probe head as measured by a high-bandwidth sampling oscilloscope.

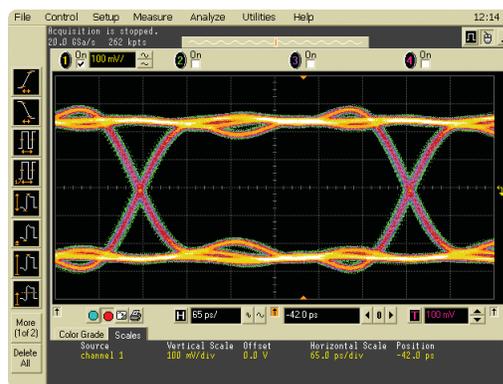


Figure 10. Measured response of 50 ps edge-speed signal using Agilent's 1134A InfiniiMax solder-in probe head.

Side-By-Side Probing Measurements on a 100 ps Edge-Speed Signal

The previous section of this application note compared probing measurements on a very high-speed signal (50 ps edge speed). However, a more realistic test is to compare measurements on a signal with slower edge speeds (100 ps or greater) that are within the bandwidth measurement capability of a 6 GHz oscilloscope/probing measurement system. Figure 11 shows the unloaded/unprobed test signal with an edge speed of approximately 100 ps as captured by a high-bandwidth sampling oscilloscope. The following screen-shots show the same probing measurements we documented in the first part of this application note. Again, the Agilent oscilloscope and probing system outperformed Tektronix oscilloscope and probing system on all counts.

Browser connection

Figure 12 shows the signal during probing with the Tektronix P7350 differential active probe. Figure 13 shows the measured response of this signal using the Tektronix TDS6604/P7350 with the browser connection. As with the 50 ps edge-speed input signal, the Tektronix P7350 differential active probe exhibits a very peaked response and does not accurately show the signal as it appears at the probe tips (Figure 12).

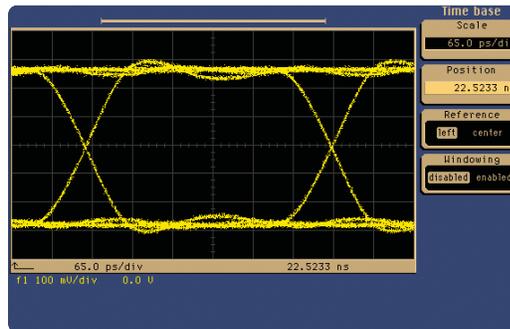


Figure 11. Unprobed/unloaded input test signal with 100 ps edge speed as measured by a high-bandwidth sampling oscilloscope.

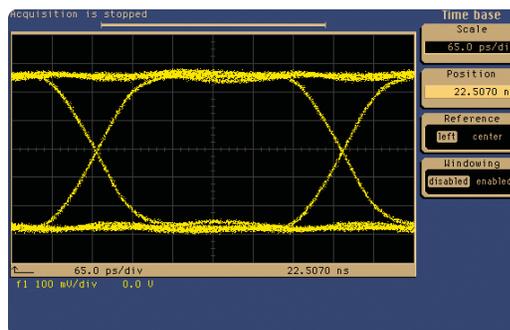


Figure 12. Loaded/probed 100 ps edge-speed signal with Tektronix P7250 active probe with browser connection as measured by a high-bandwidth sampling oscilloscope.

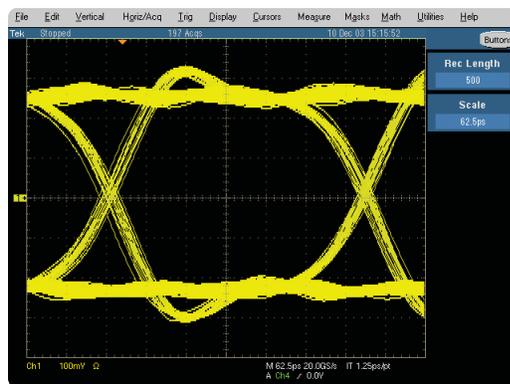


Figure 13. Measured response of 100 ps edge-speed signal using Tektronix P7250 active probe with browser connection.

Side-By-Side Probing Measurements on a 100 ps Edge-Speed Signal

Figure 14 shows the 100 ps edge-speed input signal as it is being probed by Agilent's 1134A InfiniiMax differential active probe with a browser connection. Figure 15 shows the measured response using the Agilent 54855A oscilloscope with the 1134A InfiniiMax browser connection. Again, Agilent's browser-type probe connection measurement exhibits some peaking, but shows a more accurate reproduction of the signal under.

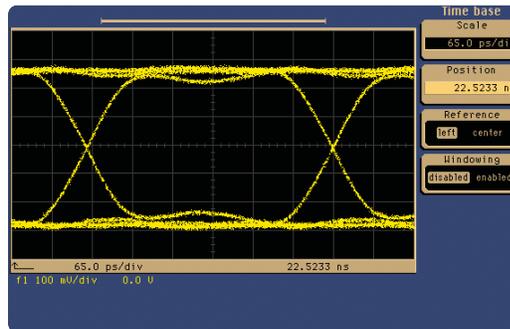


Figure 14. Loaded/probed 100 ps edge-speed signal using Agilent 1134A active probe with browser connection as measured by a high-bandwidth sampling oscilloscope.



Figure 15. Measured response of 100 ps edge-speed signal using Agilent 1134A active probe with browser connection.

Side-By-Side Probing Measurements on a 100 ps Edge-Speed Signal

Solder-in connection

Figure 16 shows the same probe loading test on the 100 ps edge-speed signal using Tektronix's solder-in connection. Figure 17 shows the measured response using this test setup. Again, we observe significant loading and excessive peaking.

Figure 18 shows loading effects on the 100 ps edge-speed signal when we probed with Agilent's 1134A InfiniiMax solder-in probe head. Figure 19 shows the measured response using the Agilent solder-in probe head. Notice that this response is a very good approximation of the actual signal at the probe tips (Figure 18) and with minimal loading.

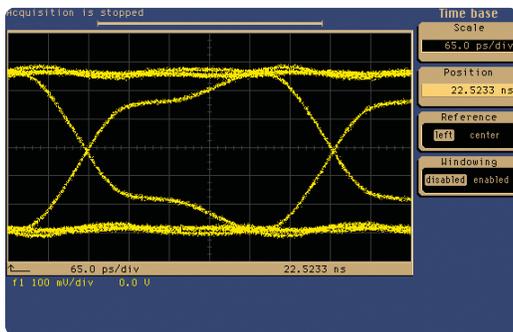


Figure 16. Loaded/probed 100 ps edge-speed signal using Tektronix P7250 active probe with solder-in connection as measured by a high-bandwidth sampling oscilloscope.

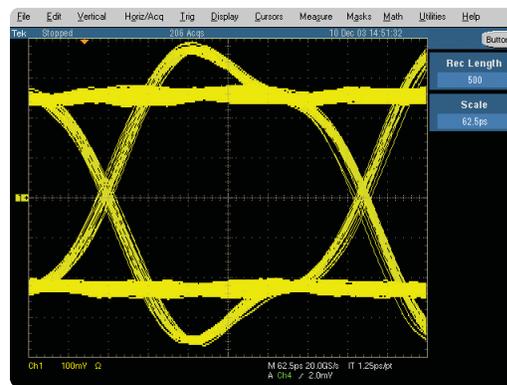


Figure 17. Measured response of 100 ps edge-speed signal using Tektronix P7250 active probe with solder-in connection.

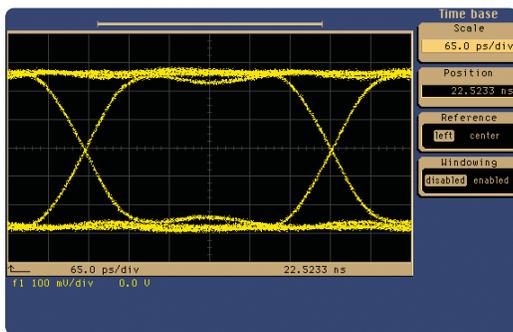


Figure 18. Loaded/probed 100 ps edge-speed signal using Agilent 1134A active probe with solder-in connection as measured by a high-bandwidth sampling oscilloscope.

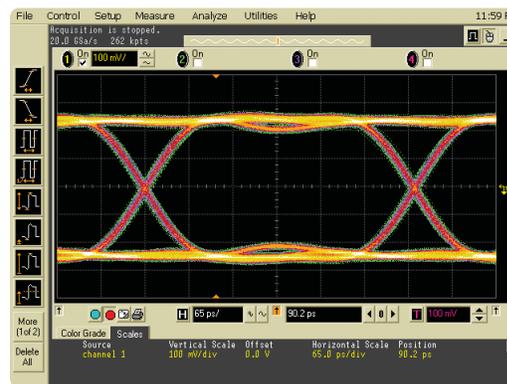


Figure 19. Measured response of 100 ps edge-speed signal using Agilent 1134A active probe with solder-in probe head.

Should You Measure “What was” or “What is”?

Agilent and Tektronix have different philosophies about whether an oscilloscope and probing system should attempt to show “what was” or “what is” at the inputs to the differential active probe tips. This philosophical difference also extends to how high-bandwidth probes are characterized and specified by each vendor. “What was” refers to the signal that was present at the test points before the probe was connected. “What is” refers to the actual signal at the probe’s tips while the probe is connected and loading the device under test.

In an ideal world, probes would have infinite input impedance and induce zero loading on a circuit under test. In the real world, all probes load circuits to some degree, especially at higher frequencies, and thereby change/alter the signal that is being tested.

With inductive peaking due to probe parasitics, a probe may be able to restore some high-frequency characteristics of the original unprobed/unloaded signal. But the degree of loading and artificial signal restoration is heavily dependent upon the

source impedance of the device under test. In the testing documented in this application note, the effective source impedance of the device under test was a fixed 25 Ω , as defined by the designed-in source impedance of the pulse/pattern generator and the load impedance of the sampling oscilloscope. But in real-world measurement situations, engineers rarely measure the characteristics of a terminated 50 Ω generator. The source impedance of a real circuit under test can vary significantly, so the effects of probe loading and induced measured peaking also can vary significantly and can be unpredictable.

As shown in some of the previous measurement examples, circuit loading and signal alteration can be significant. Unfortunately, you may never know that this unwanted side effect of probing is causing a problem in your circuit under test. *The parasitic peaking of the probes can mask loading problems.* In some cases, probing the device can actually cause a high-speed digital system to crash. Agilent active probes exhibit less peaking and less circuit loading, so they give you

a better idea as to why a circuit problem may have occurred.

When you are stress-testing high-speed devices, (for example, testing differential receiver sensitivity) there is another reason why it is important to know “what is,” rather than estimating “what was.” When you perform stress tests with a stimulus source such as a high-speed pulse/pattern generator, you use the oscilloscope to measure the actual signal at the differential inputs of the receiver to find out exactly when and why it fails, based on various types of stimulus testing, including induced jitter and reduced signal levels. Estimating what might have been at the input without the probe attached will not give you information on the specific input level that caused a failure condition. You need to know the exact failure condition at the input of the device with the probe attached. In this case, the oscilloscope and active probe actually become part of the system under test, and its effects must be included. Induced peaking will mask real failure conditions and will indicate smaller margins than are actually present.

Different Probe Specification Methodologies

As previously mentioned, Agilent and Tektronix also have different philosophies about how to characterize and specify high-speed active probes. In the past, when lower-bandwidth probes were tested and specified, you could assume that V_{IN} (input to the probe) and V_{SOURCE} (test generator output) were essentially the same. With this assumption, all oscilloscope/probe vendors used to characterize a probe's response as V_{OUT}/V_{SOURCE} . But when characterizing higher-frequency probes, such as Agilent's 7 GHz 1134A InfiniiMax active probe or Tektronix' 5 GHz P7350 active probe, you can no longer assume that V_{SOURCE} and V_{IN} are the same. In order to more accurately characterize higher-bandwidth active probes in both the time domain and frequency domain, Agilent now measures V_{IN} using a test fixture that allows observation of the input signal.

An oscilloscope probe is a voltage measuring device, so its transfer function should be specified as V_{OUT}/V_{IN} . If V_{IN} changes as a function of frequency-dependent loading, then V_{IN} must be

accurately measured along with V_{OUT} . Unfortunately, Tektronix still uses the old method of measuring and computing the transfer function of their active probes as V_{OUT}/V_{SOURCE} . But as we have shown in this paper, V_{SOURCE} and V_{IN} can be very different due to high-frequency loading. If the only type of device you ever test is the output of a generator, or if the degree of loading is predictable with a fixed amount of source impedance, then you could argue that V_{OUT}/V_{SOURCE} is a valid estimation. But the source impedance of a real device under test can vary significantly.

Since you must now take circuit loading into account with higher-frequency active probes, in addition to the specified time-domain and frequency-domain transfer function characteristics/specifications (based on V_{OUT}/V_{IN}), Agilent also provides frequency-dependent impedance plots and SPICE models for all probe head connections so that designers can accurately predict the loading effects when connecting Agilent active probes to their circuits.

Conclusion

Regardless of whether you use Tektronix' or Agilent's measurement performance standards for characterizing the performance of high-bandwidth active probes, Agilent's probes outperform Tektronix probes on all counts as documented in this application note. Agilent's 1134A InfiniiMax active probes using various probe heads (browser, solder-in) demonstrate less probe loading and more accurate reproduction of the signal applied to the probe tips. Even if you apply a Tektronix standard where you ignore probe loading and compare measured signals to unloaded/unprobed signals, Agilent's probes still out-perform Tektronix probes when you compare the same probing configurations (Tektronix browser connection versus Agilent browser connection, Tektronix solder-in connection versus Agilent solder-in connection) and when you use identical sampling techniques (real-time), as shown in this application note.

With the introduction of the new 1130 Series InfiniiMax differential active probes, Agilent adopted a new probe architecture/topology where the probe amplifier is physically displaced from the probe head using precision RF transmission line technology for high-impedance connections. This new probe technology enhances usability and measurement performance for high-bandwidth applications. In fact, Agilent's new 1130 Series InfiniiMax active probing system was recently selected as the 2002 Test & Measurement Product-of-The-Year award sponsored by EDN magazine. To our knowledge, this is the first time EDN has selected an "accessory" for this award in the Test & Measurement category.

InfiniiMax: The Worlds Best High-Speed Probing System

EDN Magazine has awarded Agilent's InfiniiMax active probe system the 2002 Innovation of the Year Award.



Glossary

Browser-Type Probe Probe or probe head designed to be held in the user's hand or to be used in conjunction with a probe stand holder.

Damping Resistors Low-value resistors (typically 100 Ω) located near the tips of high-bandwidth probes, used to minimize high-frequency probe loading and for reducing in-band resonance (ringing/peaking).

Jitter Timing error associated with the placement of high-speed digital signal edge transitions relative to their ideal location. This timing error, often referred to as time interval error (TIE) or phase jitter, can be composed of both deterministic and random error sources.

Out-of-Band Frequency content of signals that is considered to be out of the bandwidth measurement capability of a test system.

Parasitics Unwanted capacitance, inductance, and resistance of a probe that can create undesirable loading on a circuit under test.

Probe Head A probe technology developed by Agilent Technologies where oscilloscope/probe users can interchange a variety of passive probe connections from the displaced probe amplifier for various use models. This probe head technology enhances usability, reduces probe loading due to parasitics, and improves measurement accuracy.

Real-Time Oscilloscope An oscilloscope that uses high-speed sampling in order to capture signals in a single-shot acquisition.

Sampling Oscilloscope An oscilloscope that uses repetitive sampling techniques in order to capture high-bandwidth signals.

Solder-In Probe Probe head or accessory designed so that the probe can be easily soldered to the circuit under test, providing either hands-free probing or to gain access to tight-fitting spaces where a browser-type probe head can't fit.

Transfer Function The voltage transfer function, or gain, of a device or circuit is always computed as the ratio of the output voltage relative to the input voltage (V_{OUT}/V_{IN}). The ideal transfer function for a scope, probe, and scope/probing measurement system is always "1" when attenuation factors are factored into the equation.

Related Literature

Publication Title	Publication Type	Publication Number
<i>Infiniium 54850 Series Oscilloscopes InfiniiMax 1130 Series Probes</i>	Data Sheet	5988-7976EN
<i>Restoring Confidence in Your High-Bandwidth Probe Measurements</i>	Application Note 1419-01	5988-7951EN
<i>Improving Usability and Performance in High-Bandwidth Active Oscilloscope Probes</i>	Application Note 1419-02	5988-8005EN
<i>Performance Comparison of Differential and Single-Ended Active Voltage Probes</i>	Application Note 1419-03	5988-8006EN
<i>Ten Things to Consider When Selecting Your Next Oscilloscope</i>	Application Note 1490	5989-0552EN
<i>Five Applications to Help You Decide: A Comparison between Tektronix TDS and Agilent Infiniium Oscilloscopes</i>	Application Note 1489	5989-0526EN

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- Track down elusive glitches with up to 1 M points MegaZoom deep memory on all sample rates and 32 M points MegaZoom deep memory at 2 GSa/s and slower rates
- Improve reliability with solid state attenuators
- Take advantage of trigger jitter as low as 1.0 ps rms
- Ensure probing accuracy with highest performance differential and single-ended probes available (InfiniiMax 7, 5, and 3.5 GHz probing systems)

Experienced scope users know that their measurements are only as good as their probing system. And as bandwidth increases, it is increasingly important to make sure you are measuring your circuit, not your scope probe. Nothing is more frustrating than chasing down an apparent design problem, only to find that it was caused by an inferior scope probe.

Together, the newest Infiniium scopes and the breakthrough InfiniiMax high-performance probing systems offer an end-to-end measurement solution with unmatched performance, accuracy, and connectivity. The results are measurements you can trust and better insight into circuit behavior.

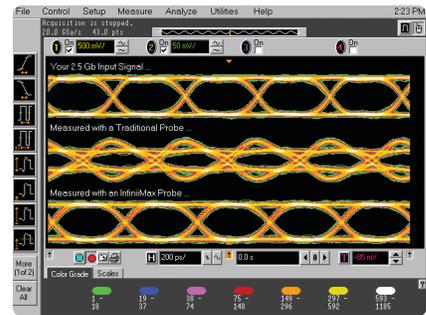


Figure 21. Compare the input on the top trace to that of a competitive probe in the center and an InfiniiMax on the bottom.

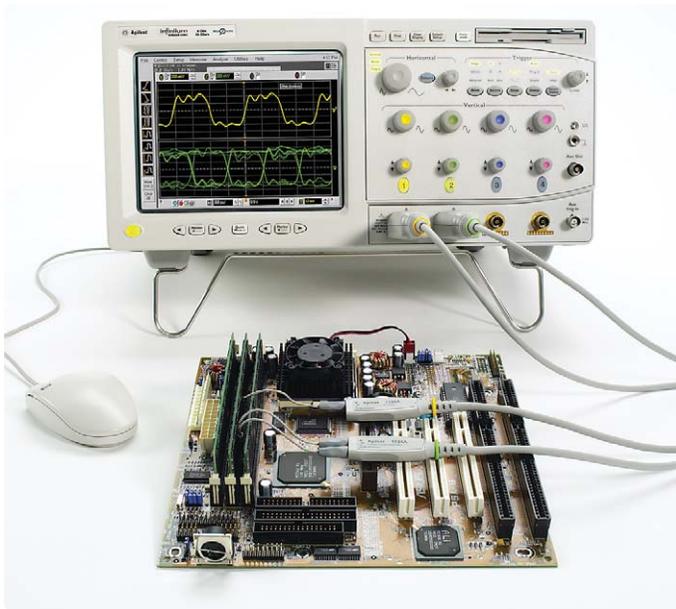


Figure 20. The newest members of Agilent's award-winning Infiniium Series are 6, 4, and 2.5 GHz high performance real-time oscilloscopes. The InfiniiMax high bandwidth active probe offers unmatched performance, accuracy, and connectivity.

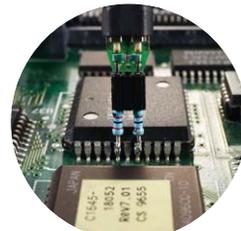


Figure 22. InfiniiMax 7 GHz differential socketed probe head.

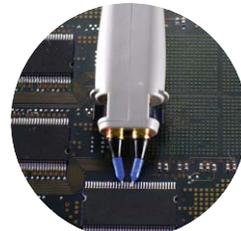


Figure 23. InfiniiMax 6 GHz differential browser probe head

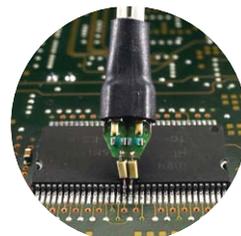


Figure 24. InfiniiMax 7 GHz differential solder-in probe head.



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