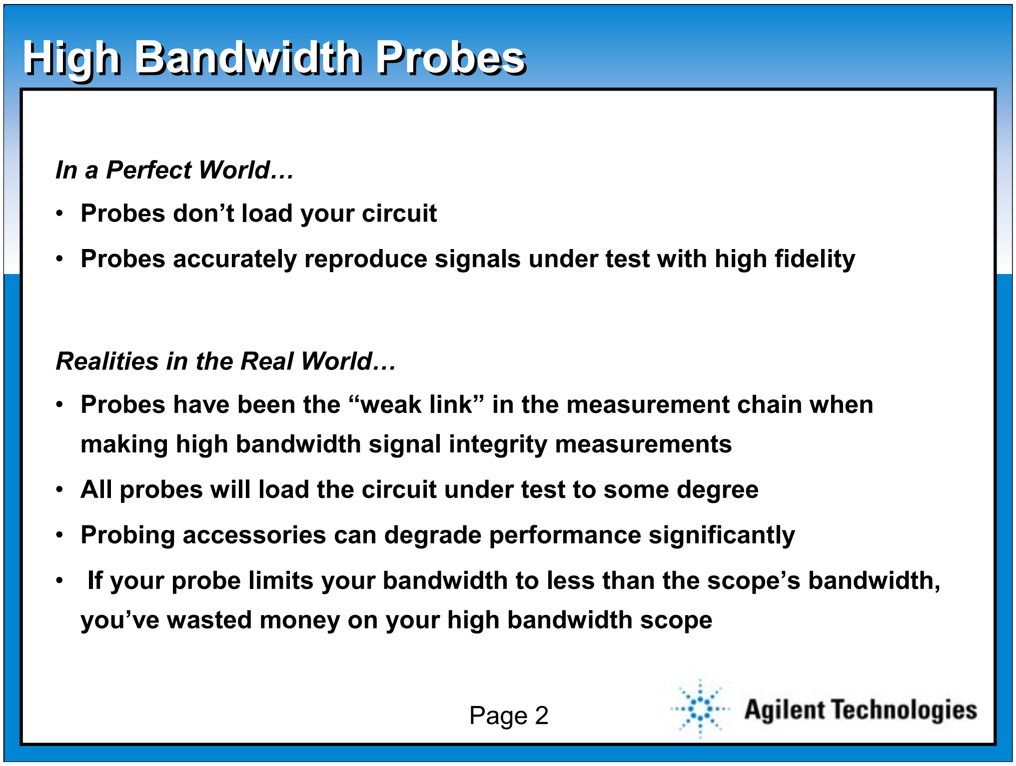
Achieving Higher Bandwidth Connectivity with High-speed Active Probes

Welcome to Agilent’s new seminar on high-speed active probing. When considering the right measurement tools for multi-GHz oscilloscope applications, probing is often an after-thought. High-speed digital designers usually select the oscilloscope first for signal integrity measurements based on bandwidth and sample rate, and then worry about how to get the signal into the scope later. This approach may be fine for applications under 500MHz. But for multi-GHz applications, perhaps today’s high-speed digital designer should consider the probing solutions first, and then worry about which scope to put behind the probes.

Today’s seminar will present some of the common problems associated with high-speed active probing, and demonstrate some novel techniques developed by Agilent Technologies for solving some of these probing problems. To begin with today, let’s take a quick look at probing in a ideal world, and also look at the realities of the real world.



High Bandwidth Probes

In a perfect world, probes don't load your circuit, and they accurately reproduce your signals under test. However in the real world, probes have traditionally been the "weak link" in the oscilloscope measurement chain for high-speed applications. All probes will load the circuit under test to some degree. So the goal with high-speed active probing is to minimize circuit loading. In addition, probing accessories are usually the primary culprit in limiting performance of measurements. And if your probe system limits the bandwidth of your measurements, you may be wasting money on your high bandwidth oscilloscope.

Let's now take a look at our agenda today that will address these real world issues.

Agenda - Higher Bandwidth Connectivity

- Traditional Active Probing Technology
  - Modeling
  - Usability Tradeoffs
  - Measured Response
- InfiniiMax Active Probing Technology
  - Modeling
  - High-Bandwidth Connectivity Options
  - Measured Response
- System Bandwidth
  - Maximally Flat versus Gaussian Response
  - Sample rate and aliasing
  - Required System Bandwidth versus Measurement Accuracy

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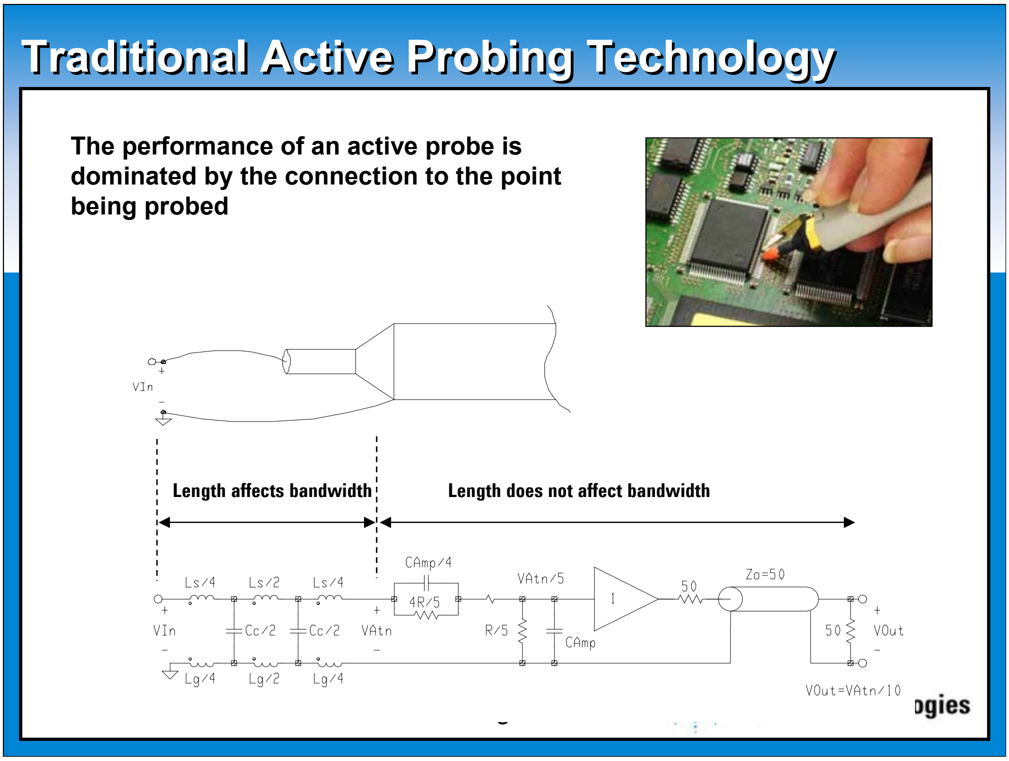
Agenda – Higher Bandwidth Connectivity

The begin with today, we are going to take a look at some the problems associated with traditional active probing. We will examine a simplified electrical and physical model of a traditional active probe, and look at some of the various use models for how active probes are commonly used today including their tradeoffs. We will then show measured responses of a traditional active probe, both in the frequency domain and the time domain.

We will then present a new approach that Agilent has recently introduced that improves measurement performance under various use models. Again, we will contrast and compare electrical and physical models under various connectivity options, and show measured responses.

Lastly, we will address system bandwidth issues. Probing is just one “link” in the measurement chain. For accurate measurements, all “links” must be considered including oscilloscope frequency response, sampling, probe amplifier, and probe connection. We will give some “rules-of-thumb” for determining the appropriate system bandwidth and sample rate to make accurate measurements with minimal error and aliasing.



Active Probing

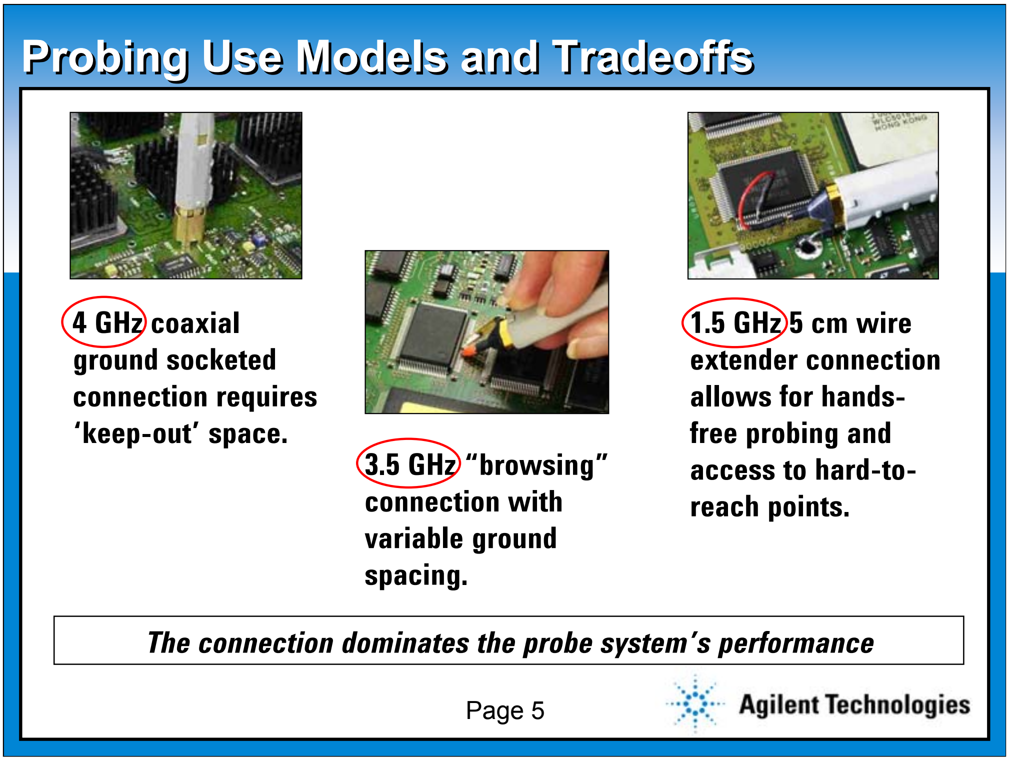
-If you need to probe your circuits with bandwidth performance in excess of 500MHz, you are probably using an active probe today… or should be. So let's now dig deeper into the issues of traditional active probing. We will show models and look at measured performance of active probing systems under a variety of probing conditions.

-Even though a particular scope vendor's active probe may have an impressive bandwidth specification which would seemingly produce excellent high frequency fidelity, the published specified performance may be under non-realistic probing conditions. In a real-world probing situation, which would include using probing accessories to attach to your signals, the traditional active probe's performance may be very different (worse!) than the published specified performance.

-To put this in perspective, let's take a closer look at a model of an active probe and it's connection. Although we will not get into the details of this model, there is one section of the electrical model that you should focus your attention on. It's the connection!. In most cases, the probe connection of a traditional active probe will determine the measurement bandwidth of the entire oscilloscope measurement system. The model for the probe connection is not just a zero Ohm, zero inductance, and zero capacitance wire. At high frequencies, the probe connection can be modeled as a transmission line, which is a series of parasitic lumped capacitors and inductors.

-As you will see during this discussion, the real-world performance of an active probing system is dominated primarily by the connection system. In other words, parasitic components to the left of the point labeled V_{atn} will be the driving factors in determining the performance of a real-world active probing system in high frequency applications.

-Let's now look at various use models that have very different connections and associated parasitics.



Probing Use Models and Tradeoffs

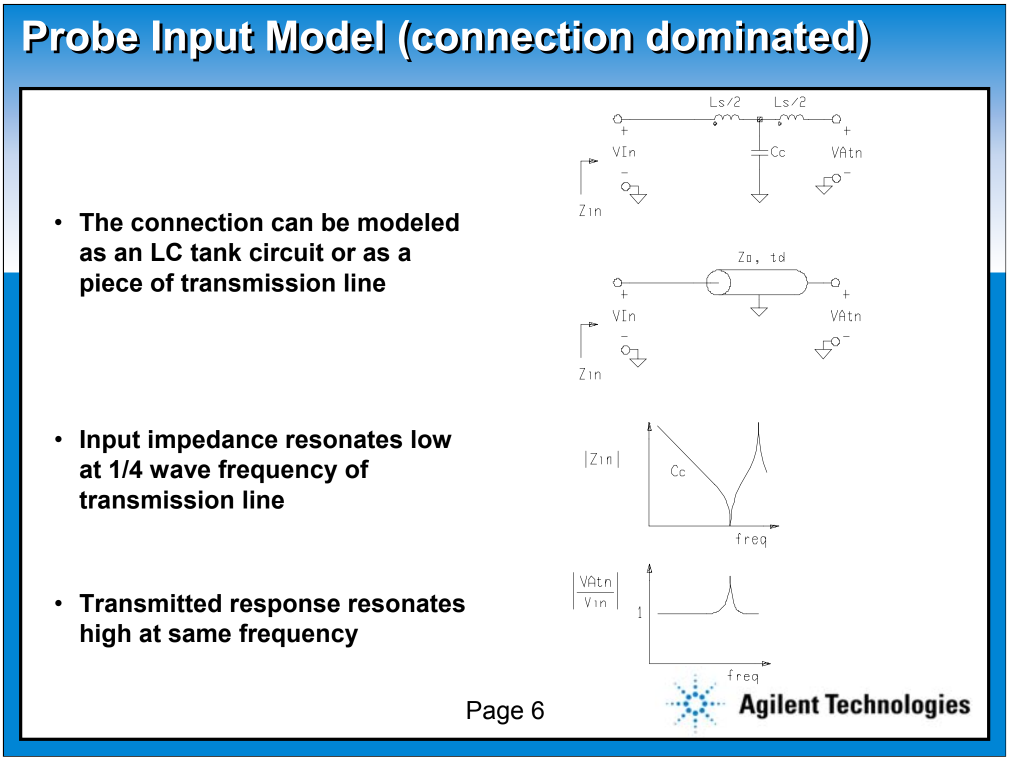
-Before digging deeper into modeling the traditional active probe and its connection, let's quickly take a look at some of the various use models of traditional active probing. To achieve the highest performance out of your traditional active probe, the ground connection length must be minimized. With Agilent's 1158A 4GHz active probe a short ground connection is achieved with a socketed coaxial connection. However, this requires soldering a special coaxial socket onto your board.

-One of the most common use models is the "browsing" connection. With the "browsing" connection, a short ground blade is used in order to easily probe various points on your circuit board design. Unfortunately, this short ground connection reduces the bandwidth of the 1158A active probe to 3.5GHz.

-Another common use model is to use short-wire connection accessories. This not only allows for hands-free probing, but also allows for probing into very hard-to-reach points, such as between closely spaced DIM cards. Unfortunately, a short 5cm wire connection at the end of a traditional active probe will limit the probe system bandwidth to just 1.5GHz... regardless of the specified bandwidth of the probe or vendor.

-As we have said, the connection is usually what dominates the performance of the traditional active probe. So let's now take a closer look at modeling just the

connection.



Probe Input Model (connection dominated)

-With the assumption of minimized ground lead connections, the model of our input connection begins to look like a single transmission line (as opposed to coupled lines). And that is exactly what it is! This model of the probe connection dominates the performance of the oscilloscope system. In most cases, you can assume that the model for the probe amplifier and oscilloscope are perfect (infinitely flat response).

-With good grounding techniques, the input probe connection can be modeled down into a simple L-C-L circuit. Or for engineers that are comfortable with the frequency/RF domain, we can model it as a simple transmission line. Unfortunately though, it is a relatively "uncontrolled" transmission line.

-Question: So what happens to an L-C tank circuit, or a transmission line at a particular frequency?

-Answer: For the L-C tank model, the input impedance will resonate low at it's resonant frequency. -Or if you consider the transmission line model, the input impedance will resonate low at the quarter wave frequency of the transmission line. And the transmitted response will be peaked at this same frequency. As you will see in a few minutes from measured characterizations that we will show, this is NOT good.

As we mentioned earlier, this resonant frequency probably will occur within the –3dB bandwidth of your measurement system for high-frequency applications using a high bandwidth active probe. We call this "in-band resonance". So, watch out!

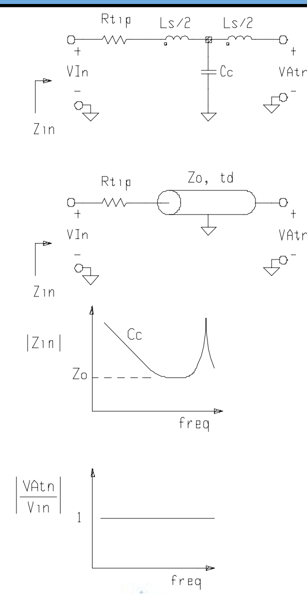
In addition to the in-band resonance problem caused by the connection, the bandwidth of the connection has a inverse relationship to the length of the connection. The longer the connection, the lower the bandwidth. Unfortunately, with traditional active probe technology, the only way to minimize bandwidth loss is to minimize the connection length. But there is a relatively easy technique to solve the in-band resonance problem. Let's see how we solve the in-band resonance problem.

Probe Input Model (properly damped)

- **Can be modeled as properly damped LC tank or source terminated transmission line**

- **Input Impedance:**
  Doesn't resonate low, never goes below R_{TIP}

- **Transmitted Response:**
  Flat is where it's at!



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Probe Input Model (properly damped)

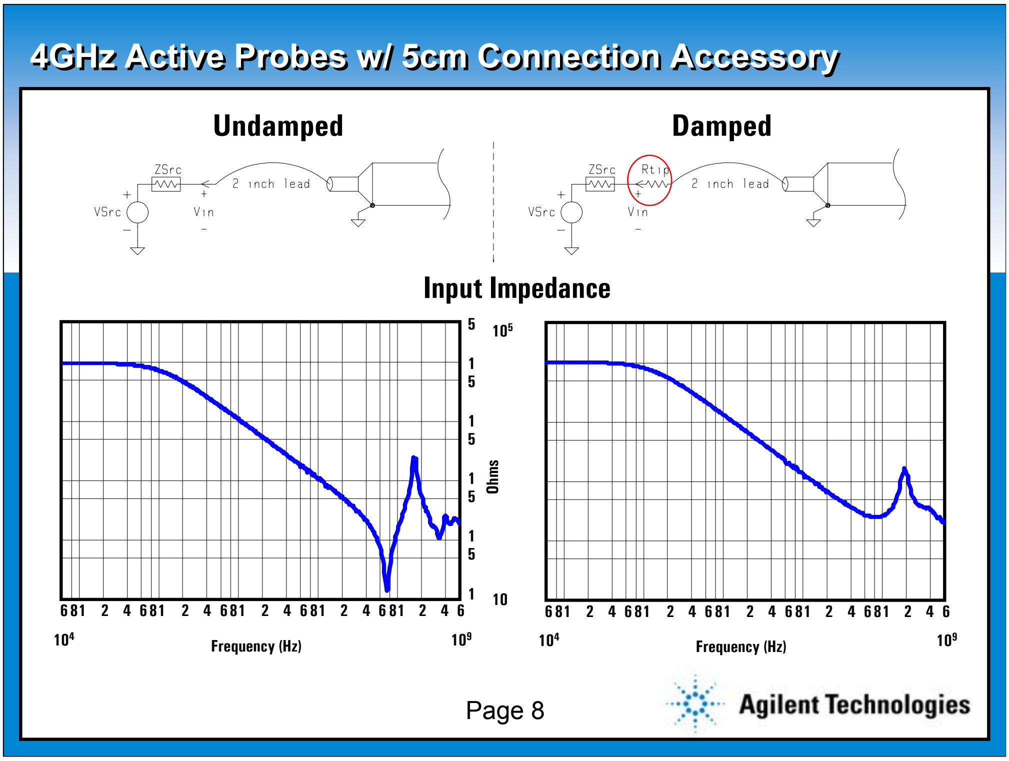
In the past the only way to keep the frequency of this resonance above the bandwidth of the probe was to use an ultra-short, stubby point at the input of the probe. Although this produces good high frequency fidelity, it is often difficult to connect such a short blunt point to the circuit.

A different method of limiting the loading effect of an L-C tank circuit is to simply properly damp the L-C tank with a small resister on the front-end of the probing system. Or in transmission line terminology, source-terminate the transmission line. This allows for a longer, easier-to-use connection to be used at the input of a probe.

With a properly damped probe input, the loading/input impedance will never drop below the value of the damping resistor, which will be in the range of 100 to 250 Ω. (The actual value depends upon the actual probing connection.) In addition, the transmitted response will no longer be peaked up, but will remain flat (ideally).

So practically speaking, how does Agilent properly damp the input connection? With Agilent Technologies newest active probes, the user is provided with a variety of probe tip connection accessories with damping resistors physically positioned very close to the connection point. One of the accessories is an insertable browsing tip. This browsing tip basically consists of a resistor embedded within the body of the tip. Other accessories include extender wires with an embedded damping resistor on the circuit-connection end of the wire. The other end of the extender wire is simply a pin that plugs into the body of the probe tip socket.

Let's now look at some measured response comparisons between a damped and undamped probe connections.



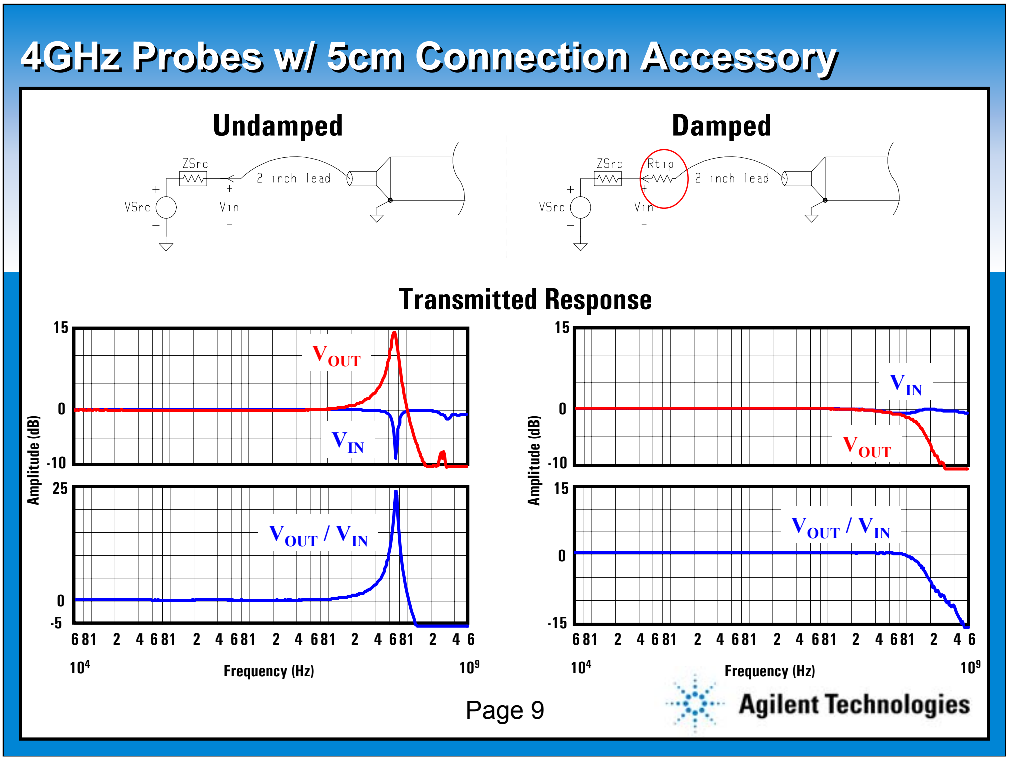
4.0GHz Probes with a 5cm Connection – Impedance Measurement

As you can see in the graphic on the left, the input impedance of the 4.0GHz probe with an undamped 5cm lead wire finds it's resonant frequency at approximately 750MHz, at which time the input impedance drops to approximately 15Ω. The low frequency impedance begins at 100kΩ.

Question: If the input impedance drops to 15Ω at the resonant frequency, what will this low impedance do to Vin (the signal at the probe tip).

Answer: Assuming that Vsource is flat, Vin will be "dinged" significantly. With a source impedance of 25Ω, the input signal would be more than cut in half at the probing point. This would most likely change your circuit's operation significantly around 750MHz.

Looking at the impedance measurement of the 4GHz probe with a properly damped 5cm lead wire accessory, we see that the input impedance doesn't resonate low. It never goes below the value of the damping resistor.

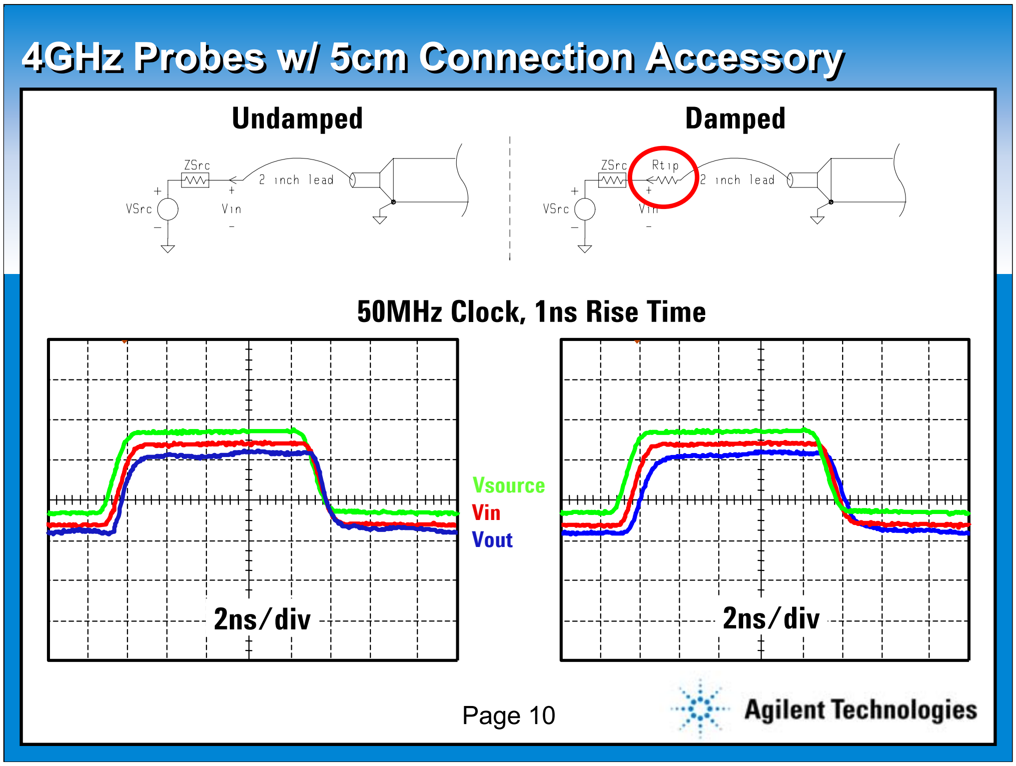


4GHz Probes with a 5cm Connection – Transmitted Response Measurement

Looking at the transmitted response measurement of the undamped probe, we can see that the Vin-measured is significantly “dinged” at the resonant frequency as we predicted. Also, Vout is peaked-up at this same resonant frequency. The resulting calculation of Vout/Vin-measured (transmitted response) shows tremendous peaking at the resonant frequency, and the overall –3dB bandwidth of the 4GHz probe with a 5cm lead wire is approximately 1.5GHz.

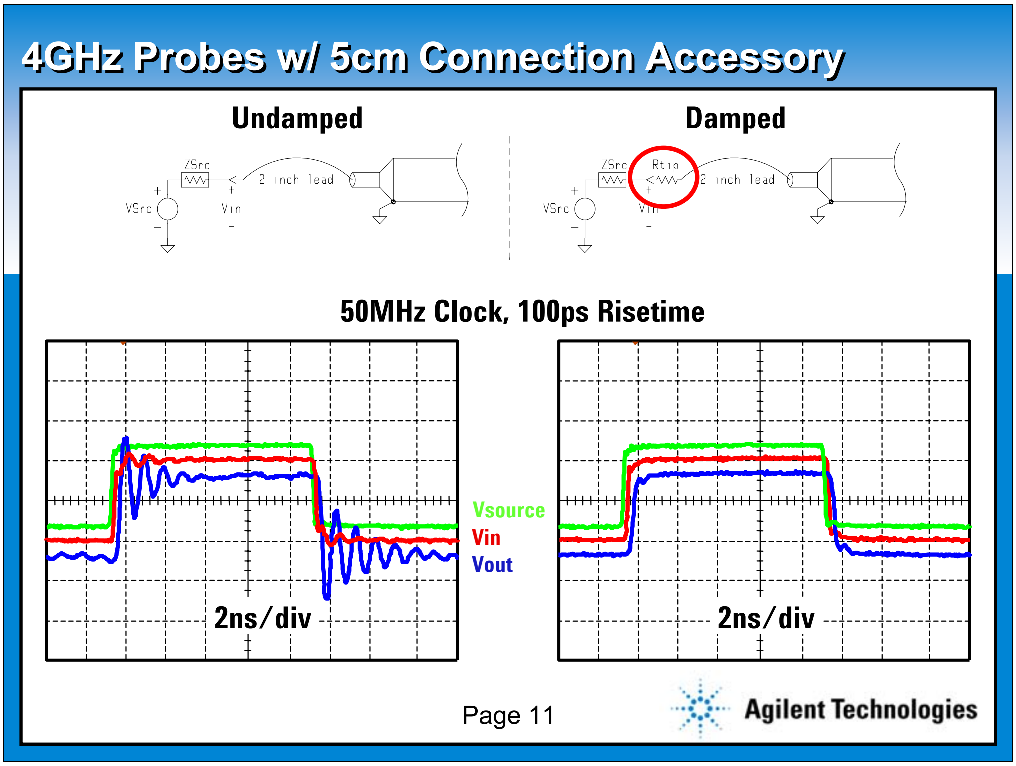
Looking at the transmitted response of the properly damped probe, we see that Vin-measured is relatively flat, and Vout is also relatively flat until it makes a natural roll-off. Again, the net bandwidth with this 5cm damped lead wire is approximately 1.5 GHz. As stated earlier with traditional active probe technology, the length of the connection will determine the bandwidth of the probing system. A higher bandwidth active probe would not increase the bandwidth of this probing system that includes a 5cm connection. The connection has determined our system bandwidth.

So, what does this peaked response as opposed to flat response mean to the time domain? Let’s take a look.



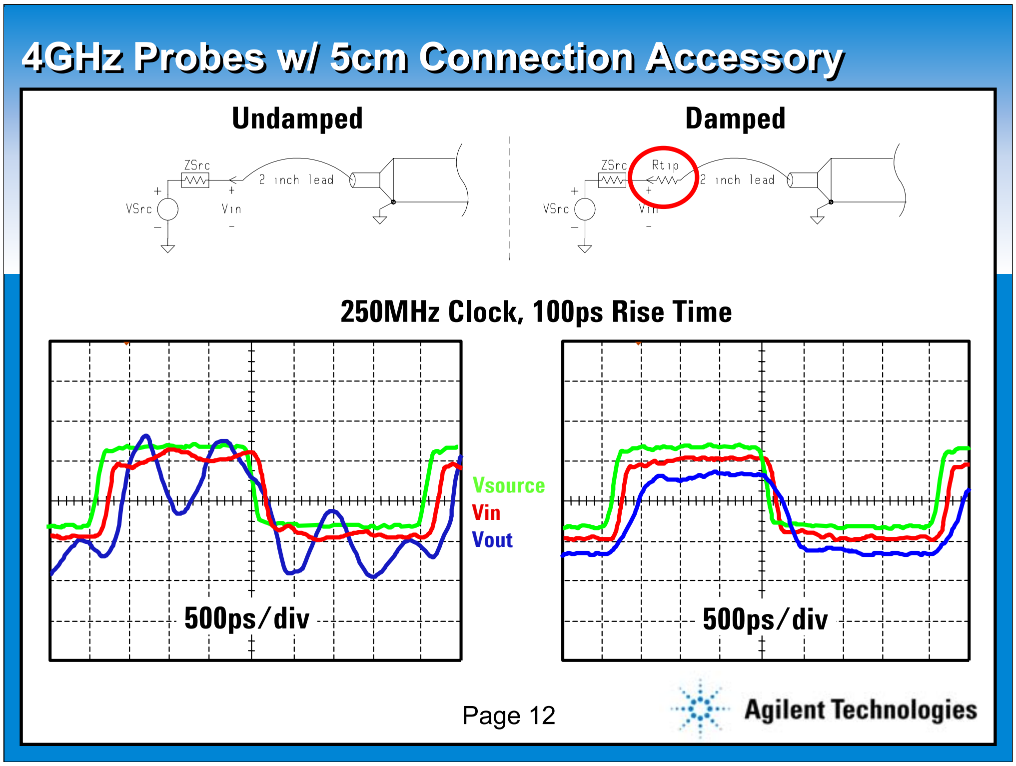
4GHz Probes with a 5cm Connection – 50MHz clock, 1ns Risetime

With a 1ns input risetime signal, both probes (damped and undamped) do a very good job of measuring this signal. But why use a 4GHz probe to measure a 1ns rising edge?



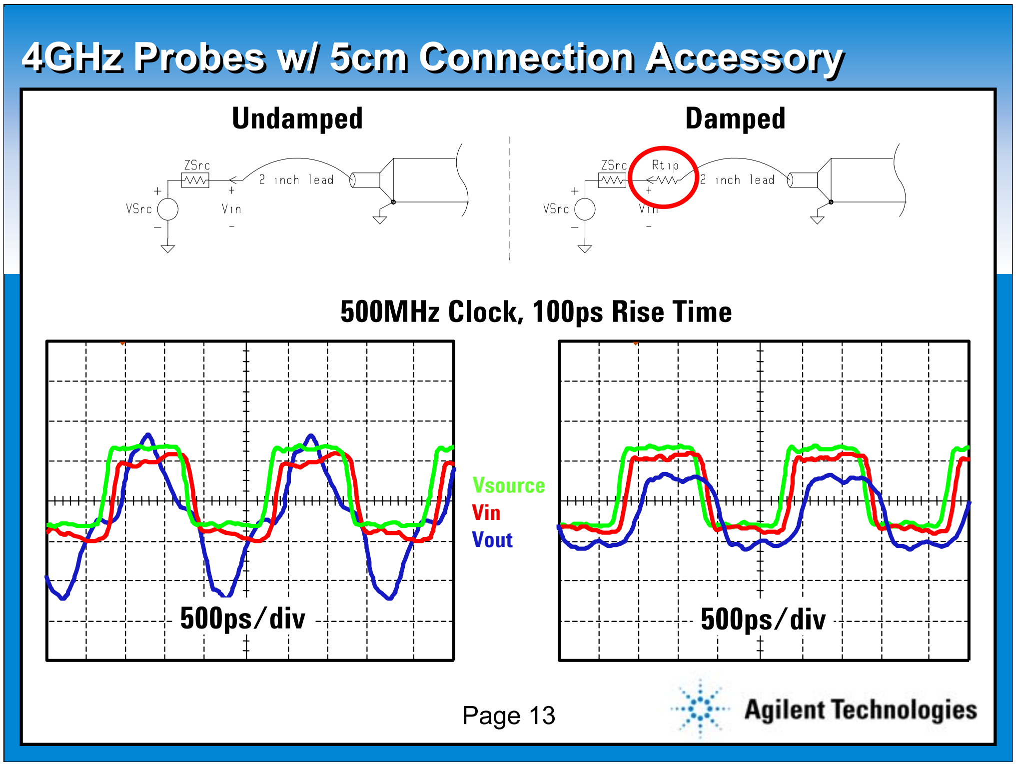
4GHz Probes with a 5cm Connection – 50MHz clock, 100ps Risetime

With a 100ps input risetime signal, you can see that not only is the undamped probe beginning to load and alter the input signal, but the measured output signal begins to show significant ringing. This is due to the resonance of the probe connection. There could be a cause for concern regarding the quality of the signal measured. The first question to ask is "is this waveform distortion real, or is there a problem with the measurement system?". If the ringing is real, is it crossing a logic threshold? With the properly damped probe, both the input and output signal look virtually identical. No cause for concern.



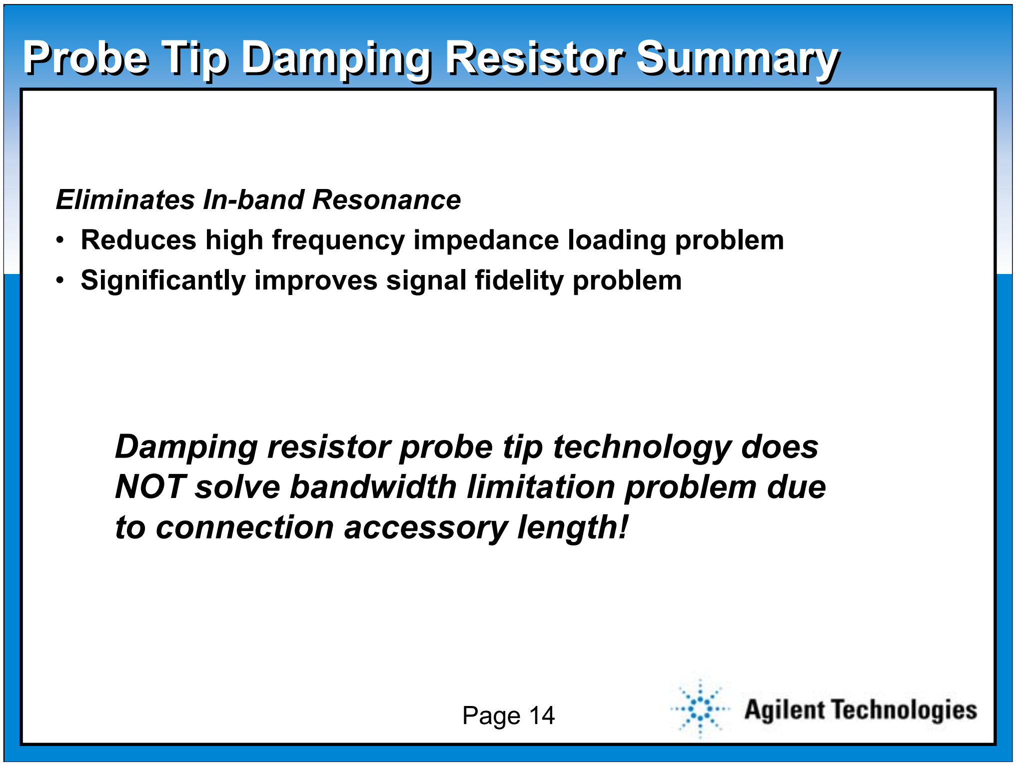
4GHz Probes with a 5cm Connection – 250MHz clock, 100ps Risetime

As we increase the clock frequency to 250MHz, the distortion caused by the undamped probe connection really begins to look ugly. Again, is this distortion real? If you were viewing this clock as an eye-diagram, you would interpret the "eye" to be almost entirely closed. The measurement with the properly damped probe maintains signal fidelity. However, you can begin to see the bandwidth limitation problem as evidenced by the slower edge speeds on the measured output signal.



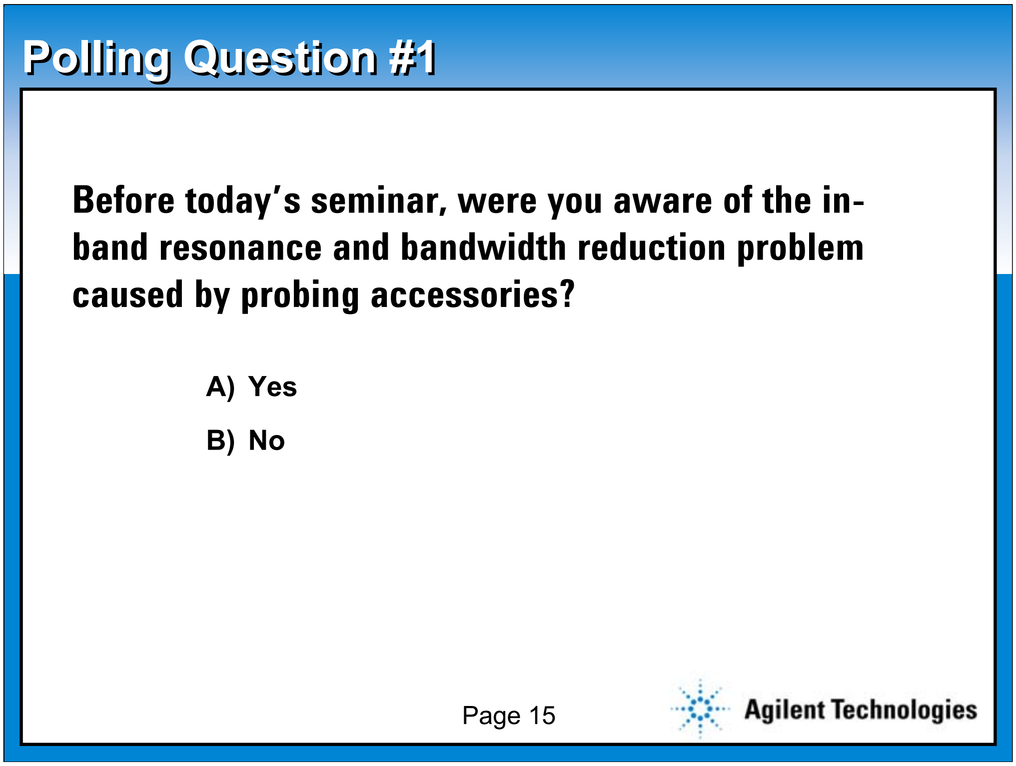
4GHz Probes w/ 5cm Connection – 500MHz Clock, 100ps Risetime

As we increase the clock speed to 500MHz, you can see that the ringing caused by the resonance begins to compound onto itself, and we end up with a very distorted waveform. At this clock frequency, the "eye" actually begins to open wider than what is real. By using the damping resistor probe accessory we maintain signal fidelity. However, in both cases, our 5cm connection has caused a decrease in bandwidth and risetime. A 5cm connection will result in a probe system bandwidth of approximately 1.5GHz, regardless of the specified bandwidth of the probe and the vendor.



Probe Tip Damping Resistor Summary

High bandwidth active probes with small damping resistors included in the connection accessories will reduce high frequency impedance loading, and will restore signal fidelity due to resonance. Unfortunately, damping resistor technology has no affect on the bandwidth loss problem caused by the connection accessory length. So, how can we increase the bandwidth of an active probing system?

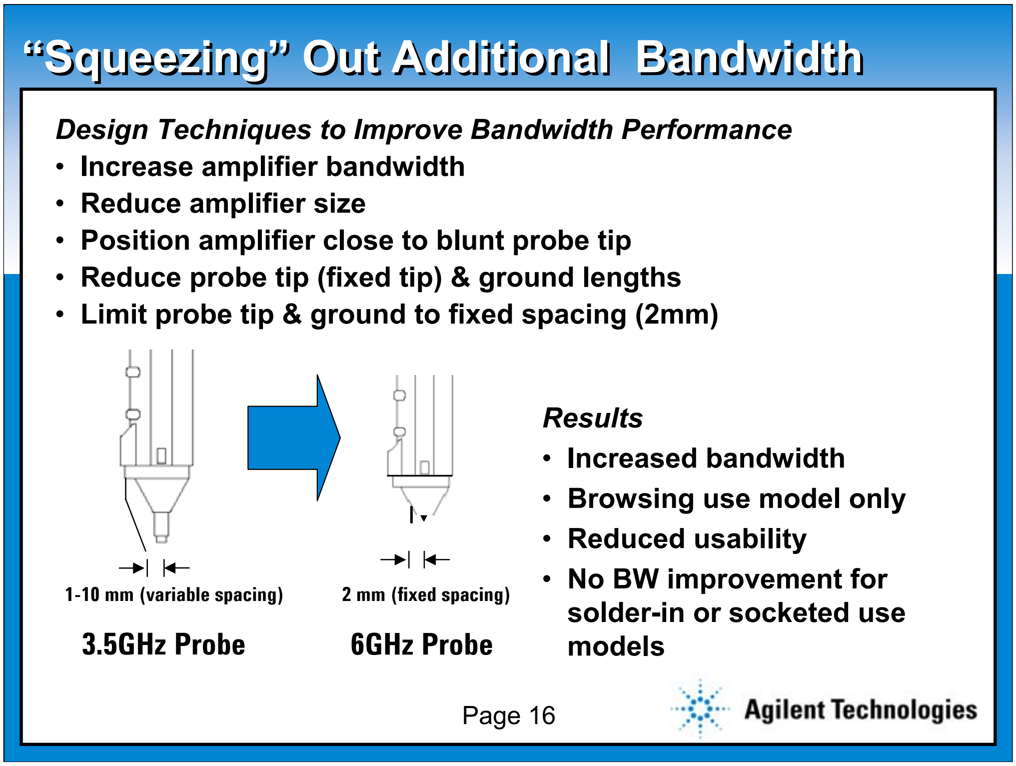


Polling Question #1

Before today's seminar, were you aware of the in-band resonance and bandwidth reduction problem caused by probing accessories?

A) Yes

B) No



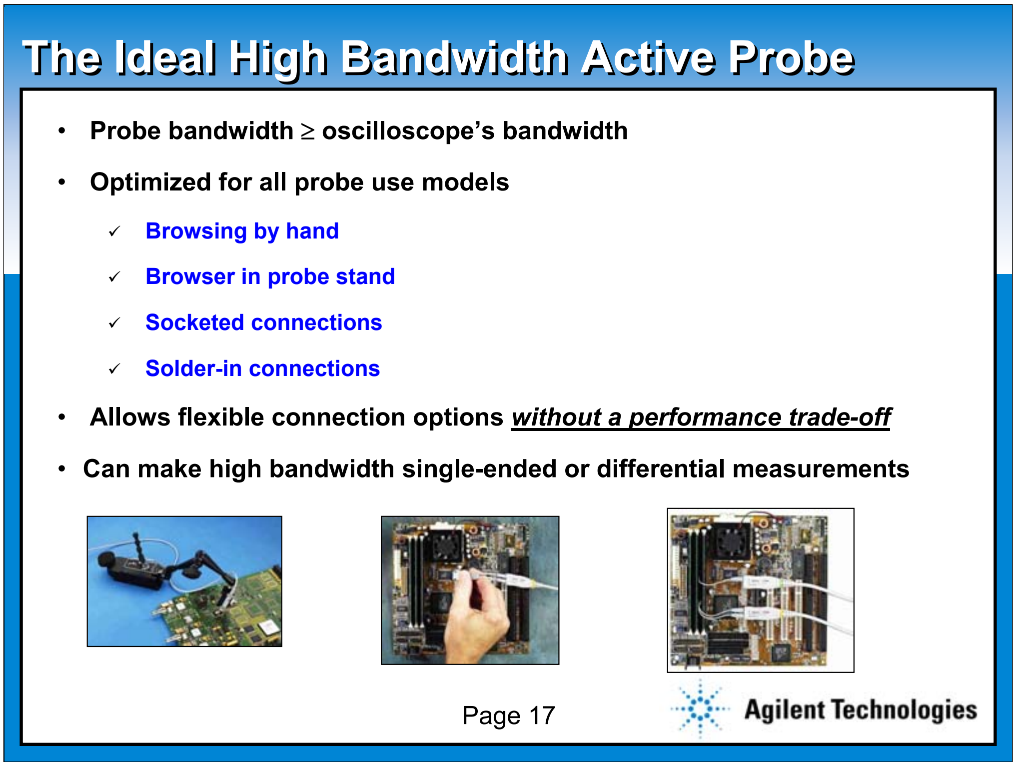
"Squeezing" out Additional Bandwidth

Increasing the bandwidth performance of a traditional active probe is primarily a mechanical challenge that involves physics. The traditional approach includes increasing the probe amplifier bandwidth, reducing the amplifier's physical size, positioning the amplifier as close as possible to the probe tip, reducing the probe tip and ground lengths, and also limiting the probe tip and ground to a very close and fixed spacing.

This is the approach that all oscilloscope probe vendors have been taking for years to increase active probe bandwidth. Using this approach, Agilent Technologies could conceivably increase the bandwidth of the 1158A active probe from 3.5GHz to 6GHz. Tektronix has recently taken this approach with their P7260 traditional active probe, which has a specified bandwidth of 6GHz.

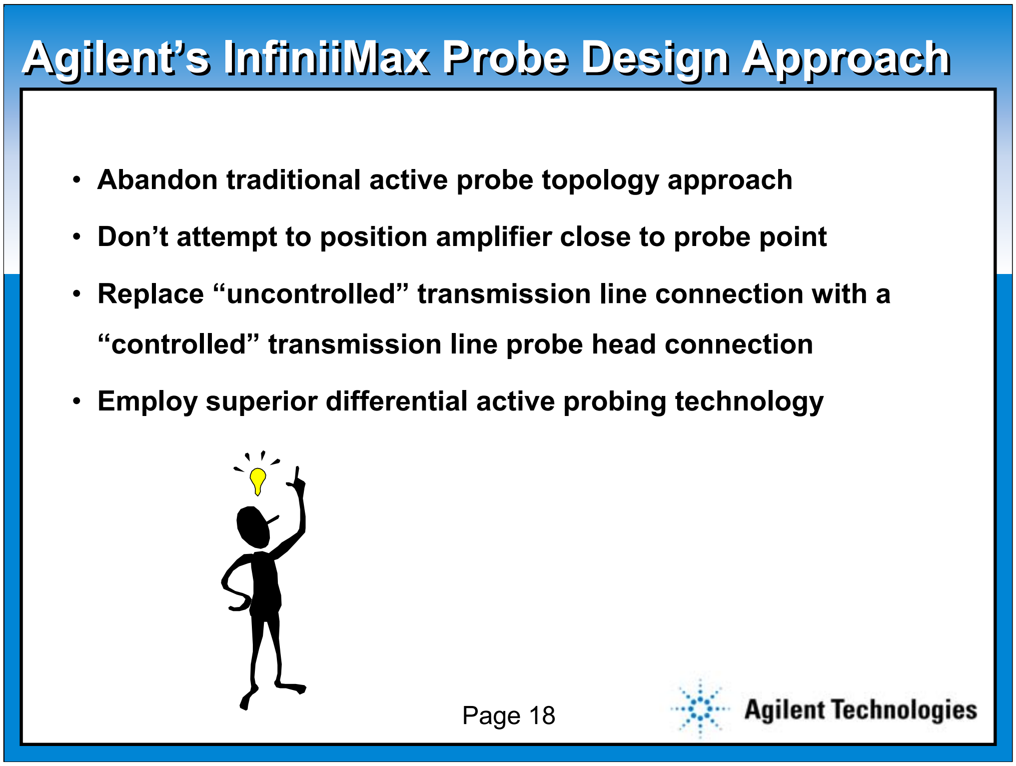
But the design approach has several tradeoffs. First of all, the reduction in size and with fixed and closely spaced connection leads, usability has been reduced significantly. In addition, this approach only increases the bandwidth for the "browsing" use model. The moment you add any accessories such as solder-in wire connections, you lose bandwidth. For example, if you attach a 5cm wire connection accessory to the end of the probe, you have just reduced the bandwidth of the probe system to approximately 1.5GHz, as we illustrated earlier. Remember, with the traditional active probe technology, the probe connection length determines the performance of the probe.

So as you see, the traditional active probe technology is up against a physical performance barrier "wall".



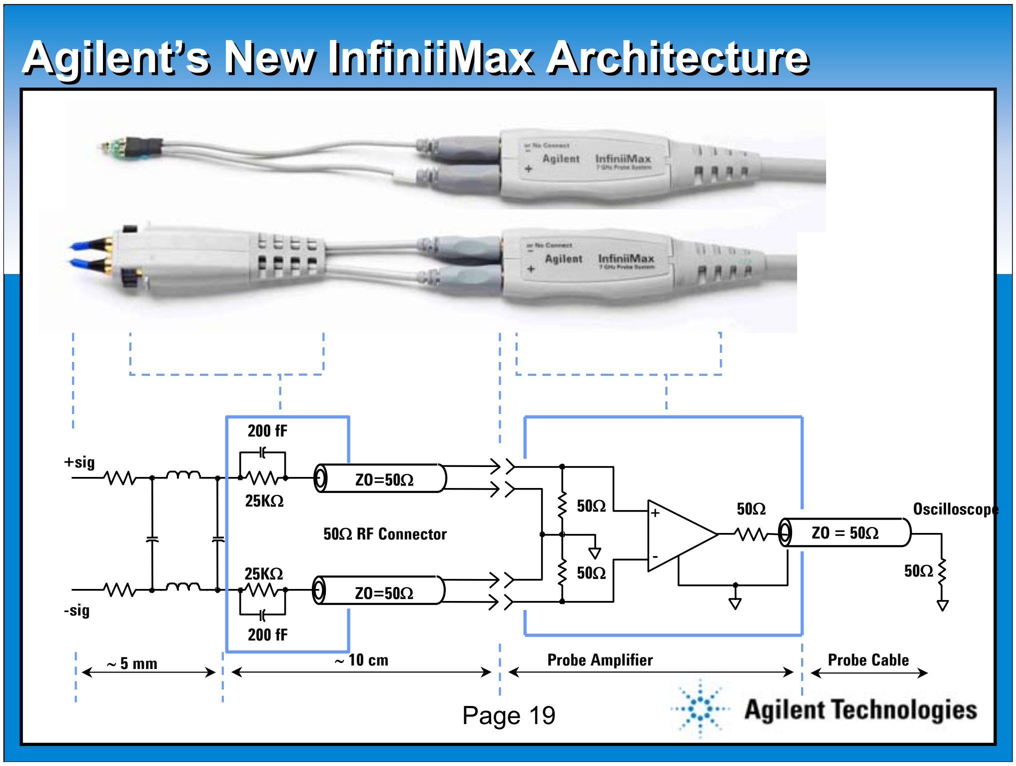
The Ideal High Bandwidth Active Probe

Let's now transition out of the real-world and back into a "perfect" world. In a perfect world, the active probe's bandwidth would always be at least equal to or greater than the oscilloscope's bandwidth. In addition, the ideal active probe would be optimized for all use models, and without any tradeoff in bandwidth due to connection lengths. And lastly, the ideal active probe would be able to make both single-end and differential measurements. Is all of this possible?



Agilent's InfiniiMax Probe Design Approach

Electrical and mechanical design engineers at Agilent Technologies realized that the traditional active probe technology was "hitting" a physical performance barrier. Producing higher probe system bandwidth without reducing usability would require a new approach. This meant abandoning the traditional active probe topology where the probe amplifier is positioned as close to the probe point as possible. However, once we made the decision to move the amplifier further away from the probe point, we then had to replace the "uncontrolled" transmission line connection with a "controlled" transmission line probe head technology. In addition, in order to make both differential and single-end measurements with the same probe, Agilent Technologies employed a superior differential active probe technology. We will address why differential probing is superior to single-ended probing a little later. For now, let's take a closer look at the electrical and physical model of Agilent's new InfiniiMax probe topology.



Agilent's New InfiniiMax Architecture

In this slide we show the physical and electrical model of Agilent's new InfiniiMax active probing system. The electrical model of the amplifier and cabling section (right sections) is essentially the same as the traditional active probe. However, the probe amplifier is a actually a differential amplifier, for either differential or single-ended connections. The big change in this topology is in the connection end. With the traditional approach, everything to the left of the amplifier section is the primary determinant of the system bandwidth depending upon the connection length. However in the InfiniiMax probe system model, the 10cm probe head connection is now essentially a "controlled" transmission line, as opposed to the "uncontrolled" transmission line connection of the traditional approach. This "controlled" transmission line probe head utilizes a 50Ω coaxial transmission line cable that is terminated at the source end with a high impedance termination (25kΩ), and then terminated at the amplifier end into 50Ω. The characteristic of this "controlled" transmission line probe head includes an in-band "zero" in the frequency domain. Within the probe amplifier is matching "pole" which results in a very flat probe system response. This pole-zero matching scheme in the frequency domain was patented by Hewlett-Packard/Agilent Technologies many years ago.

With this new active probe topology, the 10cm "controlled" transmission line probe head does NOT degrade probe system bandwidth. You can now get the probe head into very tight spacing without bandwidth loss. The section to the far left is the actual connection with damping resistors. This section of the model can affect the probe system's bandwidth depending upon the length of the connection. But with the very small 10cm probe head connection, the actual connection length can usually be minimized such that it doesn't affect the probe system bandwidth.

The single-ended model looks very similar. But instead of two 50Ohm coaxial "controlled" transmission lines in the 10cm section, there is only one 50Ohm coaxial "controlled" transmission line section.

Let's now look at some various use models for this type of active probe.

Higher Bandwidth Connectivity Solutions

- **InfiniiMax probing system offers the following options:**
  - **Solder-in probe head**
  - **Socketed probe head**
  - **Versatile differential browser**
  - **Differential and single-ended**

Differential & single-end connectivity kits

10 cm solder-in probe head

10 cm socketed probe head

Differential browsing probe head

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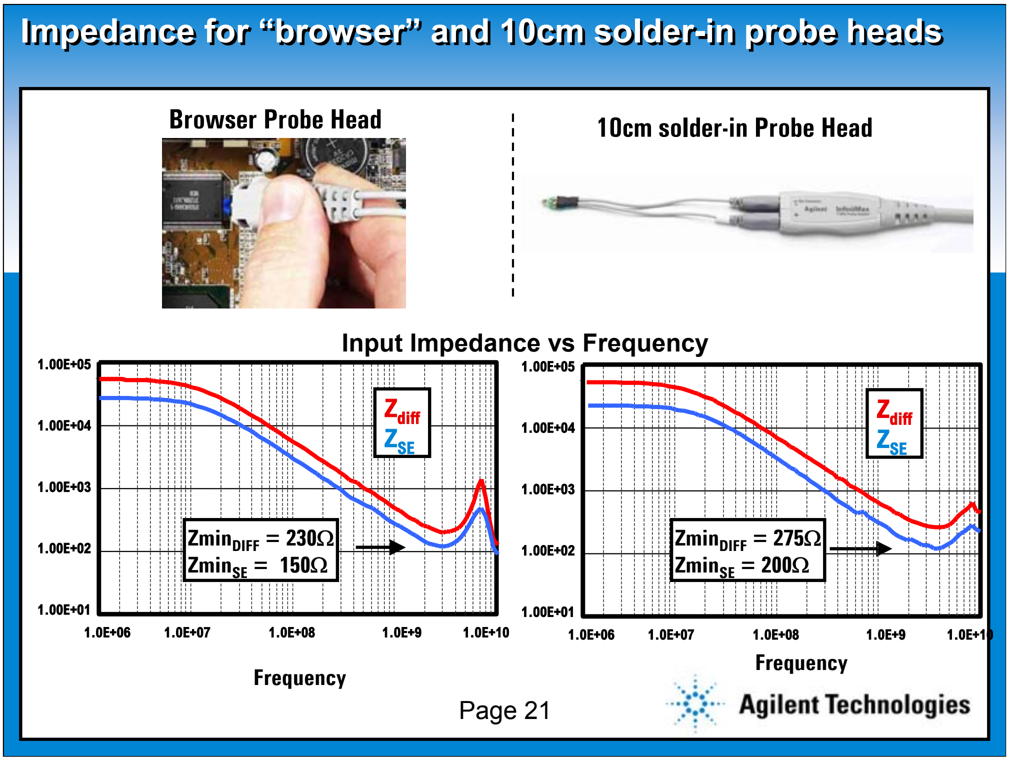
Higher Bandwidth Connection Solutions

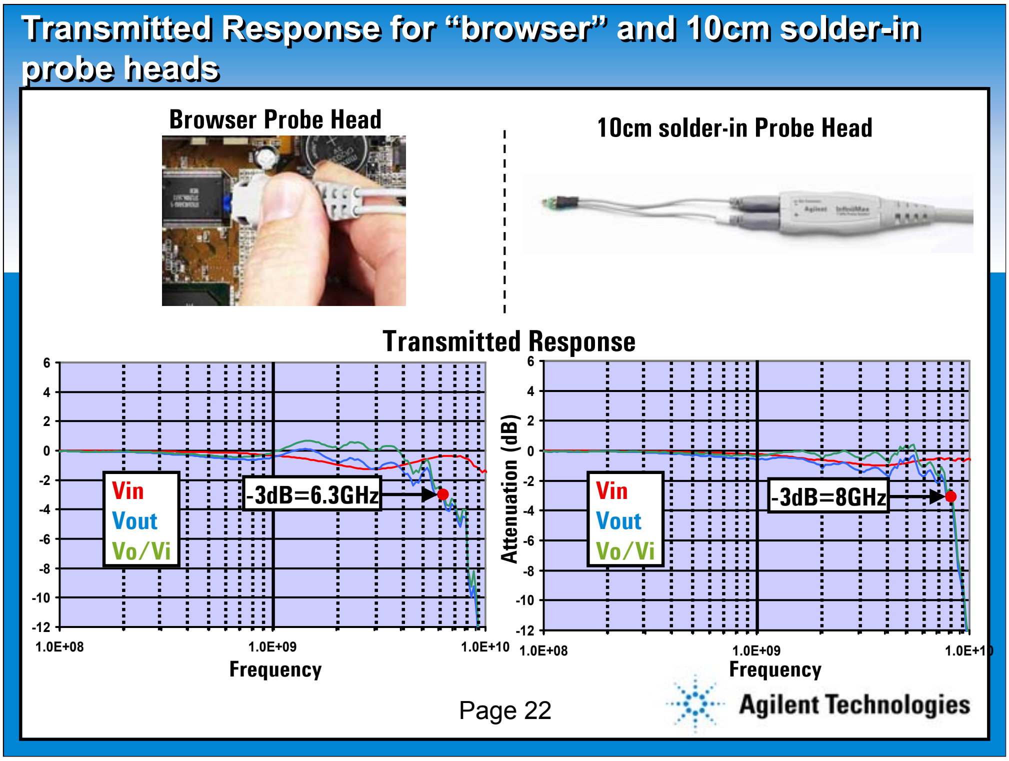
Use models for the InfiniiMax active probe system are similar to traditional active probes, including “browsing” connections, 10cm solder-in connections, and 10cm socketed connections. In addition, the InfiniiMax probe system includes both single-ended and differential measurement use models. The big difference between the InfiniiMax probe system and traditional active probe systems is probe system bandwidth. Even with long connection use models, there is no bandwidth loss penalty.

Let’s now look at some measured responses of both “browsing” and 10cm solder-in connections in both the frequency domain and time domain.



Impedance for "browser" and 10cm solder-in probe heads

In these impedance graphs we are comparing the probe system input impedance of a "browser" connection with a 10cm solder-in probe head connection. In addition, we are showing the input impedance for both single-ended and differential measurements, using a differential probe. For both of these connection options, the low frequency input impedance is 50kΩ for differential measurements and 25kΩ for single-ended measurements. As expected the impedance drops as frequency increases, but never resonates low due to damping resistor technology.

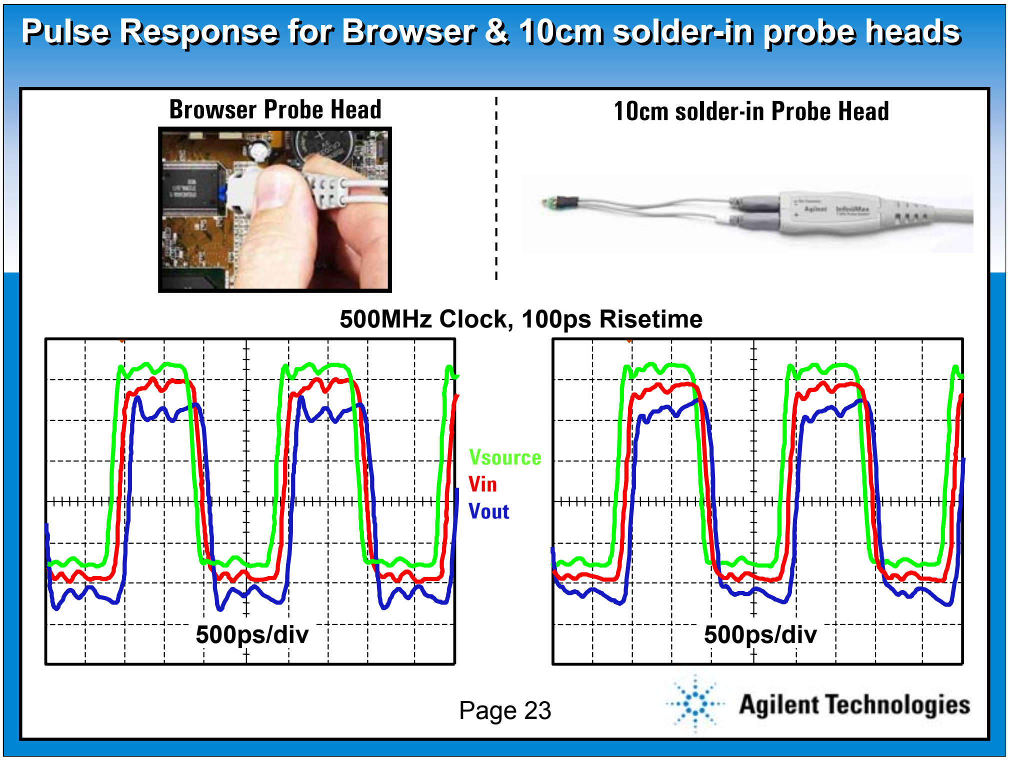


Transmitted Response for "browser" and 10cm solder-in probe heads

The red trace in each of these graphs represents Vin, which is NOT the same as Vsource. As expected, Vin takes a slight dip due to some loading as shown in the previous impedance plots. This amount of loading cannot be avoided. But Vin does not take a "dive", which would be the case if damping resistor technology was not present.

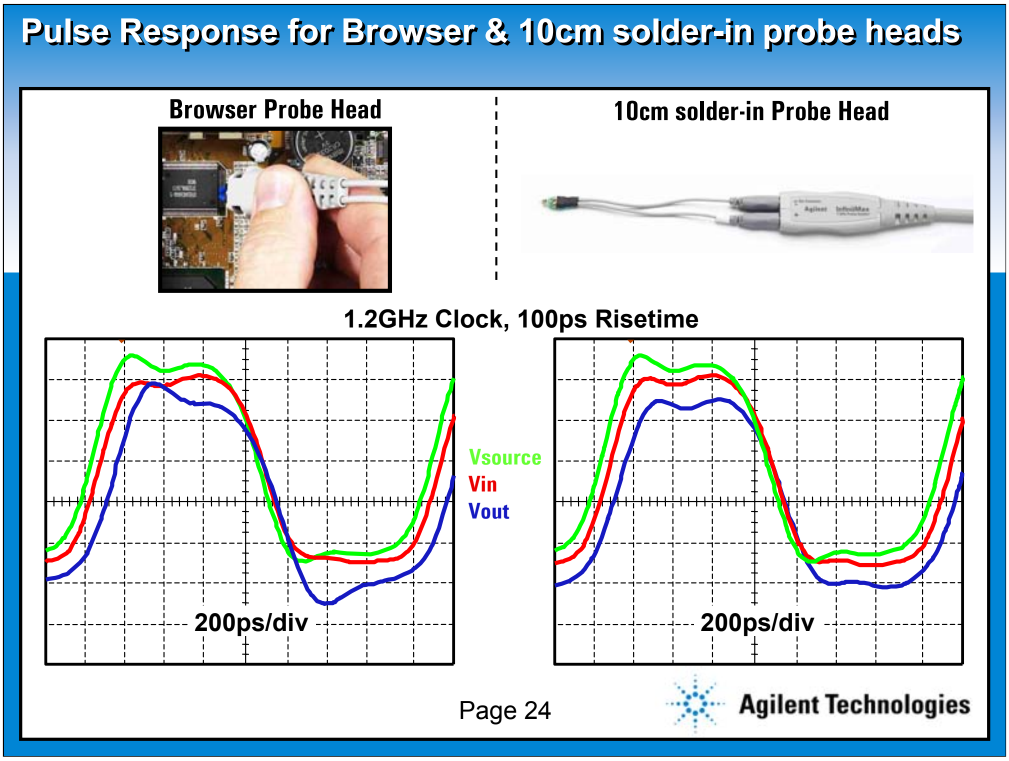
Both Vout (blue) and Vout/Vin (green) are fairly flat until they naturally roll-off at higher frequencies. The "browser" connection exhibits a –3dB bandwidth at 6.3GHz, and the 10cm solder-in probe head connection exhibits a –3dB bandwidth at approximately 8GHz. Note that this is the opposite that you would expect from the traditional probe technology. The 10cm solder-in probe head actually gives us higher bandwidth performance than the "browser" connection. This is because the actual connection length in the solder-in probe head is shorter than the "browser" connection.

Let's now look at some time domain pulse response waveforms.



Pulse Response for Browser & 10cm solder-in probe heads – 500MHz Clock, 100ps Risetime

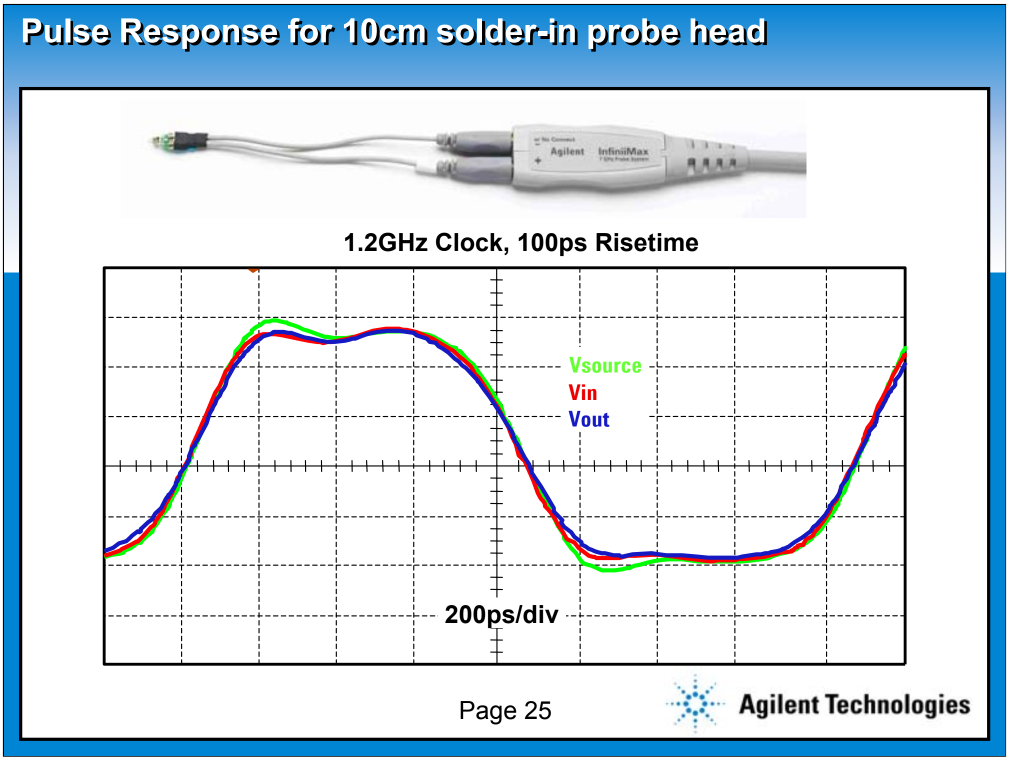
Beginning with a 500MHz clock with a risetime of 100ps, we see a very good measured response using either the "browser" probe head or the 10cm solder-in probe head. We can see a slight bit of loading on Vin with both probe measurements. With the "browser" measurement, we can see also see minimal peaking on the measured output signal. This is very typical of any "browser" type probe due to practical probe tip lengths. However with the 10cm solder-in connection, the output looks virtually identical to the input.



Pulse Response for Browser & 10cm solder-in probe heads – 1.2GHz Clock, 100ps Risetime

Even at a clock frequency of 1.2GHz, both probe use models do a very good job of measuring this fast signal with minimal loading and minimal distortion. In most digital systems today, a 1.2GHz clock frequency translates into a 2.4GHz data rate.

Again, the 10cm solder-in connection wins the contest for signal fidelity. This is just the opposite of you would expect from a traditional probe where wire accessories of minimal length signal reduce bandwidth and signal fidelity.



Pulse Response for 10cm solder-in probe heads – 1.2GHz Clock, 100ps Risetime

These are the same waveforms shown in the previous slide for the 10cm solder-in probe head with all of the waveforms overlaid on top of one another. This is as good as it gets! No other scope and probe combination can duplicate these results.. From any vendor.

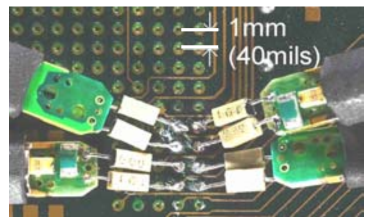
Differential versus Single-ended Active Probe for Single-ended Measurements

Differential Active Probe Advantages

- **Higher bandwidth (virtual ground plane)**
- **Variable spaced probe tips (with minimal response change)**
- **Higher common mode rejection**
- **Ease-of-use (eliminates interchanging probes)**
- **Better repeatability (reduces outer mode phenomena)**

Single-end Active Probe Advantages

- **Smaller probe heads**
- **Lower cost**



High-Density Probing

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Differential versus Single-ended Active Probe for Single-end measurements

Whether you need to make single-end measurements or differential measurements, a differential probe from Agilent Technologies will give the most accurate measurements. There are several advantages to using a differential probe for single-end measurements including:

1. A differential probe will result in higher bandwidth measurements, primarily because there is no ground connection to be concerned about. The ground connection essentially has infinite width with minimal associated resistive, inductive, and capacitive parasitics. With a differential probe, you have a virtual ground plane connection.

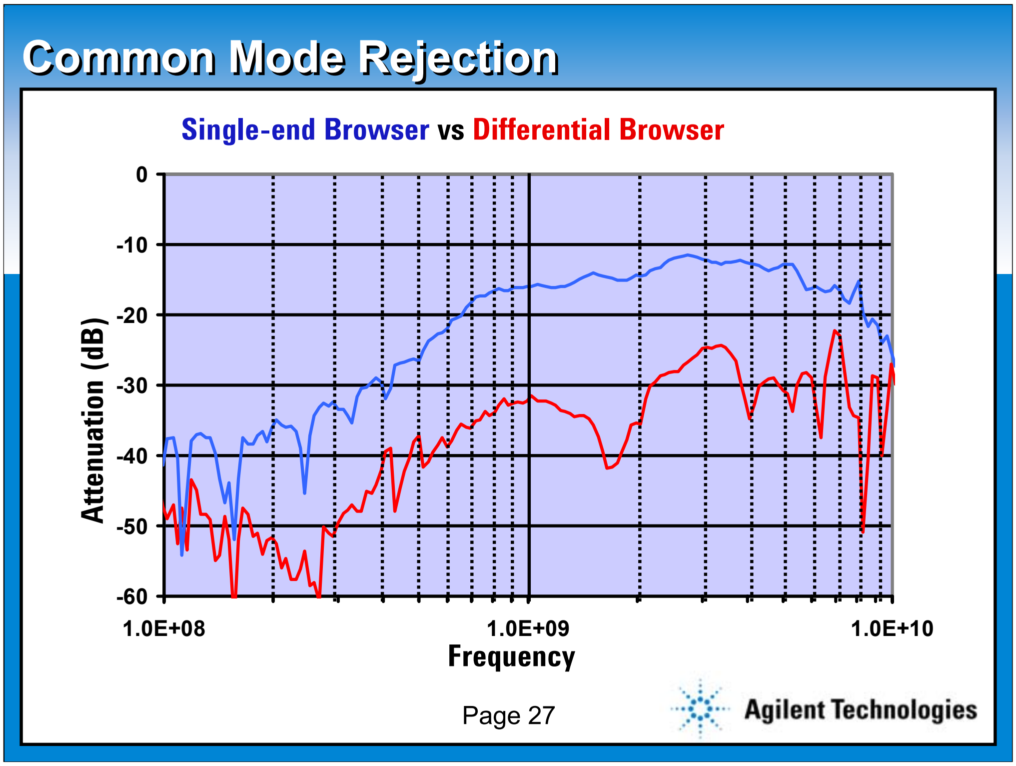
2. The differential probe has two signal connections that provide variable spaced probe tips with no bandwidth loss. A single-end probe with equivalent probe connection spacing would result in a loss in bandwidth performance, primarily due to the ground connection length (and its associated parasitics).

3. A differential probe has an inherent higher common mode rejection. A typical high bandwidth differential probe has a worst-case common rejection of 25dB as opposed to a single-end probe’s 10dB rejection. And even with single-end signals, common mode rejection is important. Real ground is not a perfect ground. As most high-speed digital designers know, ground is always moving. And with a differential probe, you can measure more accurately the difference between signal and ground.

4. Another key advantage of using a differential probe for both single-end and differential measurements is that you don’t need to interchange probes. This can be significant since active probes generally need to warm-up for about 30 minutes to give you the highest degree of repeatability. You can use the same probe while “browsing” around your design.

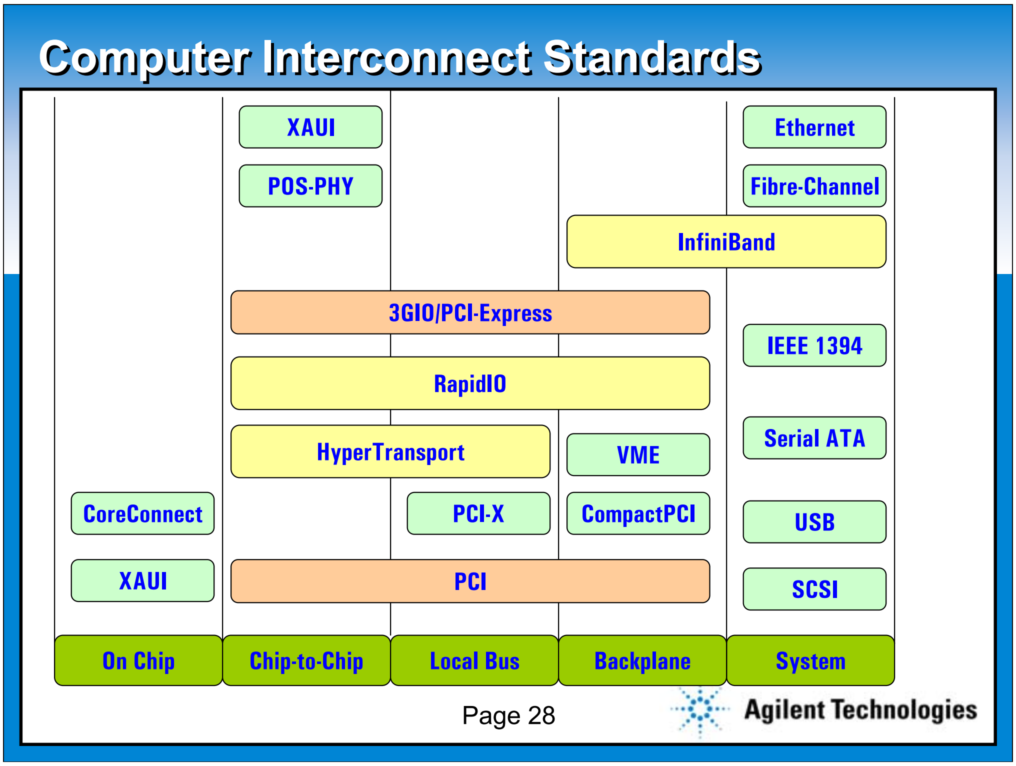
5. Lastly, a differential probe will produce better repeatability in measurements. With a single-end probe, you can often get significant variations just due to how you hold the probe and the physical position of the cable. This is closely related to the higher common mode rejection of differential probes.

There are a few advantages to using single-ended probes for single-ended measurements. First of all, the size of the single-end probe heads are smaller which can enable you to get your probe into tighter spaces. Secondly, single-ended probes cost less.



Common Mode Rejection

This slide shows the common mode rejection (in dB) for Agilent's InfiniiMax single-end probe and differential probe. The worst-case for the single-end probe is a little below –10dB and the worst-case for the differential probe is approximately –25dB. To put this in perspective, an LVDS signal with XXX signal swing and XXX common mode noise, -10dB would attenuate the common mode noise by a factor of XXX, whereas a –25dB would attenuate the common mode noise by a factor of XXX.



Computer Interconnect Standards

Besides the fact that differential probes can do a better job of measuring either single-end signals or differential signals, most high-speed interconnect and bus signals today are based on a differential technology. This charts shows some the bus standards of the past in the lower portion of the chart and some of the higher speed buses of today and tomorrow in the upper portion of the chart. ALL of the newer high-speed buses are based on a differential signaling.

Many designers are familiar with the clock rates of these buses, which move into the gigahertz range, but what about the edge rates and signal swing levels of these standards?

High-Speed Signaling Standards

Standard	Data Rate (Gb/s)	Driver Edge Rate (ps)	Receiver Sensitivity	Receiver Eye Opening or Setup/Hold
Serial		50ps to 140ps	200mVpp to 400mVpp	100ps to 140ps
PCI Express (3GIO)	2.5			
RapidIO Serial	3.125			
10GbE XAUI	3.125			
Fibre Channel 2125	2.125			
Infiniband	2.5			
Serial ATA	1.5			
Parallel				
RapidIO 8/16	2			
HyperTransport	1.6			

✓**Edge rates are decreasing below 100ps**

✓**Differential voltage swings are shrinking**

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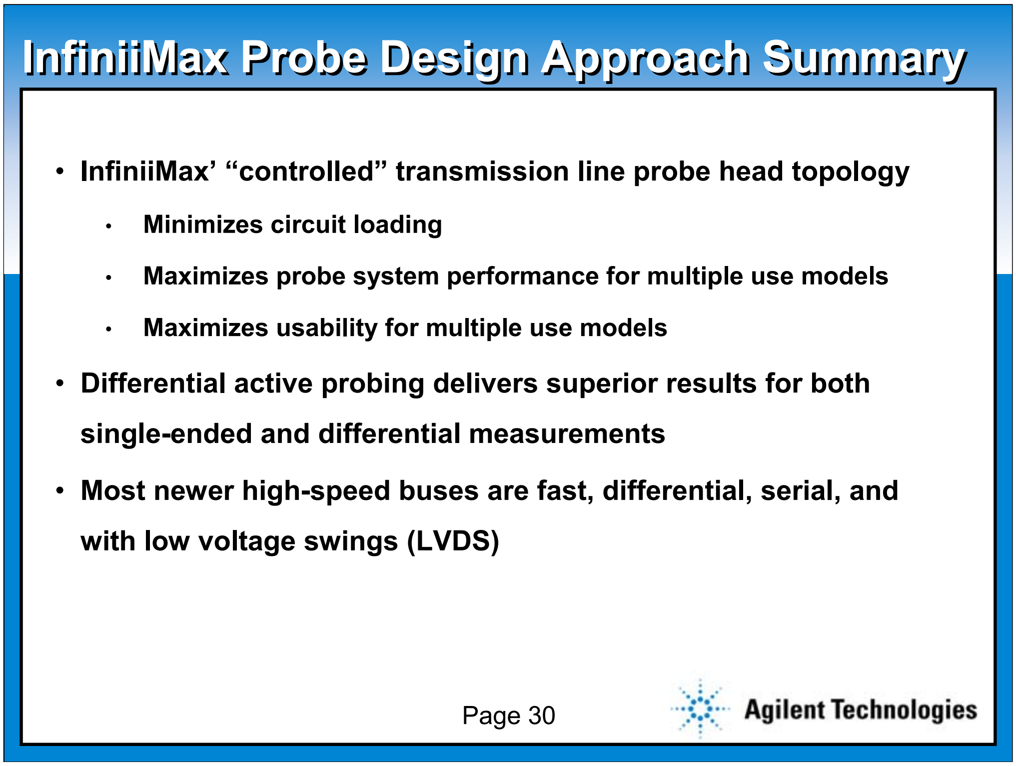
High-Speed Signaling Standards

The high-speed signaling standards listed in this table range from chip-to-chip interconnect buses, to backplane buses, to datacom links. Some of them are serial, where the clock is provided separately or embedded in the data. Some of them are parallel, with source synchronous clocking. Among these standards are several different signaling media as well: cables, multi-lane PCB traces, and even optical fiber. The common theme to these signaling standards, however, is that the minimum driver edge speeds are decreasing to at or below 100ps. Now, the risetime will be slower at the receiver, but if you are trying to verify your signals' risetimes to comply with a standard, you need to have a scope with at least 20GSa/s and 6GHz bandwidth on each channel you are measuring.

As receiver sensitivity margins and timing windows continue to shrink, it is important to have a measurement system with a low noise-floor and low timing jitter, as well as low probe loading, to ensure that you are truly measuring the error margins in your signals and not in your measurement system. In addition, differential probing is a MUST!

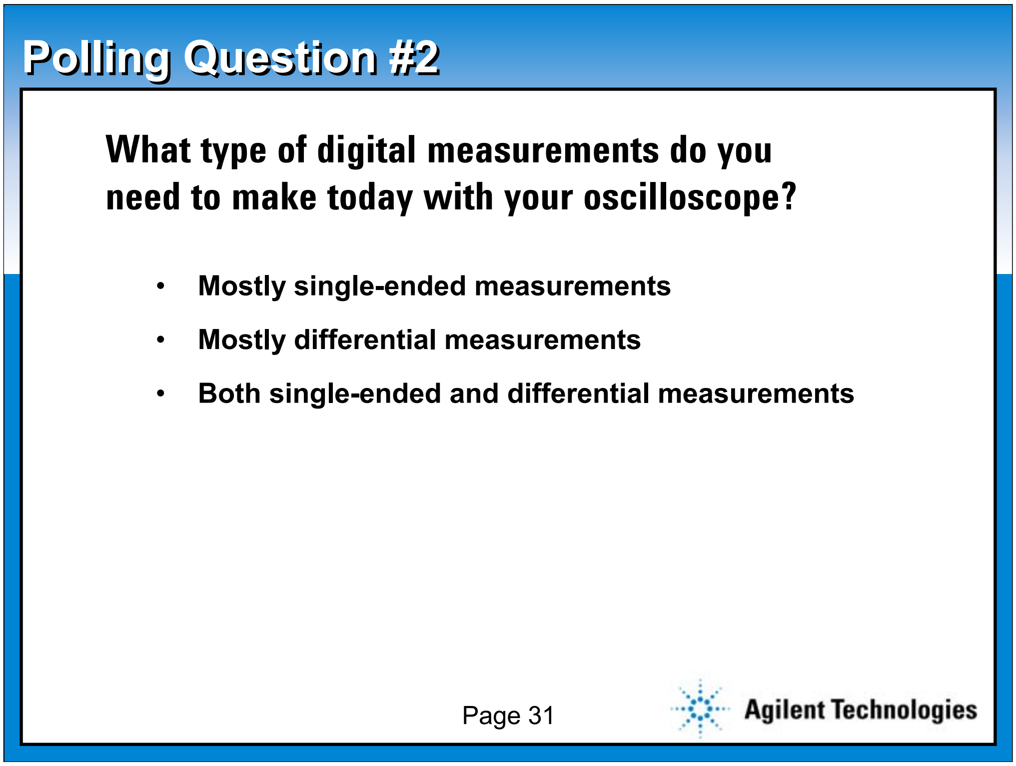


InfiniiMax Probe Design Approach Summary

Agilent Technologies has taken an entirely new approach to designing high-speed active probes that maximize signal fidelity and performance. With InfiniiMax' "controlled transmission line probe head topology, circuit loading is minimized, performance is maximized for ALL use models, and usability has been greatly improved over traditional probe technology.

Also, differential probing will deliver superior measurement results for both single-ended and differential measurements.

Lastly, most of today's newer high-speed buses are based on fast, differential, serial, and low-level signal technology. These new buses require differential probing.



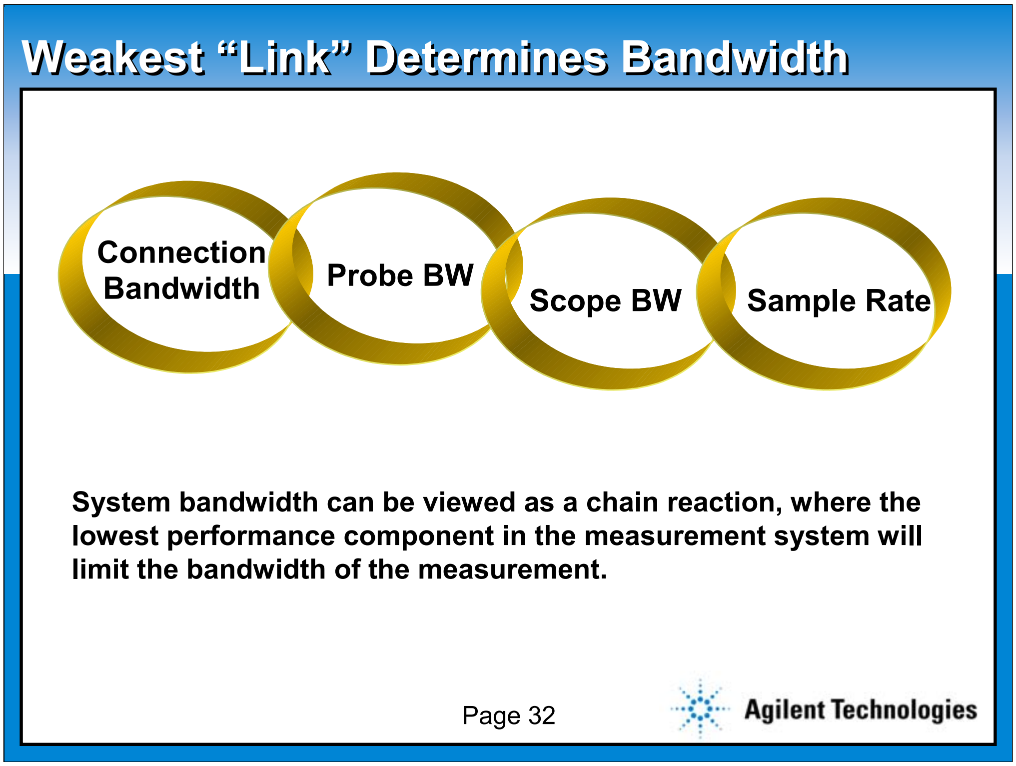
Polling Question #2

What type of digital measurements do you need to make today with your oscilloscope?

A) Mostly single-ended measurements

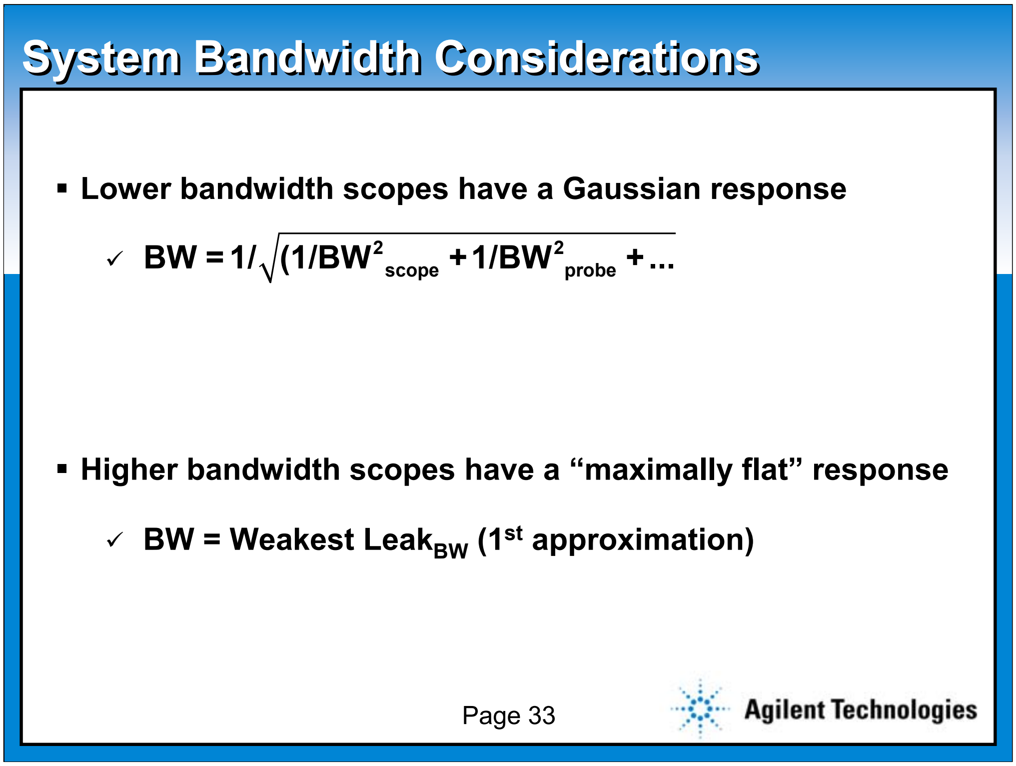
B) Mostly differential measurements

C) Both single-ended and differential measurements



Weakest "Link" Determines Bandwidth

System bandwidth is a function of many factors including probe connection, probe amplifier, oscilloscope, and sample rate per channel. As we discussed earlier, in the past probe system bandwidth has usually been the weakest "link" in this chain. However with the InfiniiMax probe system of today, all of these components must be considered. As we will see in a few minutes, for high bandwidth oscilloscope systems, system bandwidth is usually the bandwidth of the weakest "link". So, which link is the weakest in your chain?

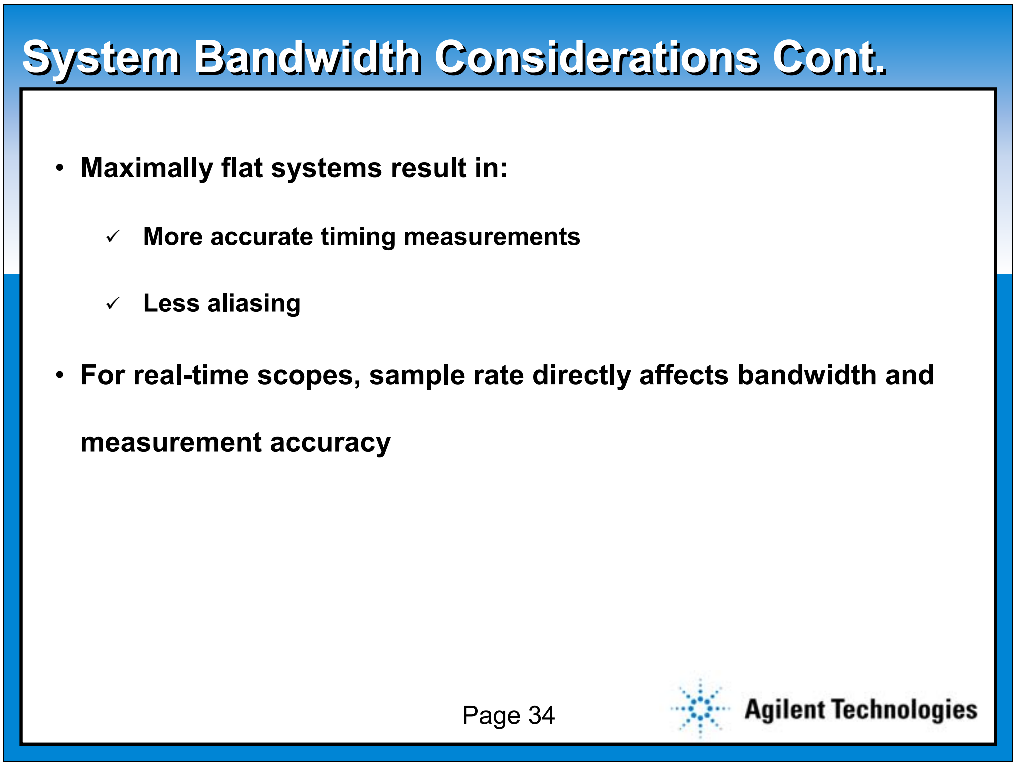


System Bandwidth Considerations

Lower bandwidth oscilloscope systems (<=1GHz) typically have a Gaussian frequency response. In a Gaussian-type system, bandwidth can be computed using the familiar square root of the sum of the squares formula:

$$BW_{system} = 1/SQRT(1/scope_{BW}^2 + 1/probe_{BW}^2 + \ldots)$$

Today's higher bandwidth real-time oscilloscopes (>1GHz) typically have what is referred to as a "maximally flat" frequency response. This means that the system response is relatively flat, and then rolls-off very quickly, rather than gradually which is characteristic of a Gaussian system. As a first approximation, the bandwidth of a "maximally flat" system is whatever the bandwidth is of the weakest "link".



System Bandwidth Considerations Continued

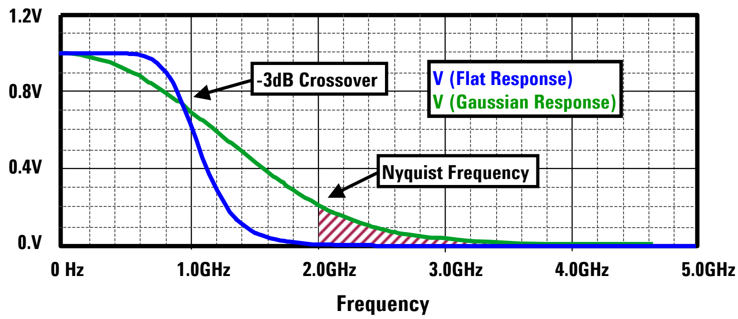
Maximally flat systems typically result in high timing measurement accuracy. If the input signal under test is band limited, then the maximally flat systems captures more of the higher frequency components of the signal up to the bandwidth (-3dB). For high-speed edge signals in the 100ps range, this is the case.

Additionally, maximally flat systems will generate less aliased reconstruction error, which is exhibited as edge “wobble” on the oscilloscope. This is because maximally flat systems do a better job of attenuating frequency components of high-speed signals above the Nyquist rate. We will show a graphic that illustrate this point in just a few minutes.

Lastly, for real-time oscilloscopes sample rate directly affects system bandwidth and measurement accuracy. Many real-time oscilloscopes have a “banner” sample rate specification that only applies to one or two channels of the scope. If the user is using all four channels, sample rate is often decimated which will result in lower bandwidth measurements. So be careful to note the sample rate per channel specification of a real-time oscilloscope, rather than just the maximum sample rate.

Sampling Alias Error

- **Gaussian response oscilloscopes have a slow rolloff in their frequency response. Frequency content above the Nyquist rate that is not significantly attenuated will manifest itself as a lower frequency signal component, creating unwanted measurement error (aliasing) in the form of edge 'wobble'.**



- **Flat response oscilloscopes eliminate alias errors by quickly attenuating frequency content above the Nyquist sampling frequency.**

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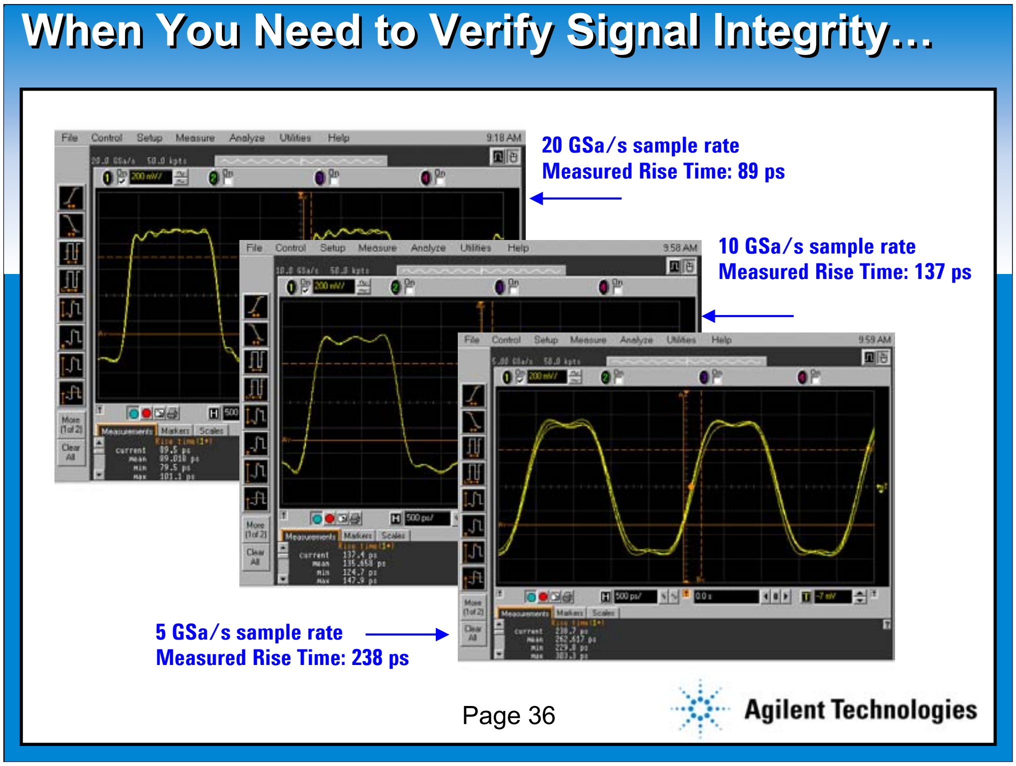
Sampling Alias Error

A common problem associated with real-time digitizing oscilloscopes is aliasing. If a signal is "under-sampled", then the resultant waveform will exhibit aliased errors. A grossly under-sampled waveform (sample rate much slower than the fundamental frequency of the input signal) will appear as an untriggered waveform of a lower frequency. An input signal that is under-sampled on fast rising edges will appear as a "wobbling" waveform. This is all related to the Nyquist theorem that states that all frequency components within a signal must have at least two sampled points per period. If this is violated, then aliasing occurs.

An oscilloscope system with a maximally flat response will naturally attenuate more of the higher frequency components of an input signal (before sampling) than a system with a Gaussian response. This will result in less aliased error and better timing measurement accuracy.



When You Need to Verify Signal Integrity…

To illustrate the point of better accuracy with higher sample rate, this slide shows the same high-speed signal captured at three different sample rates. The measured rise times of this signal vary significantly depending upon the sample rate. So the caution here is, watch out for scopes that trade-off sample rate for channels. Many high-bandwidth four channel scopes only sample at the highest specified rate (banner spec) when using just one or two of the acquisition channels.

Unfortunately, it is difficult to show the aliasing problem with a static slide. To view the "wobble" of a fast rising edge requires a live and interactive waveform display.

System Bandwidth

- **The oscilloscope bandwidth required for accurate measurements is primarily dependent on the signal's risetime, not its frequency.**

Oscilloscope Bandwidth and Accuracy		
Determine Maximum Signal Frequency (Fmax)	0.5 / Signal Risetime (10%-90%) OR 0.4 / Signal Risetime (20%-80%)	
Determine Oscilloscope Response Type	Gaussian Response	Flat Response
Risetime Measurement Error	Oscilloscope Bandwidth	
20%	1.0 Fmax	1.0 Fmax
10%	1.3 Fmax	1.2 Fmax
3%	1.9 Fmax	1.4 Fmax
Minimum Sample Rate	4 x Bandwidth	2.5 x Bandwidth

- **Flat response oscilloscopes with a bandwidth that is 1.4 times the highest frequency content in the signal will make accurate risetime measurements.**

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System Bandwidth

Let's now walk through a few simple "rule-of-thumb" calculations to determine the appropriate scope bandwidth and sample rate to capture a fast rising edge for accurate parametric measurements.

The first step is to determine maximum practical frequency component within the signal under test. This is referred to F_{max}. Howard Johnson has written a book on this topic and refers to this highest frequency component as F_{knee}. All fast rising edges have an infinite spectrum of frequency components. However, there is an inflection in the frequency spectrum of fast rising edges where frequency components higher than F_{max} are insignificant in determining the shape of the signal. For high-speed signals with a rise time characteristics based on 20% to 80% thresholds, F_{max} is equal to 0.4 times the rise time of the signal according to Mr. Johnson.

The next step is to determine the require bandwidth of the oscilloscope to measure this signal. The table in this slide shows multiplying factors for various degrees of accuracy, and for scopes with a Gaussian response or a maximally flat response. Today, all scopes from all manufacturers with bandwidths above 1GHz have (or approach) a maximally flat response.

The next step is to determine the minimum sample rate. For a Gaussian response scope the minimum scope sample rate should be at least 4X the scope's bandwidth to minimize aliasing. For a maximally flat response scope, the minimum sample rate should be at least 2.5X the scope's bandwidth. Since a maximally flat scope attenuates frequency components above the Nyquist rate better than a Gaussian response scope, then less samples are required.

Let's now look at a specific example.

System Bandwidth Calculation

Example

- **Determine the minimum required bandwidth and sample rate of a flat frequency response oscilloscope to measure a 100ps risetime (20-80%) to an accuracy of 3%:**

F_{max} = (0.4/100ps) = 4.0 GHz

Required oscilloscope bandwidth = 1.4 * 4.0 GHz = 5.6 GHz

Minimum Sample Rate = 2.5 * 5.6 GHz = 14.0 GSa/s

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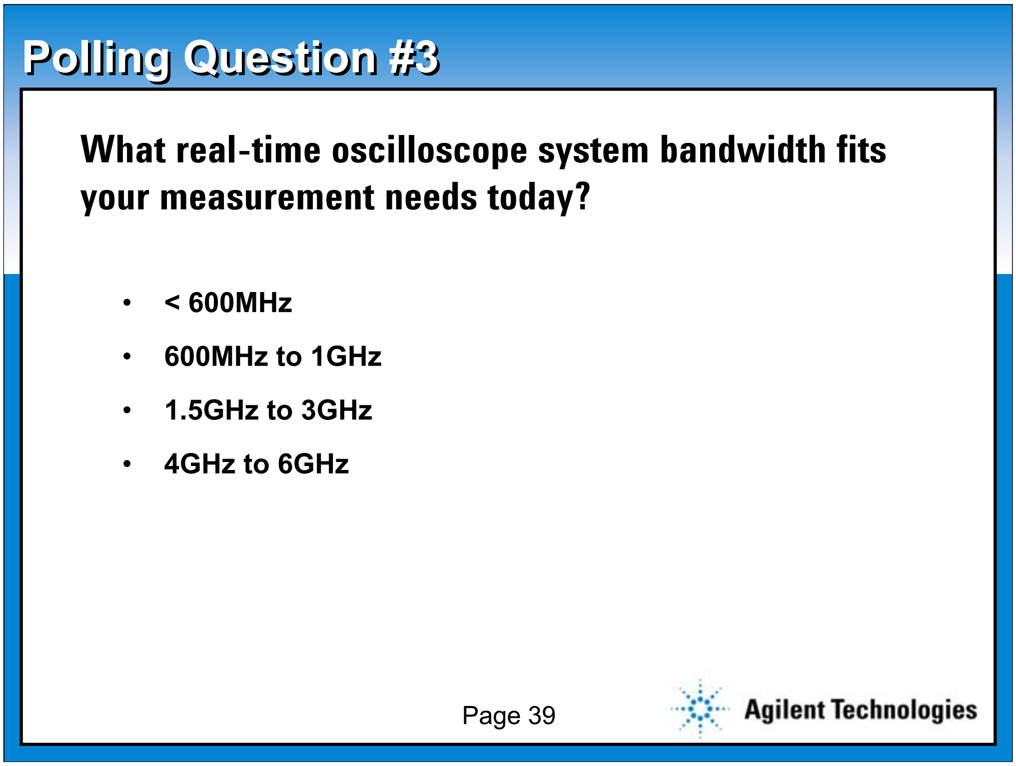
System Bandwidth Calculation

Many of today's high-speed buses and chip-to-chip signals have rise time specifications in the 100ps range (20% to 80%) as shown earlier. So, let's go walk through an example of accurately measuring a 100ps edge.

If the signal has an approximate rise time of 100ps, then the maximum practical frequency component (F_{max}) would be approximately 4GHz. For a rise time measurement accuracy of 3%, the minimum scope bandwidth should be at least 5.6GHz (assuming a maximally flat response). And then the minimum sample rate for a 5.6GHz maximally flat scope would be at 14GSa/s.

Since scopes don't come with these odd numbered specifications, practically speaking you would need a 6GHz bandwidth scope with 20GSa/s sample rate. And if you needed to make simultaneous timing measurements on multiple channels, you should insure that the sample rate does not decimate in multi-channel operation.



Polling Question #2

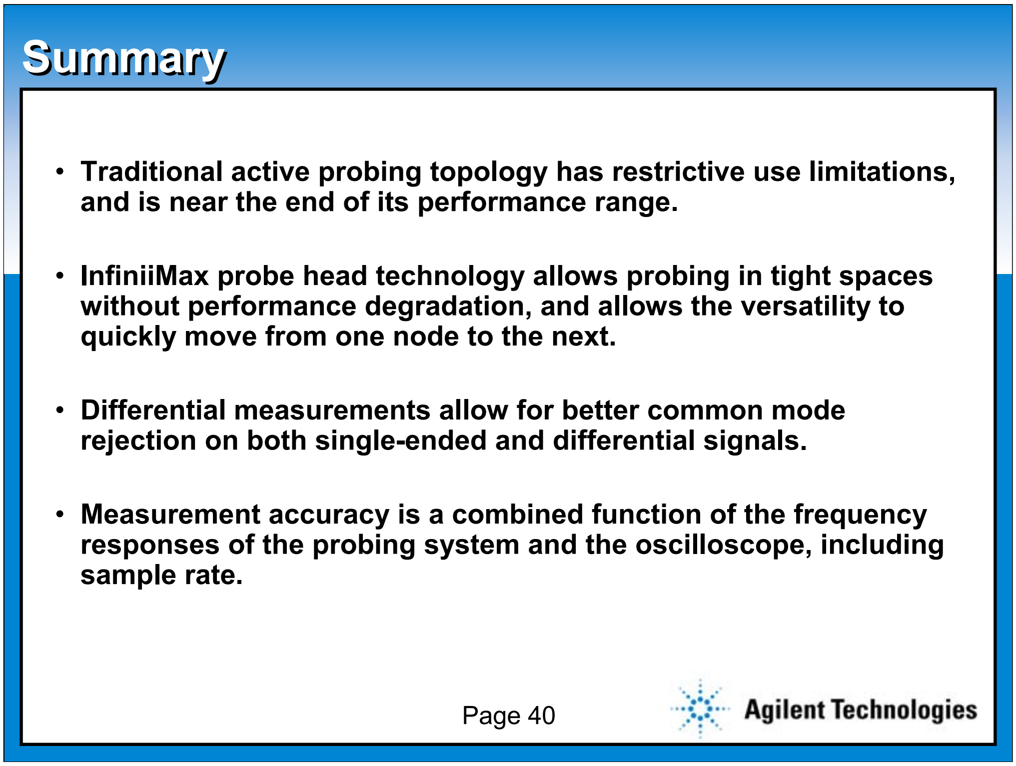
What real-time oscilloscope system bandwidth fits your measurement needs today?

A) < 600MHz

B) 600 to 1GHz

C) 1.5 to 3GHz

D) 4GHz to 6GHz



Summary

As we have learned today, traditional active probing topology is hitting a performance wall and has lots of usability limitations. If you add any accessories to this type of active probe, performance will degrade significantly.

Agilent's InfiniiMax probe head technology solves many of the problems associated with traditional active probe technology. You can now get your probe into very tight spaces without a loss of bandwidth.

Also InfiniiMax' differential technology allows for higher accuracy because of better common mode rejection for either single-ended or differential measurements. We recommend that you use a differential probe for both. In addition, you don't need to change probes when making various kinds of measurements (single-end and differential).

And lastly, oscilloscope system measurement accuracy is a combined function of the frequency response of the probing system, the oscilloscope, as well as the sample rate per channel specification.

Agilent 54850 Infiniium Performance Series

New

4GHz to 6GHz

- 4 channels
- Up to 32 MB deep memory
- Up to 20 GSa/s sample rate/channel
- MEGA Zoom technology
- Infiniium award-winning usability

www.agilent.com/find/infiniium

Model	BW	Channels	Sample Rate Per Channel	Standard Mem/Ch	Optional Mem/Ch	Price (US)
54854A	4 GHz	4	20 GSa/s	256K	1M/32M	$49,995
54855A	6 GHz	4	20 GSa/s	256K	1M/32M	$58,995

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Agilent's 54850 Infiniium Performance Series Oscilloscopes

For the highest performance real-time oscilloscope measurements, Agilent Technologies has just introduced the new 54830 Infiniium Performance Series of oscilloscopes. There are two models to choose from with 4GHz and 6GHz bandwidth. Both of these scopes can sample up to 20GSa/s on all four channels. This is the highest real-time bandwidth and highest sample rate per channel on the market today. Standard memory per channel is 256K. With the optional memory, memory depth increases to 1M per channel with sample rates up to 20GSa/s, or 32M per channel for sample rates of 2GSa/s and lower. And Agilent's new InfiniiMax probing system is compatible with this new series of scopes to provide up to 6GHz system bandwidth.

Let's take a closer look at the InfiniiMax probe system now.

InfiniiMax High Performance Probe System

Configuring an InfiniiMax Probe System

1. **Choose a probe amplifier based upon performance needed**

Model	Bandwidth	Price
1131A	3.5 GHz	$2,450
1132A	5.0 GHz	$3,700
1134A	7.0 GHz	$5,100

2. **Choose one or both connectivity kits.**

- Differential (E2669A) $3,450

- **Better measurement quality for differential and single-ended signals**
- **Interchangeable parts reduce setup time**

- Single-ended (E2668A) $1,400

- **More cost effective for single-ended only**

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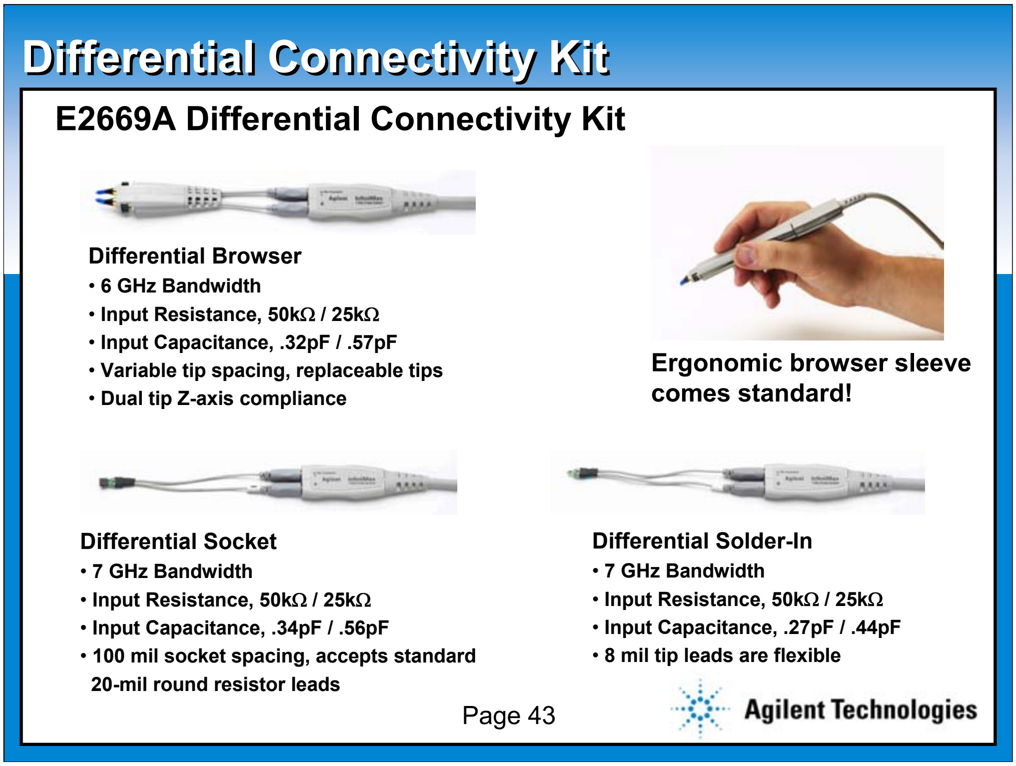
InfiniiMax High Performance Probe System

With Agilent’s new InfiniiMax high performance probe system, you have a choice of three different amplifier systems with bandwidth ranging from 3.5GHz to 7GHz. All three of these probe amplifiers are compatible with either single-ended or differential measurement probe heads.

You must then choose either a differential or a single-end connectivity kit to mate to the probe amplifier. Or you can purchase both. If you choose to purchase the single-end connectivity kit, then you can only make single-ended measurements with this type of probing system. However, if you choose to purchase the differential connectivity kit, you can make either single-ended or differential measurements with the same probing system. And as we mentioned earlier, the differential probing system provides the highest performance measurements for either single-ended or differential measurements.

Let’s now take a look at what comes with each of the probing connectivity probing kits.



Differential Connectivity Kit

The differential connectivity kit comes with three different probe heads that attached to the amplifier. This gives you lots of use model flexibility. The most common use model for most engineers is “browsing”. The differential browser will deliver 6GHz typical system performance for both single-ended and differential measurements with a 6GHz bandwidth oscilloscope. The differential socket and solder-in probe heads can be used when hands-free probing is desired, or if you need to access hard-to-reach measurement points. These particular probe heads deliver even high performance capabilities.

Also included in the differential connectivity kit is a ergonomic browser sleeve. This ergonomic sleeve slips over the differential browser probe head and amplifier assembly giving you tool that is often easier to use for the browsing use model.

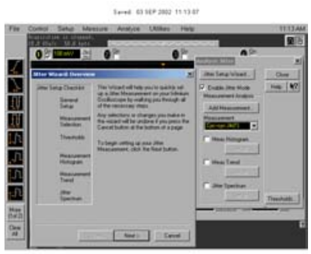
Single-ended Connectivity Kit

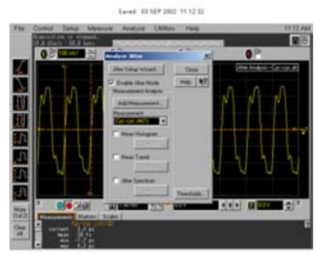
The single-ended connectivity kit comes with a similar set of probe heads for various use models in making single-ended measurements. The main advantage of the single-ended connectivity is that most of the probe heads are smaller than the differential probes, allowing you to get to even harder-to-reach measurement points.

You might note that the bandwidth specification of the single-ended browser is just 5.5GHz. Agilent could have easily designed this particular probe head to deliver at least 6GHz performance if the probe connection lengths had been made shorter. However, we felt that usability was of higher importance. If you need to make 6GHz single-ended measurements, then we recommend that you purchase the differential connectivity kit, which can make both single-ended and differential measurements with at least 6GHz bandwidth performance or higher.

Jitter Analysis - Easy to Use, Easy to Understand

- Key measurements include: cycle-cycle jitter, n-cycle jitter, period jitter, time interval error, setup and hold time, measurement histograms, measurement trending and jitter spectrum
- Integrated into the oscilloscope application
- Setup Wizard guides the user on setup of the jitter measurement, describes what the measurement does and tells you when to use it





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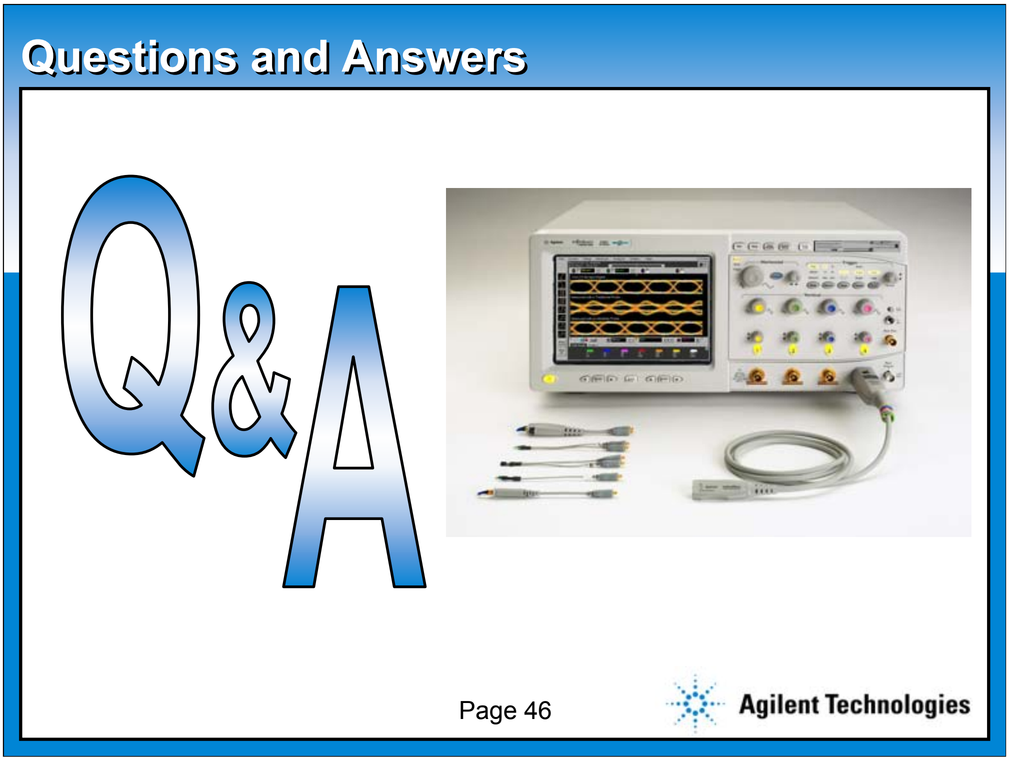
Jitter Analysis – Easy to Use, Easy to Understand

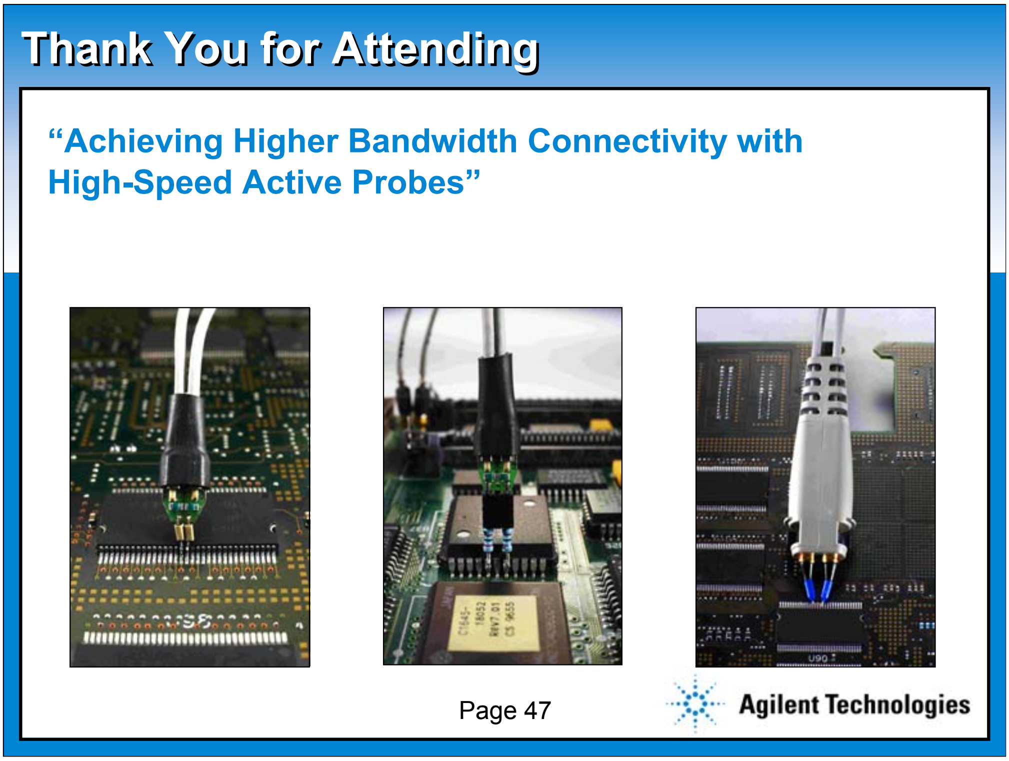
One measurement option that is available with Agilent's performance series oscilloscope is a jitter analysis package. Some of the statistical measurements included in the optional software analysis are cycle-to-cycle jitter, n-cycle jitter, period jitter, time interval error, setup & hold time, measurement histograms, measurement trending, and jitter spectrum.

This new jitter measurement package is tightly integrated into the oscilloscope allowing for fast update rates, and integrated displays. In addition, this measurement package comes with a set up Wizard that makes setting up the measurements very intuitive and easy.



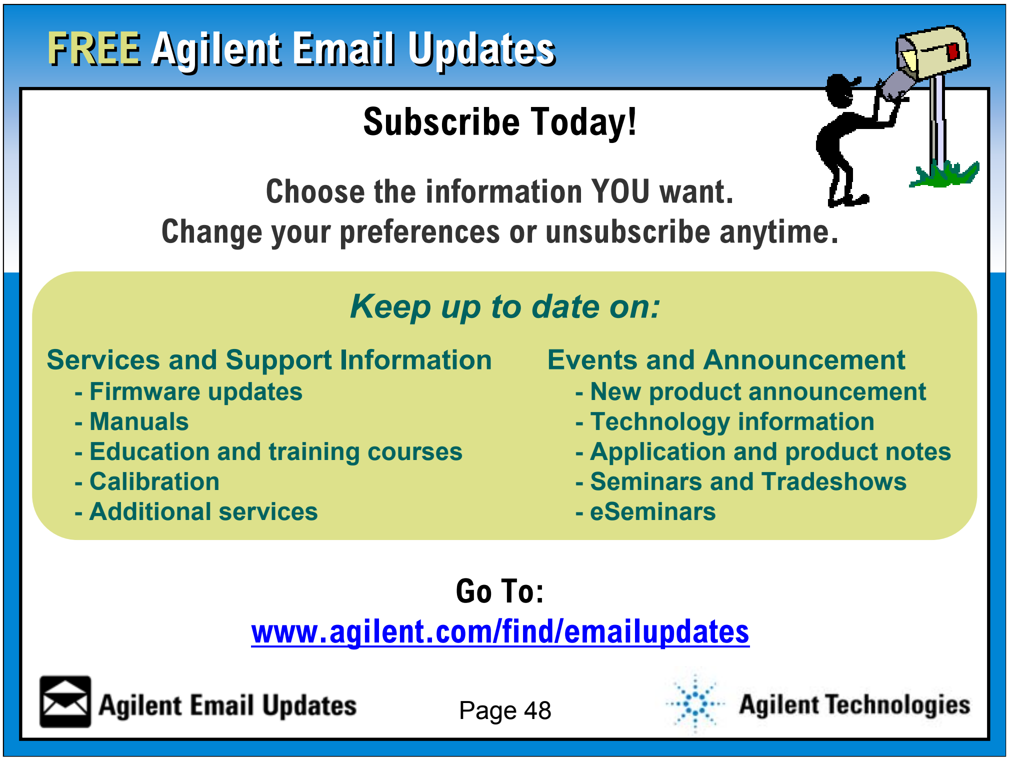
Question and Answers

At this point, we encourage you to ask any questions regarding high-speed probing and system bandwidth.



Thank You for Attending

Thank you for attending today's seminar on "Achieving Higher Bandwidth Connectivity with High-Speed Active Probes". We encourage you to complete the evaluation form in order to provide Agilent with feedback on today's seminar.



In a moment we will begin with the Q&A but 1st, for those of you who have enjoyed today's broadcast, Agilent Technologies is offering a new service that allows you to receive customized Email Updates. Each month you'll receive information on:

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