Making the Logical Connection - How to Choose and Plan for Logic Analyzer Probes

FuturePlus Systems

When finished, customers should take away the following:

1. Agilent offers customers a wide variety of logic analyzer probing solutions
2. Agilent probes offer the lowest possible loading
3. Agilent understands the trade-offs involved with various probing solutions and where the different alternatives make sense.
4. Agilent now offers a new leading-edge connector-less probing system.

What Do You Look For in a Logic Analyzer Probing Connection?

- **Low Signal Loading**
- **High Connector Density**
- **Low Clearance and Ease of Attachment**
- **Good Reliability**

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When considering logic analyzers, one of the most important aspects of a logic analyzer is the probes. Everything in a logic analyzer measurement depends on the probes: the logic analyzer only sees what comes through the probes.

The load presented by the probe to your target system is an important consideration.. This is particularly true at high edge speeds. Any resonance in the probe load can significantly affect the signal integrity of your system.

Probe density is important. Logic analyzers typically are connected to tens or hundreds of signals in your target system. You'd like to connect to all those signals with a minimum cost in board area. We'll talk more about some more reasons why density is so critical when we get to that section of this presentation.

Ease of attachment is important. You'd like to apply your time to debugging or validating your circuit, not hooking up the logic analyzer.

Reliability is one of the most critical requirements of a probe. When you use a logic analyzer, the assumption is that you suspect that your circuit exhibits some failure.. Agilent places extremely high priority on reliability in probing. The logic analyzer can't be any more reliable than the probes.

In the rest of this presentation, we'll be looking in depth at each of these areas.

The Basic Problem

The probe is part of the circuit.

The circuit is part of the probe.

Probing affects both:

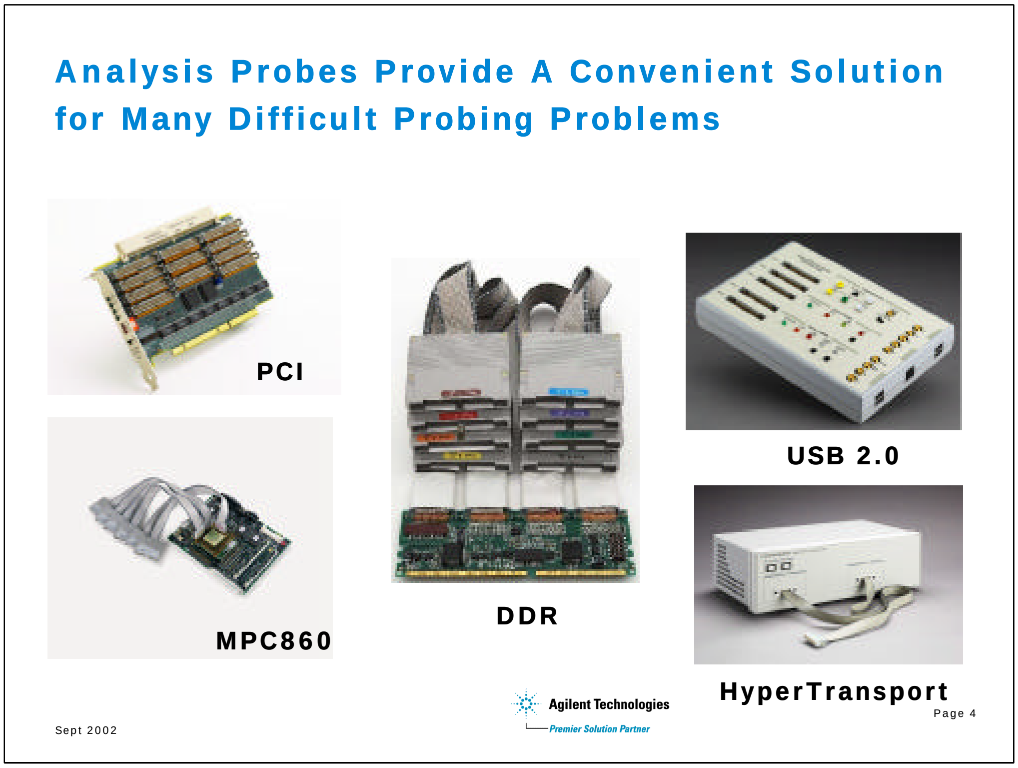
• the data the logic analyzer sees and

• the data the receiver sees.

In the good old days, when clock rates on most buses were below 100 MHz, you could basically ignore the effects of logic analyzer probes. But at today's speeds, the effects of the probe must be analyzed and accounted for in the circuit design. Your carefully-designed and optimized circuit won't operate the same with the probe as it does without it. The implication of this fact is that you have to start thinking about probing way back in the design phase, even before you start board layout.

At a sufficiently high speed, any connection on a PC board – or even a bond wire inside a package – must be thought of as a transmission line.

Unfortunately your logic analyzer (or scope for that matter) can't tell you if you're probing method is bad and you've ruined the signal integrity of the signals you're trying to measure.



Where mechanically, electrically, and economically feasible, Agilent or FuturePlus Systems will create an off-the-shelf probing solution for a standard processor or bus. These are known as preprocessors or analysis probes. Examples currently shipping include PowerPC, MPC8260, HyperTransport, DDR, PCI, PCI-X, AGP, USB 2.0, ISA, and IA-32 and IA-64 front-side buses.

However, there are cases where it’s not possible to create a standard probe, or where custom, proprietary buses are employed. Designers still have the need to debug and validate these systems. This is the area where a logic analyzer’s general purpose probing system becomes important.

There are multiple options to choose from when a standard probing solution is not available. Some are common to the major logic analyzer vendors; and some are vendor-specific. The rest of this presentation will cover these different types and show the advantages and disadvantages of each.

What Do You Look For in a Logic Analyzer Probing Connection?

- Low Signal Loading
- High Connector Density
- Low Clearance and Ease of Attachment
- Good Reliability

What Factors Influence Overall Probe Loading?

- Stubs
- Vias
- Pads
- Connectors
- Probes
- Instrument input impedance

The first consideration of probing is:
Can you make accurate measurements of your signals?

Probe Load Modeling Methods

- **"IN CIRCUIT"**
- **Includes SMT pads and PC Board mounting effects**
- **Derived from measurements**
- **Easily verified with measurements**
- **Potential Weakness: Variance in layout methods**

- **"FREE SPACE"**
- **Does NOT include SMT pads or PC Board mounting effects**
- **Derived from simulation results**
- **Tough to verify with measurements**
- **Weakness: Ctotal = Cprobe + Ctarget**

  Not a realistic model

Agilent's probe load models are based on measured data, and include SMT pads and PC Board mounting effects. Various test configurations have had very little effect on the measured load.

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Now let's consider probe loading. A potential confusion factor here is that there are two methods used for developing probe load models, in-circuit and free-space. The in-circuit approach treats probes the way you actually use them, in your circuit, with mated connectors, mounted on your circuit board. The free-space approach is theoretical, derived from simulations. It's difficult to know how to apply a free-space model to a real situation, since probes don't dangle in "free space" in the real world. To effectively utilize the free-space model, you would need to know how to modify the model to include the fields surrounding the probe in your target system. In other words, you have to develop your own complete model.

In-circuit models as published by Agilent are validated with measurements, and are easy to verify with measurements. They represent the actual measured behavior of the probe and mating connector mounted on a PC board and connected to a transmission line, so they are directly applicable. You can insert the model with confidence in your simulation to assess the impact of the probe and connector on your circuit.

The limitation of in-circuit models that you must keep in mind when assessing probes is that the test circuit used for the measurements may be different from your target environment. For example, if a ground plane is closer than it was in the test fixture, the capacitive load may be higher. But at least the models are validated by measurements on a real PC board, on a real 50-ohm transmission line. It's unclear what "free space" models mean, as they cannot be verified by measurements.

Agilent has chosen to use in-circuit models, validated by measurements. Agilent believes there is too much room for error in the "free-space" model. The potential weaknesses of the test configuration board not being identical to the target configuration are trivial compared to the certain errors in a "free-space" model.

Methods of Measuring Probe Load and Its Effects

The three methods are used to characterize connectors and probes:

- **Vector Network Analyzer (VNA) Impedance Measurements**
- **Time Domain Reflectometry (TDR)**
- **Time Domain Transmission (TDT)**

At Agilent we have employed three methods of characterizing probe loads in-circuit.

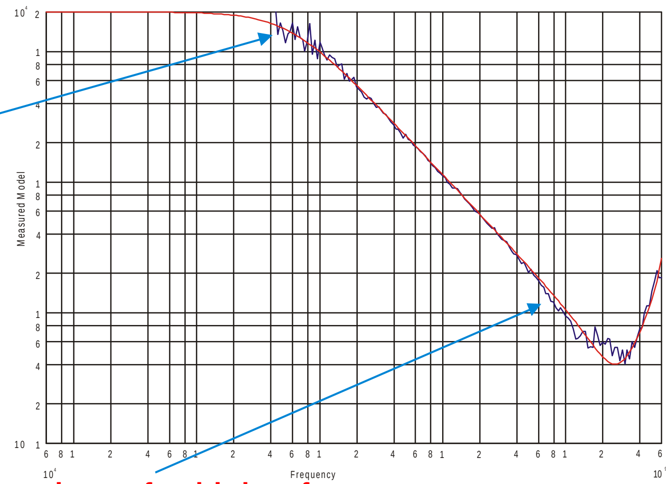
A vector network analyzer can be used to measure the impedance, and this can be compared to the results of a simulation with the published in-circuit model. This is the most accurate and precise way to validate the accuracy of the model. The results are not terribly intuitive, and the information may be hard to apply to answer the question "What does the probe load do to the signals in my system?"

In time domain reflectometry, a fast-rising voltage step is launched down a transmission line toward the probe and connector. The reflection caused by the reactance of the probe and connector is an indication of how the probe's impedance affects signals in the time domain. TDR contains the same information as a VNA measurement, the only difference is that the information is now in the time domain, not the frequency domain, and is therefore more intuitively easy to relate to time-domain signals.

Probably the easiest and most intuitive measurement to interpret and apply to real-world signals in your system is the time domain transmission measurement. A time-domain transmission measurement precisely characterizes the changes in an actual time-domain step signal as the probe load is added to the transmission path. You can think of the signals in a time-domain transmission measurement as how the signals in your system would look after adding the probe, if your circuit started off with ideal step inputs.

VNA Impedance Plot: What Does It Mean?

High impedance for low frequency content means little attenuation.



Lower impedance for higher frequency content means significant attenuation and dulled edges.

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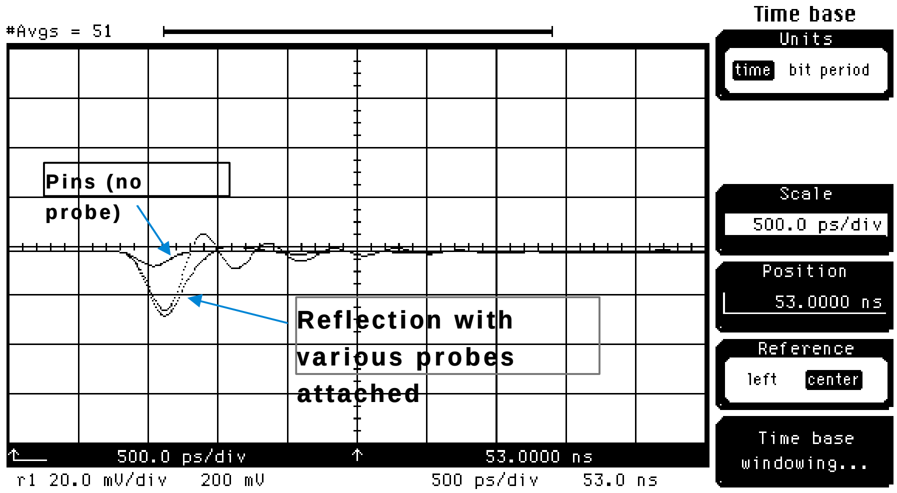
An Impedance plot shows the loading a probe will have on each frequency component of a signal. Higher frequency components are more attenuated by capacitance (low impedance) in a probing system than lower frequency components.

TDR Example: Flying Lead Sets



TDR measurements show you where and how big impedance discontinuities are in a net.

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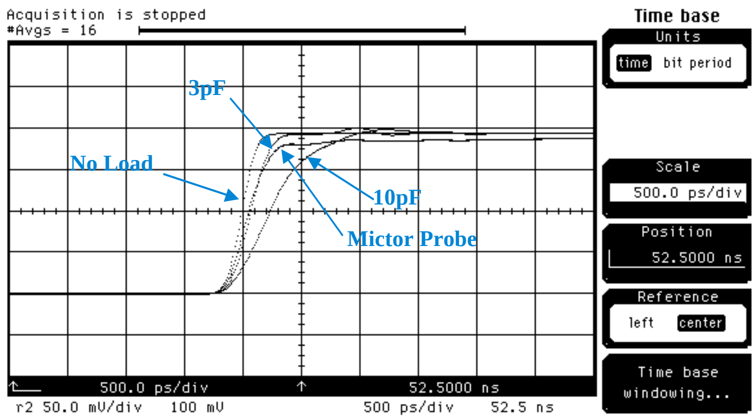
A TDR (Time Domain Reflectometry) measurement shows where impedance discontinuities are in your circuit, and also provides a measure of how big the discontinuity is.

This slide is a TDR (time domain reflection) measurement of a probe pin with no probe, and then with two different kinds of probes attached. Agilent uses TDR measurements to characterize and minimize impedance continuities of its probes in circuits. Large impedance discontinuities cause reflections and ringing on the measured bus. A well-designed probing system with high impedance will cause only minor impedance discontinuities and have little effect on the probed signals.

TDT Example: Mictor-based probe



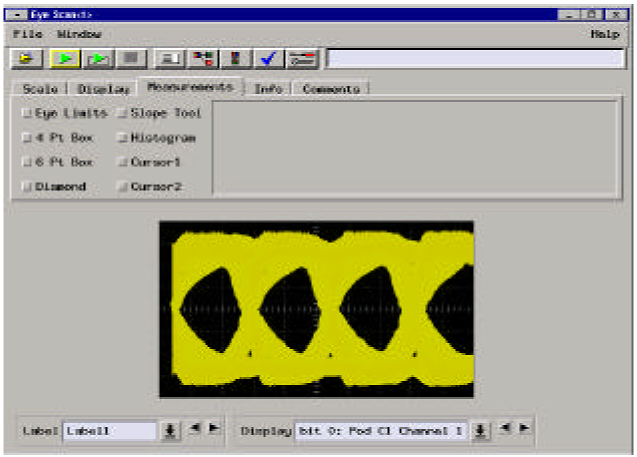
TDT measurements show you the net effect of impedance discontinuities on an edge transmitted through a net.

A TDT measurement (Time Domain Transmission) shows how an edge traveling through a net (or circuit) is affected by that circuit. In particular for probing systems, it shows how the loading (or impedance discontinuity) of the connector/probe system slows, dulls, or distorts the edges on a bus.

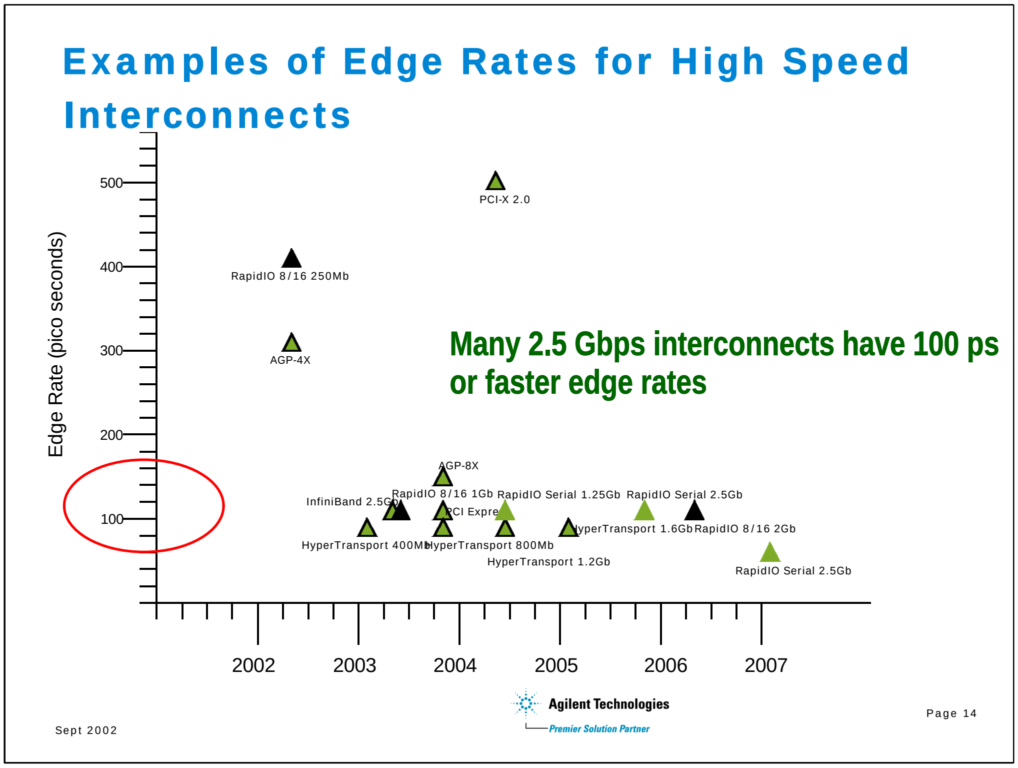
This slide shows a TDT measurement of a 250ps edge with no load, a 3pF load, and Mictor-probe, and a 10pF load. You can see that the mictor-based probe is very similar in effect to the 3pF load, so has a simplified loading of 3pF.

Why is a dulled or distorted edge significant in a logic analyzer probing system? Because it effects both the accuracy of the data captured by the logic analyzer, and the integrity of the data read by the receiver on the bus.

How Dulled Edges Close the Eye Diagram of a Bus



A closed eye may cause the receiver, logic analyzer, or both to capture incorrect data.



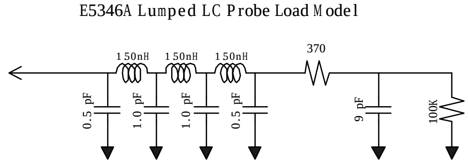
This slide shows the comparative edge rates represented by a number of cutting-edge bus standards. While 1 ns edges may have been typical in yesterday's and many of today's designs, many of tomorrow's designs will start requiring edge rats around 100ps. Among these are designs using new standard buses such as RapidIO, PCI Express, or HyperTransport. While edge rates and data rates are correlated, it's hard to establish a general relationship between the two, but you can see that 2.5 Gbps interconnects tend to have edge rates around 100ps.

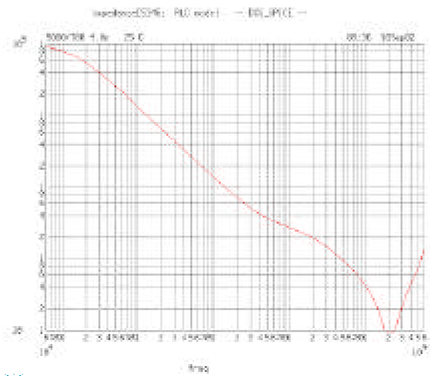
Faster edge rates enable higher bit rates, but also mean higher frequency content of designs. Connectors and probes that may have worked for slower edge rate systems often have unacceptably high loading that will slow edges, close data eyes, and cause the probed bus to cease working. Faster edge rates require probing systems design to measure higher frequencies.

Mictor-based Probe Model and Impedance Plot

Agilent E5346A

- **Simplified loading is 3p**
- **Appropriate for up to 600Mb/s signals**





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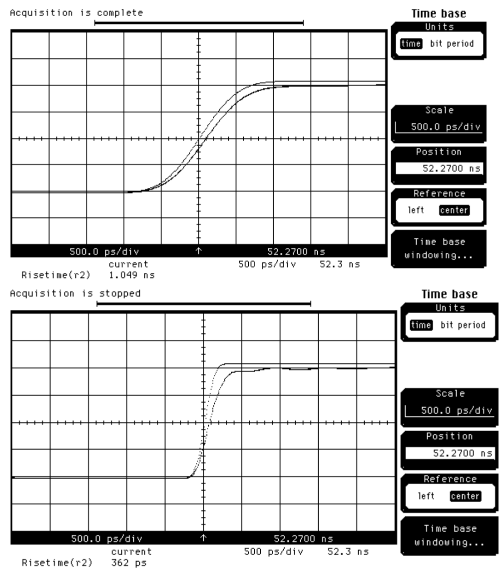
The first class of probes we will examine is the mictor-based probing system. Here you can see the impedance plot and load model of the probe and connector mounted on a typical target system. The simplified load is 3pF, as we saw earlier in the TDT plots.

Effect of Mictor-based Probes on Edge Speeds

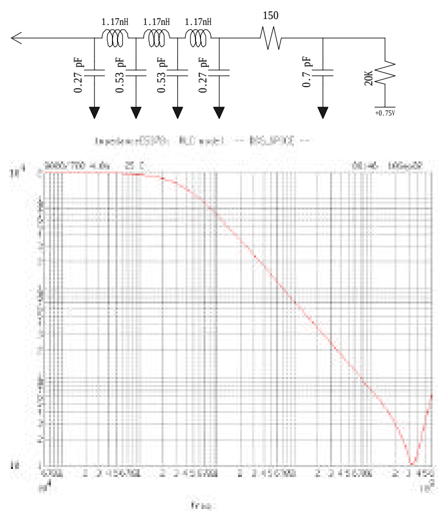
- A 1ns edge is only about 5% affected by a Mictor-based probe.

- A 250ps edge is unacceptably slowed by 45%. Edges this fast require the next class of probes.



Samtec-based Probe—Using Oscilloscope Probing Technology

Lumped LC Trans Line Model
4-5GHz off slighly, faster transient analysis



Agilent E5378A and E5379A

- Simplified loading is 1.5pf
- Appropriate for up to 1.5Gb/s signals

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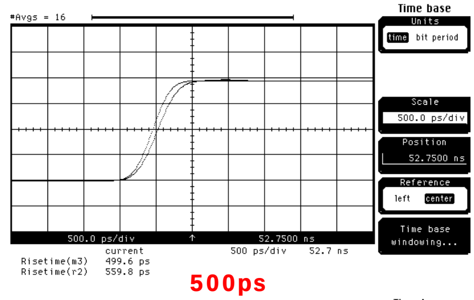
Agilent worked with connector vendors to identify a better connection solution that would address these problems. The result of that effort was the selection of a connector from Samtec.

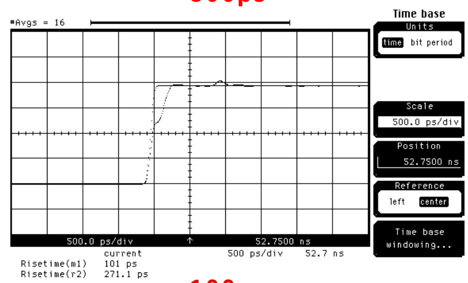
Effect of Samtec-based Probes on Edge Speeds

- A 500ps edge is about 10% affected by Samtec probes.



500ps

- A 100ps edge is 170% altered and requires a higher class of probe.



100ps

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What About Flying Lead Probes?

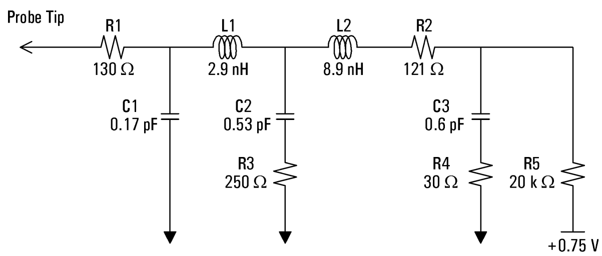
- **When connectors aren't possible.**
- **When you need to probe a few signals that aren't part of a bus group.**

Every engineer needs this in their back pocket. You can't plan for everything!

As an engineer you'd like to plan for everything, but that isn't always possible. If you don't have room on your target system for connectors, or weren't able to route some signals to connectors, you need a good general purpose probing solution. Flying leads give you the ability to probe almost anywhere around your target system to find the information you need.

General Purpose “Flying Lead” Probes

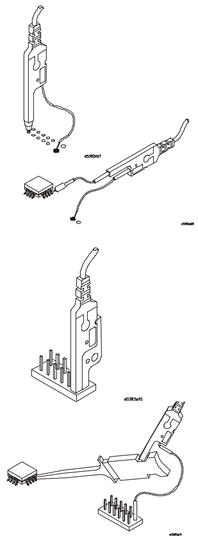
Agilent E5382A Flying Leads



E5382A Equivalent Load Model (w/ 130 Ohm Resistive Pin)

Flying Lead Probing Accessories and Loading

The same as Infiniium scope accessories!



Description	Lumped C	Maximum speed
130 Ohm Resistive Pin and Solder-down Ground Lead	1.3 pF	1.5 Gb/s
5cm Resistive Lead and Solder-down Ground Lead	1.5 pF	1.5 Gb/s
Flying Lead and Ground Extender	1.6 pF	1.5 Gb/s
Grabber Clip and Right-angle 2.0 pF Ground Lead	2.0 pF	600 Mb/s

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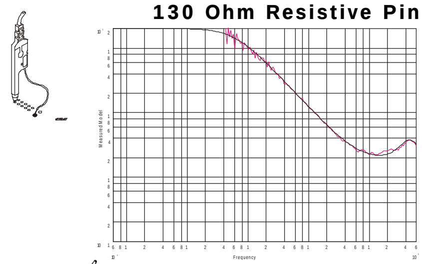
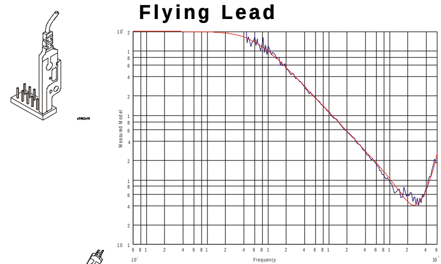
Impedance Plots of Flying Lead Accessories

Measured vs. Modeled 20k Impedance, 60 kHz to 6GHz plot

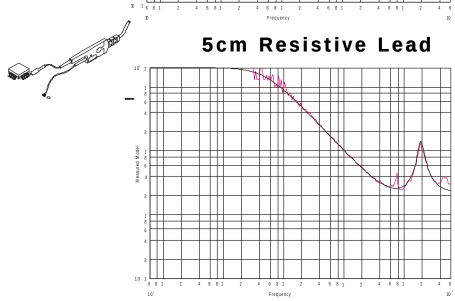
130 Ohm Resistive Pin



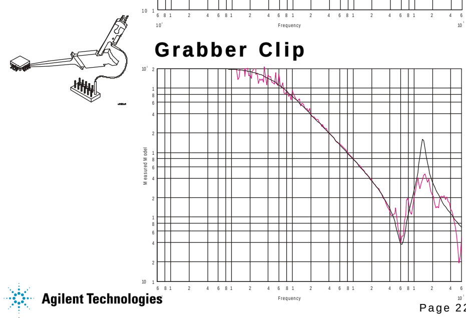
Flying Lead



5cm Resistive Lead



Grabber Clip



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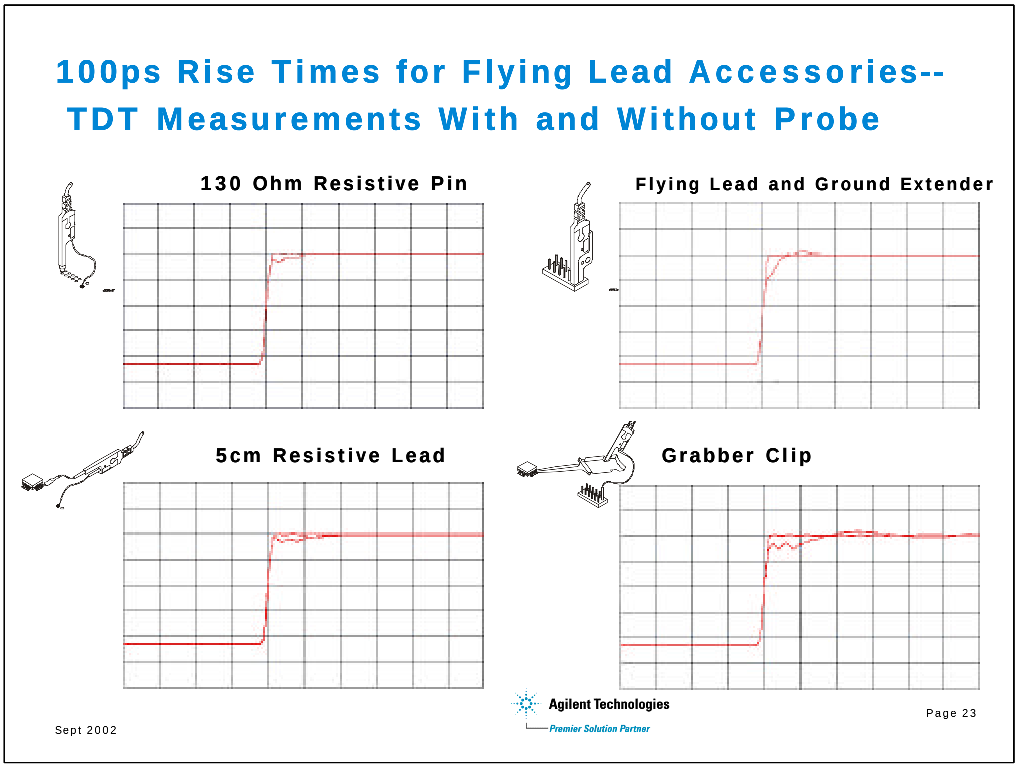
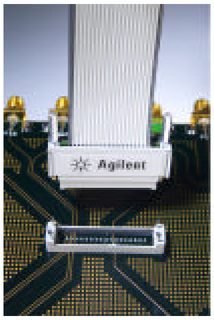
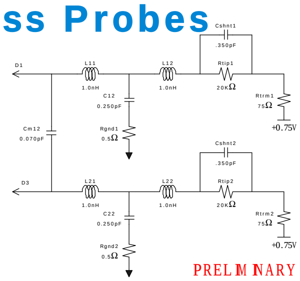
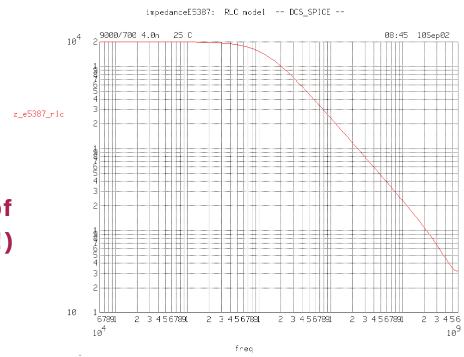


You can see that each type of flying lead accessory has a different affect on a 100ps edge. In general the affect is less than that of a Samtec probe.

Soft Touch Connectorless Probes



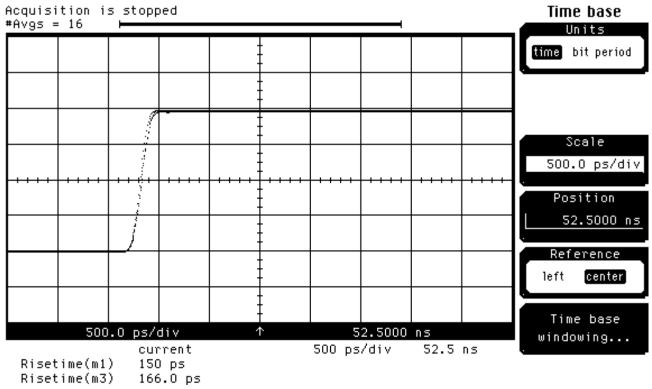




Agilent E5387A and E5390A Soft Touch Probes

- Simplified loading is <0.7pf (The lowest in the industry!)
- Appropriate for at least 2.5Gb/s

Effect of Soft Touch Connectorless Probes on Edge Speeds



TDT measurements of the soft touch probe show only about 10% dulling of a 150 ps edge.

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What Do You Look For in a Logic Analyzer Probing Connection?

- Low Signal Loading
- High Connector Density
- Low Clearance and Ease of Attachment
- Good Reliability

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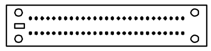
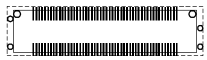
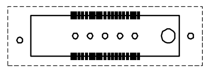
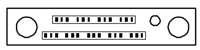
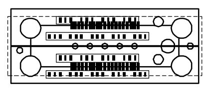
Probe Density Comparison Including Other Available Probing Technologies

Description	Scaled Drawing	# Signals Single-Ended	# Signals Differential	Density (channels/cm^2)	
Agilent Soft Touch		34	17	14/7	
Agilent Samtec		34	17	12/6	
Agilent and Other Mictor		34	N A.	10/N A.	
Compression		17	8 or 9	8/4 4/2	(no nut bar) (w/ nut bar)
Mictor->Compr		34	N A.	8/N A.	

Soft Touch and Samtec probes have the best signal density. Compression probes require the most board space.

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First let's compare density. For connecting to many signals, a mass probing scheme is usually desirable, as it yields the largest number of connections per unit area. This means you lay our your board to have some sort of connector or land pattern on it. Three mass probing systems are available today:

Probes based on Amp Mictor connectors are provided by both Agilent and Tektronix. The probe density is identical.

Agilent provides probes based on a Samtec 100-pin connector.

Tektronix recently introduced a system which uses elastomer-based compression probes, which do not require a mating connector on the PC board.

Tektronix has made public claims that this system provides the highest density. Let's examine that claim. On this slide we show to-scale drawings of the footprint for each probing system. The Tektronix footprints come from Tektronix's published manual, 071-1059-00.

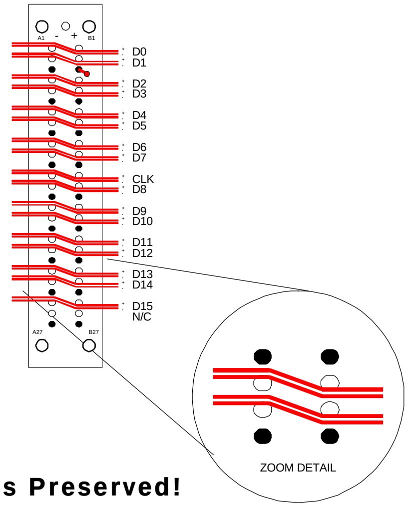
As you can see, the Tektronix compression probes require ~60% more board space on the top side of the board for the same number of connections as either alternative technology. One compression probe has in fact a slightly smaller footprint than either the Samtec or Mictor connectors, so if you only need to probe 17 signals, you save a bit of space with the Tek probe (~20% - 204 mm2 vs 252 mm2), at least on the top side of the board.

The last outline drawing illustrates the comparison in a very telling way. Tektronix offers an adapter to connect two of the elastomeric comression probes to a Mictor connector. As you can see from the drawing (taken from Tektronix' manual), the outline of the adapter is larger than the Mictor connector. The dimensions of the adapter footprint are dictated by the outlines of the two compression probes that it takes to make the same number of connections as the one Mictor connector.

However, the density story for the elastomeric probe gets even worse, as we'll see later.

Routing Affects Density and System Performance

Differential pair routing for soft touch probe footprint



Differential Pair Spacing is Preserved!

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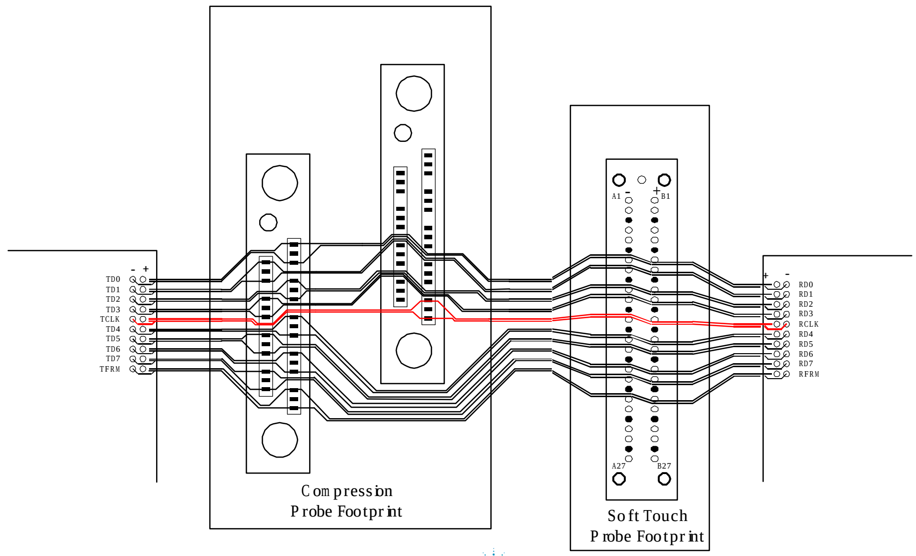
The routing of signals through a connector can affect the performance of the bus and the density of the connection. In this example, the suggested routing of differential pairs through the soft touch pads allows the designer to preserve the spacing of differential pairs and to add very minimal length to each trace.

RapidIO Interconnect—A Comparison of Soft Touch and Compression Probe Routing



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Here is a specific example of the routing of a RapidIO Interconnect. RapidIO is a differential bus with 8 data bits, a frame bit, and a clock. The compression probe requires a second connector for the clock, and splitting of each differential pair to route to the pads. A substantial amount of board space is used to route the signals through the connector, and each trace has some differences in path length, even some of the differential pairs.

The soft touch layout allows for a simple route-through of the pads and uses the least amount of board space.

Design Rules For Stubs to Connectors

Rule #1: NO STUBS.

Agilent has designed connectors so that if you place them on a bus, they'll work the first time.

If you can't route-through the connector:

#2. Keep stubs as short as possible.

- Try to keep stub length less than 20% of signal rise time.

#3. Keep stub impedance as high as possible.

- Keep stub impedance > target bus impedance.

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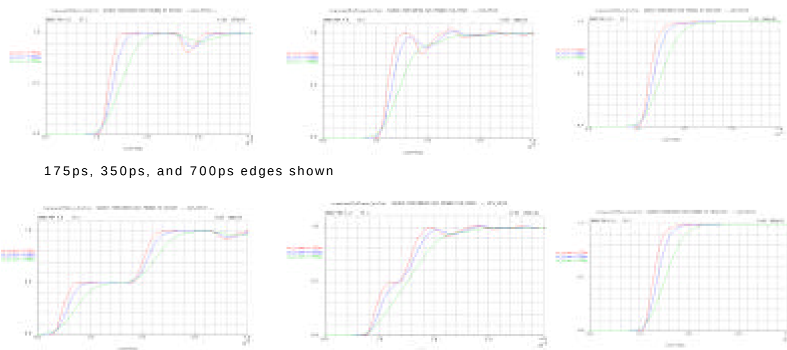
The first rule for designing in stubs to connectors is NO STUBS. If you remember nothing else from this presentation, I've succeeded. However, in many cases, stubs with some value of damping resistor can still yield a functional solution. It all depends on the timing and voltage margin in your circuit. Some simple calculations and rules of thumb will tell you if you're at least in the right ballpark for a starting point.

Where Should You Place Connectors on a Bus? Source-terminated Bus Example



It does make a difference. In general, connectors should be as close to the receiver as possible.

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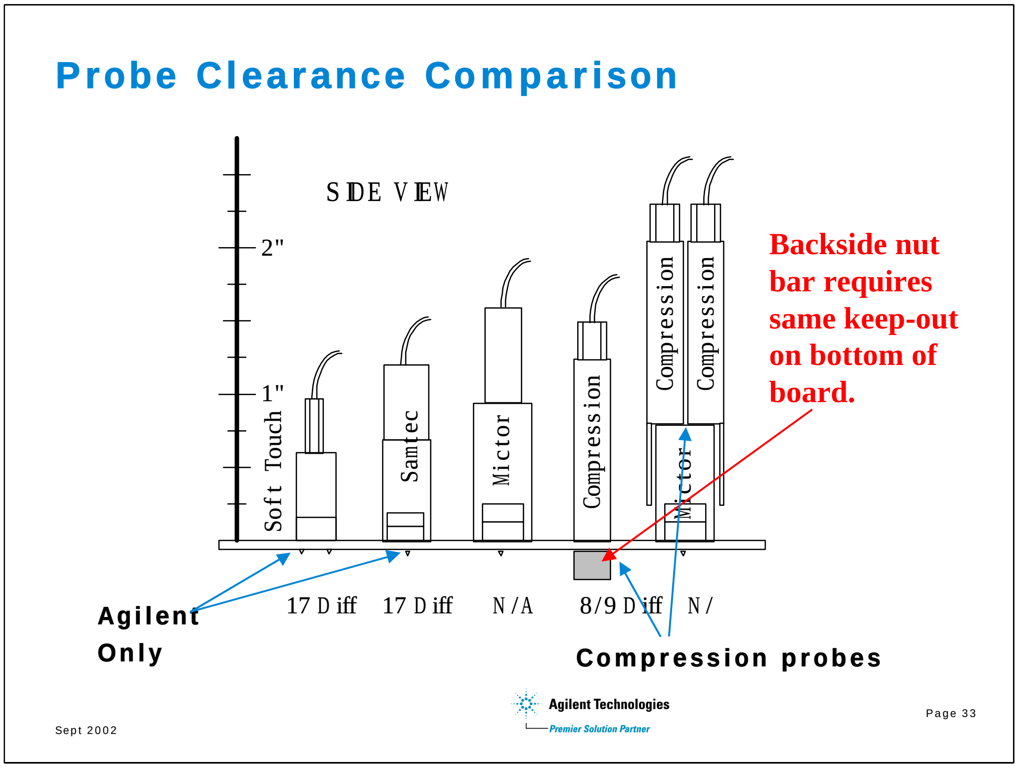
For a source-terminated bus, the only reasonable place to probe is at the receiver. This is because, on a source-terminated bus, the only place where the signal reaches full amplitude on the incident wave is at the receiver. The driver end of the transmission line doesn't reach full amplitude until the signal propagates to the receiver, is reflected back, and finally reaches the driver.

It does make a difference where you place the connector. There are some exceptions, but as a general rule placing the connector as close to the receiver as possible gives the best measurement results.

What Do You Look For in a Logic Analyzer Probing Connection?

- Low Signal Loading
- High Connector Density
- Low Clearance and Ease of Attachment
- Good Reliability



Now let’s look at clearance, how high the probes stick up above the circuit board. You can see that the lowest profile is achieved by the Agilent Samtec-based probes.

In this view, also note the back side of the board. If your board thickness is <0.093”, the compression probe requires a nut bar to be used on the back side of the board. The keepout area on the back side of the board for the nut bar is the same as the probe land keepout area on the top side of the board. Mictor-based probes and Agilent’s Samtec-based probes do not require any keepout area on the back of the board.

By the way, we agree that the nut bar is necessary for most boards. Impeccably planar boards are extremely important for this technique - as we found out years ago. Any bowing compromises the integrity of this connection.

Compare Ease of Attachment

Agilent Mictor and Samtec

One step:

1. Attach the probe to the connector

Agilent SoftTouch

Two steps:

1. Attach probe
2. Tighten screws

Compression Probe

Seven Steps:

1. Remove elastomeric protector
2. Clean board using alcohol
3. Dry board with nitrogen
4. Clean probe using alcohol
5. Dry probe with nitrogen
6. Insert nut bar through board from back side
7. Torque screws to 1 in-lb.

Repeat for every 17 channels

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Now let's move on to compare ease of attachment. The compression probes require the above steps each time they are connected. And keep in mind, it takes twice as many compression probes to connect the same number of signals, so you get to go through those steps more often.

The Mictor, Samtec, and Soft Touch probes have a very easy and reliable connection method so you can be up and running more quickly and easily. You shouldn't need a PhD in probing to get your measurements working.

What Do You Look For in a Logic Analyzer Probing Connection?

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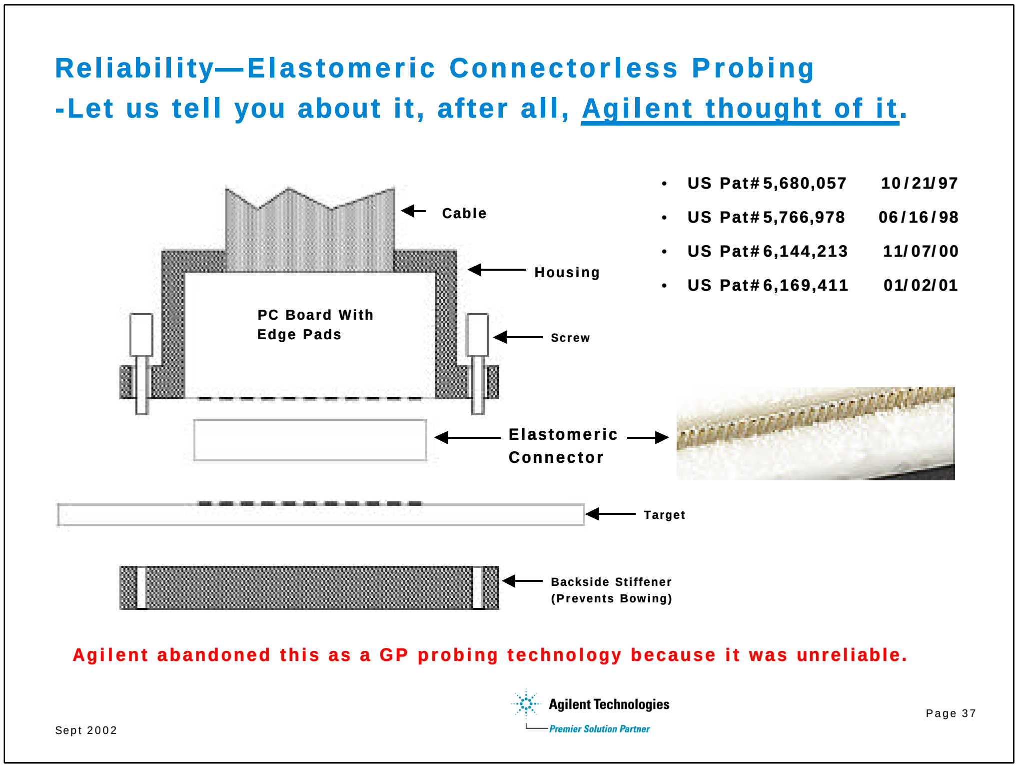
Agilent is always looking for improvements in probing technology, because we realize that probing is not and never will be "ideal," and is therefore always open to improvement. Agilent has conducted very serious investigations at various times into elastomerics (among many other alternatives) as a probing technology. We are aware that the technology of elastomerics is improving and evolving, so we have frequently reviewed and investigated this technology. Our conclusions have been that we don't feel sufficiently confident in the reliability of elastomeric connections to pass that risk on to our customers. Elastomeric probes also typically require gold-plating of contacts, an expensive process not available on all production lines.

Agilent has in fact a wealth of experience with elastomeric connectors in other applications, so we speak as experts.



There are applications where elastomeric probing <u>does</u> make sense. It's used in cell phone key pads, for example, with gold plated contacts. As cost conscious as those manufacturers are, they certainly wouldn't use gold unless it was absolutely necessary.

Agilent has used elastomeric connections for mass probing the legs of QFP packages where mechanical conformity is required. In that example we know that what we're connecting to is rigid and planar because the package is specified that way.

Reliability – Soft Touch Technology

Compliant – not sensitive to planarity

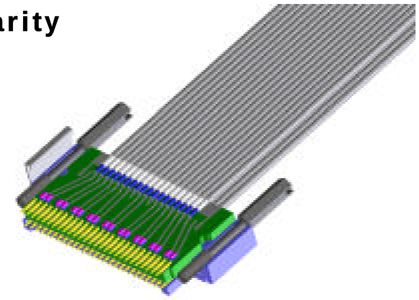
- **No stiffener required**

Not sensitive to contamination

- **No special cleaning required**

Durable

- **No consumable parts**



Technology designed originally for critical medical applications

- **Extensive abuse testing**

Soft Touch probes are good for 100s of insertions, vs. 10s of insertions for elastomeric compression probes. (Samtec probes are good for 1000s of insertions.)

Summary: What Do You Look For in a Logic Analyzer Probing Connection?

- **Low Signal Loading**
- **High Connector Density**
- **Low Clearance and Ease of Attachment**
- **Good Reliability**

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To Summarize, the first thing you need in logic analyzer probing is low signal loading to ensure that you can make accurate measurements of your signals.

The second thing you look for is high connector density so you use the least amount of board space to probe your signals. Related to that, you want connectors that are easy to route-through and that don't add unnecessary length to your bus.

The third thing you should look for is a low clearance and ease of attachment. Many card cage designs require low-clearance probing systems to allow measurements on installed cards.

In general, you want to spend your time making measurements not debugging your probe attachment, so you want a reliable connection that will last as you move it to different target boards.

Probing Comparison Summary

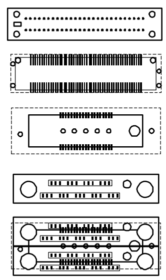
Probing Technology	Total Loading	Maximum Speed	Density (channels/cm^2) (SE/diff)	Ease of Connection
Soft-Touch Connectorless	< 0.7 pF	>2.5 Gb/s	14/7	Easy (Must design-in)
Samtec	1.5 pF	1.5 Gb/s	12/6	Easy (Must design-in)
Mictor	3 pF	600 Mb/s	10/N.A.	Easy (Must design-in)
Flying Lead	1.3 – 2.0 pF	1.5 Gb/s to 600 Mb/s	N.A.	Harder (No design-in required)
Elastomeric Compression	0.7 pF	>1.25 Gb/s	8/4 (No nut bar) 4/2 (w/nut bar)	Harder (7-step process, must design-in)
Mictor to Compression Adapter	>3 pF	600 Mb/s	8/N.A.	Easy (Must design-in)

Here’s a chart that summarizes some of the key characteristics of each probing technology.

Summary

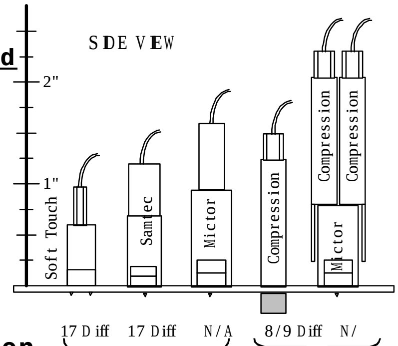
Description	Channels/cm² (SE/Diff)
Agilent Soft Touch	14/7
Agilent Samtec	12/6
Mictor	10/N A.
Compression	8/4* 4/2+
Mictor to Compression Adapter	8/N A.

TOP VIEW



*No nut bar
+With nut bar

Density and Clearance



Ease of Connection

Agilent's Way: Plug & Test!

The other way—7-steps

Loading

Mictor	3 pF
Samtec	1.5 pF
E5382A Flying Leads	1.5 pF
Compression	0.7 pF
Soft Touch	< 0.7 pF

TDT Test on 200 ps edge.
Agilent specs include pads, pins, & probe.

Reliability

Agilent designs
highly reliable
probing technologies

Resources

For more information see the following:

- Probing Solutions for Logic Analysis Systems
  http://cp.literature.agilent.com/litweb/pdf/5968-4632E.pdf
- Designing High Speed Digital Systems for Logic Analyzer Probing:
  http://cp.literature.agilent.com/litweb/pdf/5988-2989EN.pdf
- E5382A Flying Lead User's Guide:
  http://cp.literature.agilent.com/litweb/pdf/E5382-97000.pdf
- Soft Touch Probe Design Guide:
  http://cp.literature.agilent.com/litweb/pdf/E5387-97001.pdf
- Your Agilent AE for consulting on probing issues.