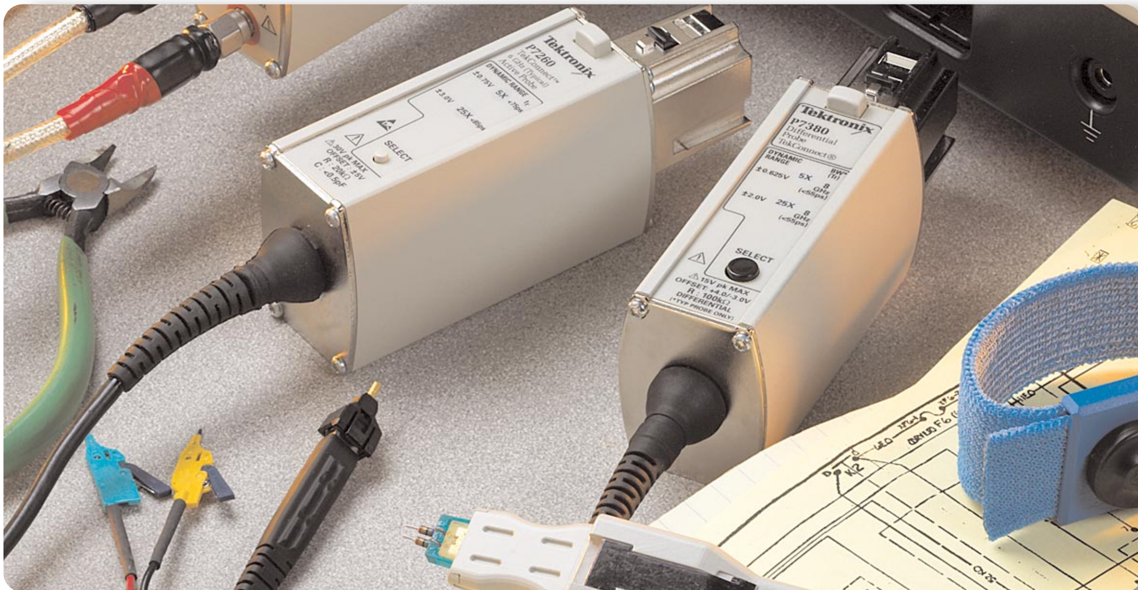
Z-Active™: A New High Performance Probe Architecture



A probe is a critical element in an oscilloscope measurement system. An oscilloscope probe provides the physical and electrical connection to the circuit under test. It also buffers and conditions the signal for the oscilloscope channel input. Increasing signal speed for digital communications has placed new demands on probe electrical performance. Decreasing circuit dimensions and the increasing use of differential signaling have also placed new demands on probe attachment performance. The P7380 active differential probe has been designed to meet these market needs for increased probe performance. The P7380 probe employs a new probe architecture that provides improvements in electrical performance, both increased measurement fidelity and reduced probe loading. The new P7380 probe design also provides improvements in probe physical attachment, allowing greater flexibility and more cost effective and reliable physical interconnects.

Introduction to the New P7380 Probe

The P7380 is an active differential probe with the electrical performance to provide measurement fidelity for the latest multi-Gbps differential signaling applications. The electrical banner specifications for the P7380 probe are listed below:

– Bandwidth (probe only)	> 8 GHz
– Risetime (10%-90%)	< 55 ps
– Risetime (20%-80%)	< 35 ps
– Attenuation	5X/25X selectable
– Differential Mode Input Range	±0.625 V (5X) ±2.0 V (25X)
– Input Operating Voltage Range	+4.0 V to –3.0 V
– DC Input Resistance	100K ohm differential
– AC Loading	Z_{MIN} > 300 ohm (differential)
– CMRR	> 50 dB to 1 MHz > 35 dB to 800 MHz > 20 dB to 8 GHz
– Noise	< 30 nV/√Hz (5X) < 75 nV/√Hz (25X)

The P7380 probe also provides a flexible tip structure for a variety of probe tip attachment methods. The P7380 probe tip mechanical design provides for both versatile and reliable probe interconnects at a reasonable cost.

The picture of the P7380 probe in Figure 1 shows that it was designed with a physically small probe head for improved physical attachment to fine pitch components, small diameter vias, and narrow circuit board traces. The picture also shows that the small probe head is attached to the probe tip amplifier with a pair of flexible extension cables. The combination of a physically small probe head and flexible extension cables enables attachment of the P7380 probe to circuit connections in physically confined locations that would be impossible with more conventional probes. The probe tip amplifier is connected to the P7380 probe control box with a lightweight conventional cable assembly that provides communication and power to the probe amplifier, as well as a high-speed signal interface to the attached oscilloscope. The patented TekConnect interface is used at the P7380 probe control box to provide excellent signal fidelity over the full probe bandwidth and intelligent control of probe features from the attached oscilloscope.

▶ **Figure 1.** *P7380 Probe.*

The decreasing size of circuit components and the transition to high speed differential signaling have required an increase in physical connection options beyond the traditional fixed probe input pins. Requirements for probe physical connections now include solder-down connections, handheld adapter connections with variable spacing control, fixtured connections using articulated probe arms, and even coaxial connections (see P7380SMA Probe sidebar). The P7380 probe supports a variety of different physical connection options with its family of Tip-Clip™ adapters.

The P7380 probe head features a pair of button contacts for signal interconnect. The physical interconnect between these button contacts and the circuit nodes being probed is made using a Tip-Clip adapter like that shown in Figure 2. The Tip-Clip adapter snaps into place on retention features molded into the P7380 probe head. The Tip-Clip adapter is designed to provide a high performance, yet economical, probe attachment interface. The solder-down Tip-Clip adapter shown in Figure 2 has a pair of mini-axial lead resistors embedded in a non-conductive elastomer to connect the circuit signals to the probe head button contacts. Other Tip-Clip adapters use embedded flex circuits of varying lead length to extend the distance between the probe head and the soldered resistors, with little loss of electrical performance even for the longest length flex circuit. The handheld adapter (P7380HHA) for the P7380 probe can also be considered a form of Tip-Clip adapter, since the P7380 probe head is captured in the handheld adapter clamshell structure and includes embedded damping resistors in the variable spacing pin connections.

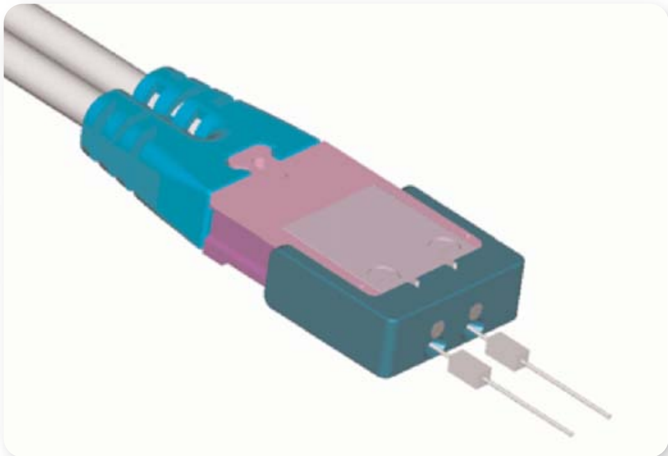


Figure 2. *Solder-Down Tip-Clip Adapter.*

It might be expected that the electrical performance of the P7380 probe would be degraded by the addition of the 2.4 inch long probe head extension cables. Adding that much length to the input signal path of a conventional active probe would ordinarily cause serious signal fidelity problems, particularly with a very high bandwidth probe like the P7380. The new

P7380SMA Probe

Digital data transmission is undergoing a transition from parallel data bus architectures to serial data channel architectures. New serial data standards, such as PCI Express and Infiniband, define point-to-point communication with high-speed differential signaling, where clock timing is essentially embedded in the data stream. The physical layer test requirements for these new serial data standards define compliance test points at which system level interface testing must be performed. To ensure interoperability between system components from different vendors, compliance tests are performed to verify amplitude, timing, and jitter performance. Some of these physical layer compliance tests require the serial data link to be broken and terminated by the measurement interface, which is typically a 100 ohm differential termination. For the most reliable measurement connection, many compliance tests are performed with compliance load boards or breakout boards, which are populated with SMA connectors in the signal paths.

P7380 probe architecture, however, has been designed to split the probe attenuator between the probe head assembly and the probe tip amplifier assembly. The P7380 probe architecture includes the extension cable as a circuit element between the probe attenuator series elements in the probe head assembly and the probe attenuator termination elements in the probe tip amplifier assembly. The design of the new P7380 probe architecture will be examined more fully after reviewing several more conventional probe structures that are utilized in a novel way in the new probe architecture.

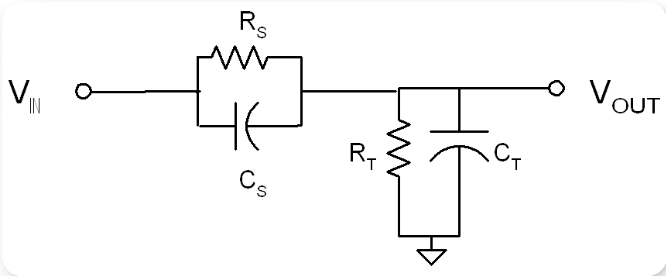


Figure 3. *Compensated Attenuator.*

Perspective—The Compensated Attenuator

The fundamental circuit structure used in both conventional active and high-resistance passive probes is the compensated attenuator. The compensated attenuator is shown in its simplest form in Figure 3. An input attenuator structure is used on probes both to increase dynamic range and to reduce probe loading on the circuit-under-test. A probe input attenuator increases dynamic range by dropping a fixed percentage of the input signal across the attenuator series elements. The attenuated signal is then passed on to the probe and oscilloscope amplifiers, having been reduced by a calibrated attenuation factor. A probe input attenuator reduces the probe loading by isolating the input from loading factors inherent in the probe structure and oscilloscope input.

The P7380SMA probe has been designed specifically for use in serial data compliance testing. The key specifications for the P7380SMA probe are listed below and are similar to the P7380 probe, but also show some differences, primarily due to the P7380SMA probe's low impedance termination input.

– Bandwidth (probe only)	> 8 GHz
– Risetime (10%-90%)	< 55 ps
– Risetime (20%-80%)	< 35 ps
– Attenuation	2.5X/12.5X selectable
– Differential Mode Input Range	0.625 Vpp (2.5X) 3.0 Vpp (12.5X)
– Common Mode Input Range	±2.5 V
– DC Input Resistance	100 ohm differential
– Return Loss	> 27 dB to 5 GHz > 20 dB to 8 GHz
– CMRR	> 50 dB to 100 MHz > 35 dB to 1 GHz > 20 dB to 5 GHz > 15 dB to 8 GHz
– Noise	< 13 nV/√Hz (2.5X) < 40 nV/√Hz (12.5X)
– Termination Voltage Range	±2.5 V
– Termination Voltage Modes	AUTO/INT/EXT selectable
– Auxiliary (inverted) Output	

The P7380SMA probe includes a differential SMA input interface with a special 1 meter long, flexible cable assembly that has guaranteed probe performance at the cable assembly SMA input connectors. The P7380SMA cable assembly has been designed with differential signal skew < 1 ps and has a cable loss characteristic that is compensated by a pre-emphasis network in the probe amplifier. The use of an SMA connector interface and a high quality 50 ohm input termination network provides a reliable, repeatable measurement interface for the P7380SMA probe.

In the case of a passive probe, although the attenuator will increase the probe dynamic range, the attenuator is used primarily to reduce the loading effect of the relatively large probe cable capacitance. The passive probe cable capacitance is the primary contributor to the attenuator shunt capacitance, C_T (Figure 3). The attenuator series capacitance, C_S, in the probe tip structure reduces the effect of the shunt capacitance, C_T, by the attenuation factor, $(1+C_T/C_S)$. For example, the attenuator in a 10X passive probe will reduce 100 pF of cable capacitance to only 10 pF at the attenuator input. The DC loading of a passive probe is also reduced, from 1M ohm to 10M ohm in a typical passive probe design.

In the case of an active probe, a buffer amplifier follows the compensated attenuator to drive the signal down the probe cable. Although the attenuator in this case will reduce the effect of the probe buffer amplifier input capacitance, the attenuator is used primarily to increase the limited dynamic range of the buffer amplifier. The linear dynamic range of an active probe is largely limited by probe power supply voltages which are selected to avoid transistor breakdown, and for thermal management control. Although the probe buffer amplifier input capacitance does contribute to the attenuator shunt capacitance, C_T, parasitic capacitance in the attenuator structure itself tends to dominate the effective probe input capacitance, especially for very high bandwidth probes. Although an active probe input capacitance is much smaller than a passive probe input capacitance, the AC loading of an active probe must also be much smaller than a passive probe, because it is used for higher frequency probing. The attenuator input resistance is also generally lower in value in an active probe than a passive probe.

An understanding of the compensated attenuator structure is helpful in understanding the P7380 probe

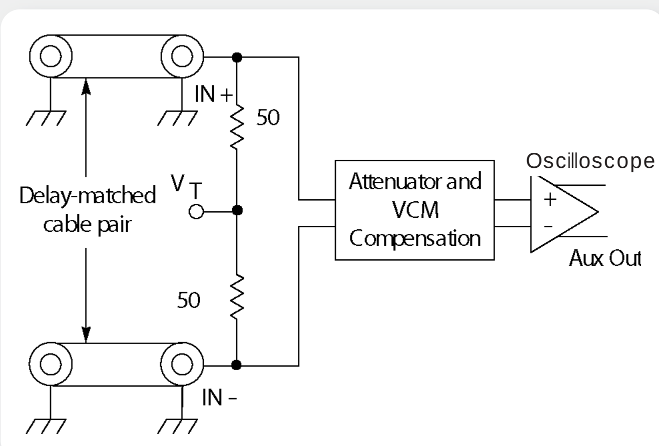


Figure A. *P7380SMA Probe Termination Network.*

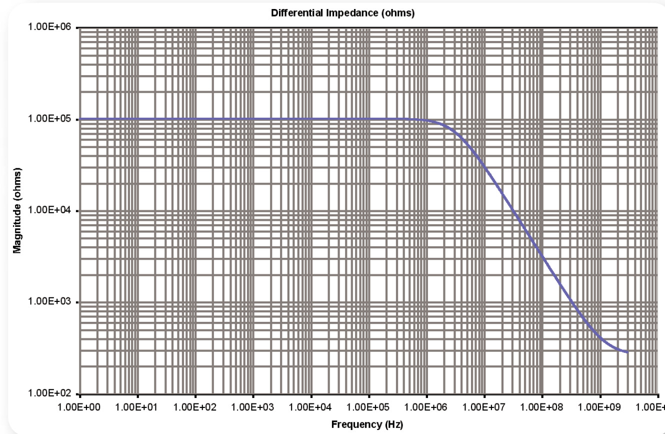
The P7380SMA probe also provides the flexibility of an adjustable termination voltage at the common mode node between the two 50 ohm input termination resistors as shown in Figure A. The P7380SMA probe termination voltage can be adjusted to match the input signal common mode voltage for minimum DC loading on the input signal. The termination voltage AUTO mode is designed to automatically set the termination voltage to this minimum DC loading condition. The termination voltage can also to varied either under internal or external control to stress test the input signal driver or set the termination to a required pull-up or pull-down value.

The P7380SMA probe also introduces a valuable new probe feature, an Auxiliary Output. The Auxiliary Output provides an independent, buffered output signal from an SMA connector on the probe amplifier housing. Although the Auxiliary Output is attenuated by the selected probe attenuation factor and has an inverted signal polarity, it quite closely matches the probe main output signal performance. The Auxiliary Output can be used, for example, as a sampling oscilloscope trigger signal or clock recovery module input. It could also be used as the input signal to a spectrum analyzer or other 50 ohm input measurement instrument to measure something other than the time domain response of the probed signal.

architecture. The key performance characteristics of the compensated attenuator network are gain and input impedance. Constant probe gain with frequency is one of the main contributors to measurement fidelity. Input impedance, which generally varies with frequency, is what determines probe loading. Attenuator gain is ideally constant from DC to the highest signal frequency component in order to preserve probe measurement fidelity. For an active probe, where a unity gain buffer amplifier follows the input attenuator, the probe amplitude performance is typically specified by gain accuracy at DC and by bandwidth, which indicates gain rolloff with frequency. Bandwidth is defined as the frequency at which the probe gain has dropped by 3 dB from the gain measured at DC. Although the DC gain accuracy may indicate gain error of only a few percent, it should be understood that the 3 dB bandwidth represents about a 30% gain reduction in the measured signal amplitude. That is the primary reason that a probe with as high a bandwidth as possible should generally be used, since the signal gain error of a probe will typically be smaller for signal frequency components well below the specified probe bandwidth.

The ideal frequency response of a 5X compensated attenuator, for example, should show a constant gain factor of –14 dB, including the region near the LF breakpoint frequency [$F_{BKPT} = (1/2\pi R_S{*}C_S) = (1/2\pi R_T{*}C_T)$]. The LF breakpoint frequency for a compensated 5X attenuator with R_S = 40K ohm, C_S = 0.25 pF, R_T = 10K ohm, and C_T = 1 pF, is about 16 MHz. If the attenuator is not properly compensated, the frequency response plot will show either peaking if $C_S > C_T/(AF-1)$ or a premature rolloff if $C_S < C_T/(AF-1)$. [Note: AF is defined here as the resistive attenuator factor, $AF = (1 + R_S/R_T)$].

The ideal pulse response of a compensated attenuator should have a fast rise time without a peaked or overly damped response. If the attenuator is properly compensated, the output pulse response will be an attenuated, but flat, version of the input pulse. If the attenuator is not compensated properly, at the input pulse edge, the output pulse response will either overshoot the level of the resistive attenuation factor or not rise to that level. If the attenuator is peaked, the voltage will rise initially above the resistive attenuation factor level and then decay exponentially to that level with a time constant equal to $(R_S+R_T){*}((C_S{*}C_T)/(C_S+C_T))$. Similarly, if the attenuator is over damped, after rising to the damped step level, the voltage will rise exponentially to the resistive attenuation factor level with the same time constant as in the peaked case.



▶ **Figure 4.** *Compensated Attenuator Input Impedance Frequency Response.*

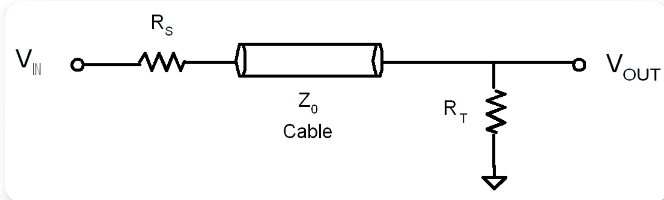
A plot of input impedance variation with frequency for the compensated attenuator is shown in Figure 4. The compensated attenuator input impedance follows the equation:

$Z_{IN}(\omega) = (1/(j\omega C_S + 1/R_S)) + (1/(j\omega C_T + 1/R_T))$

The input impedance at DC has the highest value and is constant from DC to the LF breakpoint frequency. In this low frequency region, the impedance of the attenuator bridging capacitors is much larger than the attenuator resistors, giving an input impedance, $Z_{IN} = R_S + R_T$. At the LF breakpoint frequency, $\omega_{BKPT} = (1/R_S{*}C_S) = (1/R_T{*}C_T)$, the impedance of each bridging capacitor has dropped to match its associated attenuator resistor, which reduces the probe Z_{IN} by 3 dB (about 30%).

For frequencies above the LF breakpoint frequency, the input impedance drops at 20 dB/decade. If the simple model were valid, the input impedance of the compensated attenuator probe would continue to drop until it reaches zero. A real world model, however, must include probe parasitics that can dramatically alter the probe input impedance. A real world model would include lead inductance, both that internal to the probe and that external in the interconnect to the circuit. To be complete, it should also include parasitics associated with the probed circuit network itself. Lead inductance tends to resonate with the probe input capacitance and, although it may increase the probe input impedance, tends to cause undesirable ringing in the measured signal response. In order to reduce ringing in the compensated attenuator probe response, a more complete compensated attenuator model should include an input damping resistor.

One common measure of probe input impedance at high frequencies is input capacitance. The input capacitance of the simple compensated attenuator probe model is the series combination of C_S and C_T: $C_{IN} = (C_S * C_T) / (C_S + C_T)$. A more complete measure of probe input capacitance must include probe tip lead capacitance. Although input capacitance does give some measure of probe loading at high frequencies, it is not as complete as a plot of measured input impedance with frequency, which includes damping resistance. An input damping resistor is small relative to the compensated attenuator resistor values, but will interact with the attenuator capacitors at high frequencies. The input damping resistor serves to limit how low the probe input impedance drops at high frequencies and helps to damp out resonance problems due to lead inductance. Although the addition of a probe damping resistor to the compensated attenuator probe input can dramatically help probe performance, it is not a cure-all. Even with a probe damping resistor in place at the probe tip, the addition of excessive probe lead length at the probe attachment point can still result in resonant circuit effects. This is particularly true for sub-100 ps signal edge rates.



▶ **Figure 5.** *Z_0 Probe Attenuator.*

Perspective—The Z_0 Probe

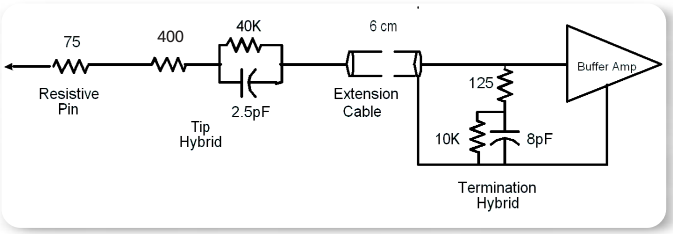
An alternative probe architecture to the compensated attenuator that is sometimes used for probing high frequency circuits is the Z_0 probe. The Z_0 probe name refers to the presence of an embedded transmission line in the probe attenuator structure. The Z_0 probe is also called a resistive-divider probe or a low impedance passive probe, both terms that also describe the basic probe structure. As shown in simple form in Figure 5, the Z_0 Probe attenuator is a resistive divider formed from an input series resistor, R_S, and a low loss coaxial cable that is terminated by a shunt termination resistor, R_T. In the most common measurement configuration, a high bandwidth oscilloscope channel input impedance serves as the Z_0 Probe termination resistance. The characteristic impedance, Z_0, of the coaxial cable is selected to match the 50 ohm input impedance of the high bandwidth oscilloscope channel, which provides a broadband, constant impedance termination for the resistive divider. Setting the series resistor, R_S, to 450 ohms results in a 10X resistive divider and a 500 ohm probe input impedance. Because of its passive structure, including the use of a coaxial cable with a broadband frequency response, a Z_0 probe can be designed for very high bandwidth performance without suffering the gain rolloff of an active buffer amplifier. Although a 500 ohm input impedance is much lower than the DC resistance of a typical active or passive compensated attenuator probe, the impedance is constant over a broad frequency range, not rolling off above a few MHz like the compensated attenuator.

The attenuation factor of the Z_0 probe model can be calculated as a simple resistive divider because the input impedance of the terminated cable transmission line equals the 50 ohm termination resistance from DC to a multi-GHz frequency limit. Because of the terminated cable topology, the primary effect of the Z_0 probe cable is to simply delay the input signal with minimal distortion. For a 10X Z_0 probe, the attenuation factor, AF, equals $(R_S + R_T) / R_T = (450 + 50) / 50 = 10$. The simple Z_0 probe model does not include parasitic components that ultimately result in probe gain rolloff at very high frequencies.

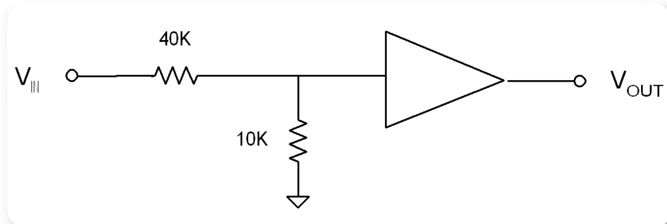
One of these parasitic components that is often specified for a Z_0 probe is the probe input capacitance. The input capacitance of a Z_0 probe includes contributions from both bridging capacitance across the input series resistor, R_S, as well as parasitic lead capacitance from the probe tip connection structure. The Z_0 cable capacitance has little effect on the probe input capacitance because the cable is terminated with a broadband resistive termination. The bridging capacitance will peak the probe gain at high frequencies as it shorts out the attenuator divider series resistor. Conversely, parasitic lead capacitance will tend to reduce the amount of signal reaching the divider, which effectively reduces probe gain at high frequencies. Another parasitic effect that can affect gain rolloff is cable loss, due to both skin effect and dielectric losses. A well-designed Z_0 probe will attempt to compensate for these gain variations at high frequency by balancing the peaking and roll off effects. A final parasitic effect that can affect Z_0 probe performance at very high frequencies is the VSWR of the oscilloscope channel input. If the oscilloscope input is not a perfect termination, then input signal reflections at the oscilloscope input will propagate back down the probe cable, reflect at the probe head series resistor mismatch, propagate down the cable again, and finally be displayed as a reflection artifact on the oscilloscope channel display.

The relatively low input impedance of a Z_0 probe can unfortunately affect the gain accuracy of probe measurements. The attenuation factor of the 10X Z_0 probe calculated from the resistive divider model may not include the effect of the signal source impedance. For a typical high frequency signal impedance of 25 ohms, which represents a terminated 50 ohm transmission path driven by a 50 ohm signal source, the gain error due to probe loading is about –5%: Gain Error = ((500 / 525)-1). This gain error can be compensated by reducing the series input resistor by the size of the signal source impedance, if the signal source impedance is known. Although the compensated attenuator probe experiences similar and often worse gain errors at high frequency, as its input impedance rolls off, its DC loading is much lighter. The input impedance of the Z_0 probe, however, is low even at DC. Because of the heavy probe loading at DC, the Z_0 probe may cause signal source problems in some applications. For signal sources with either a large DC common mode voltage or that are unable to drive a low DC input load, significant signal distortion may result.

Although the Z_0 probe input impedance is relatively constant from DC to GHz frequencies, the effect of probe parasitics eventually rolls off the input impedance. If properly designed, the input capacitance of a Z_0 probe can be made quite small, on the order of 0.1-0.2 pF. Measurement of this small capacitance, however, generally requires special fixturing to minimize parasitic probe tip lead capacitance. If care is not taken to minimize ground lead length in making connection to circuit nodes with a Z_0 probe, the probe input impedance may decrease and probe bandwidth may be significantly reduced. Although input connection lead length can degrade probe performance, the primary resistor input of a well designed Z_0 probe helps to minimize this problem. Compared to a compensated attenuator probe, a Z_0 probe exhibits a more damped response and tends to be less sensitive to longer probe input connection lead length.



▶ **Figure 6.** *Z-Active Probe Architecture (P7380 Probe).*



▶ **Figure 7.** *P7380 Probe Simplified DC Model.*

The New P7380 Z-Active Probe Architecture

A simplified schematic of the new Z-Active probe architecture used in the P7380 probe is shown in Figure 6. The Z-Active probe architecture is more complex than the compensated attenuator and Z_0 probe architectures, because it is a combination of both those structures. In the P7380 probe design, the Z-Active architecture acts like a compensated attenuator for signal frequencies from DC to about 160 MHz. For signal frequencies above 160 MHz, up to the 8 GHz bandwidth of the P7380 probe, the Z-Active architecture acts like a Z_0 probe. This combination of characteristics from the more traditional compensated attenuator and Z_0 probe architectures is the key to the improved electrical performance of the Z-Active architecture. The Z-Active architecture electrical performance enables the P7380 probe to have reduced high frequency probe loading and excellent measurement fidelity. The Z-Active architecture also supports improved performance for probe attachment to fine pitch components and signal traces with its split attenuator and extension cable structure. While not a fundamental part of the Z-Active architecture, the innovative Tip-Clip design for the P7380 probe contributes to improved ease of use and cost effectiveness in probe attachment.

In order to better understand the Z-Active probe architecture, a sequence of simplified P7380 probe models will be presented that are valid over different frequency ranges. To simplify the analysis of the probe network, only the positive half of the probe input structure will be shown in the following models. If should be understood that a matching negative half probe input structure is actually present in the complete P7380 differential probe model. The simplified DC model of the P7380 probe in Figure 7 is a simple 5X resistive divider, formed by the high value attenuator resistors. At DC the bridging capacitors across the 40K and 10K attenuator resistors in Figure 6 can be considered open circuits and removed from the probe network. At DC the extension cable can be replaced by a simple wire connection, since any resistance in the extension cable coaxial center conductor is negligible compared to the high value attenuator resistors. Similarly, the 75 ohm Tip-Clip damping resistor, the 400 ohm probe input series resistor, and the 125 ohm extension cable termination resistor are small enough relative to the attenuator resistors to be ignored and are also replaced by wire connections. The 100K ohm differential input resistance of the P7380 probe provides a very light DC probe load for the measured signal source. Since some popular serial data sources, CML for example, have a much higher DC common mode voltage than differential mode voltage swing, a light DC probe load helps to minimize possible signal distortion due to common mode bias loading.

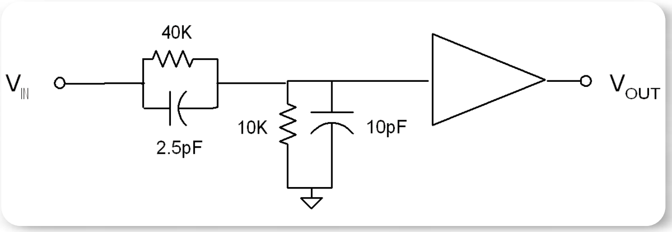


Figure 8. *P7380 Probe Simplified LF Model.*

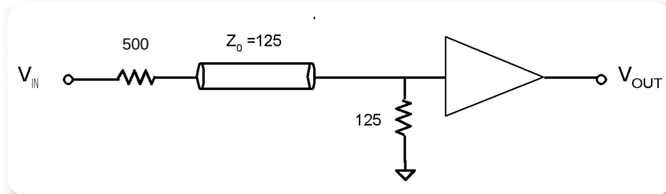


Figure 9. *P7380 Probe Simplified HF Model (including 25 ohm source impedance).*

At AC signal frequencies below 160 MHz, the LF model of the P7380 can be represented as shown in Figure 8. In the LF model frequency range, the P7380 Z-Active probe architecture acts like a conventional compensated attenuator, although with somewhat larger bridging capacitors than might be expected for the high P7380 bandwidth. The larger bridging capacitors are primarily an artifact of the extension cable design in the Z-Active probe architecture. In the LF model frequency range, the probe single-ended input impedance drops from the 50K ohm DC resistance level because of the compensated attenuator bridging capacitors. This impedance rolloff begins near the LF mode breakpoint frequency of about 1.6 MHz (1/2*π*40K*2.5 pF). As was previously described in the compensated attenuator section, at frequencies above the LF breakpoint frequency, the probe input impedance drops off at a 20 dB/decade rate.

At the LF model breakpoint frequency of 1.6 MHz, the Tip-Clip damping resistor, the probe input series resistor, and the extension cable termination resistor are all small enough to be ignored and are replaced by wire connections. In the LF model frequency range, the relatively short extension cable can be modeled as a discrete component. Because the extension cable in the LF frequency range is unterminated and loaded with high value resistances, it can be modeled as a discrete capacitor, with its capacitance set by the cable length and distributed capacitance factor. The 2.4 inch long probe extension cable with a 10 pF/ft distributed capacitance can be modeled in the LF model frequency range as a 2.0 pF discrete capacitor. The extension cable capacitance is effectively in parallel with the bridging capacitor across the 10K ohm attenuator termination resistor. The sum of the extension cable capacitance and the termination resistor bridging capacitance is shown bridging the compensated attenuator model in Figure 8. This combined termination bridging capacitance value results in the capacitance necessary to give a compensated attenuator with a 5X attenuation factor over the LF model frequency range.

At signal frequencies above about 160 MHz, the HF model of the P7380 probe can be represented as shown in Figure 9. In the HF model frequency range, the P7380 probe Z-Active architecture acts like a conventional Z_0 probe structure. The transition from the compensated attenuator model at LF frequencies to the Z_0 probe attenuator model at HF frequencies effectively stops the rolloff of the probe input impedance due to the compensated attenuator bridging capacitors. The Z-Active architecture improves probe loading performance at high frequencies by stopping the input impedance rolloff at a higher level than is possible with a simple damping resistor. In the HF model frequency range, the DC attenuator resistors are so large relative to the bridging capacitors that they can be considered open circuits and removed from the HF model. Although at the HF breakpoint frequency, the DC attenuator bridging capacitors are comparable in impedance value to the probe input series resistors and extension cable termination resistor, as frequency increases they rapidly become negligible and have been replaced by wire connections in the simplified HF model. In the HF model frequency range, the extension cable is finally modeled as a 125 ohm transmission line, which is terminated by the HF model termination resistor. The 500 ohm series input resistor acts as a resistive divider with the HF model termination resistor to provide the P7380 probe 5X attenuation factor in the HF model frequency range. Taking into account the nominal 25 ohm source impedance, the simplified Z_0 probe model in Figure 9 provides a constant 600 ohm input impedance over the HF model frequency range, although a model with real-world parasitics would at some frequency begin to show a drop in input impedance.

The 500 ohm series input resistor shown in the P7380 HF model in Figure 9 includes several resistive elements in the probe input structure. It includes a 400 ohm resistor in the P7380 probe head attenuator hybrid, a standard resistor of 75 ohms embedded in the Tip-Clip interconnect, and a nominal signal source impedance of 25 ohms. The signal source impedance is included in the probe gain model to try to minimize gain error due to the signal source impedance. Although a 25 ohm signal source impedance seems to be the most common high-speed signal transmission configuration, there are certainly exceptions. A 75 ohm transmission line environment that is driven by a 75 ohm source and terminated by a 75 ohm termination resistor will have an effective 37.5 ohm source impedance when probed. The gain error due to this slight variation from the nominal 25 ohm source impedance can either be accounted for with high frequency signals by adjusting the input attenuation factor in the attached oscilloscope or by modifying the embedded Tip-Clip adapter resistors. By changing the solder-down resistors in the Tip-Clip adapter from the standard 75 ohms to 62.5 ohms, the probe gain at high frequencies can be corrected for a 37.5 ohm signal source impedance.

The simplified models of the P7380 probe Z-Active architecture will now be examined in more detail to try to understand the probe's electrical performance, both for measurement fidelity and for probe loading. The P7380 probe frequency response and pulse response will both be examined to show the excellent performance of the new Z-Active probe architecture. The test fixture that will be used to examine both probe measurement response and probe loading is shown in Figure 10, where a solder-down Tip-Clip has been used to make a reliable connection to the differential signal path. The test fixture is designed to be driven by a differential signal source from a pair of SMA connectors. The exposed pair of 50 ohm coplanar transmission lines allows the differential signal to be probed at the center of the test fixture. The other end of the transmission lines must be terminated in 50 ohms, either with SMA termination caps or with a measurement instrument to measure the effect of probe loading. If the test fixture is driven by and terminated with a network analyzer, then probe gain response and probe loading with frequency can both be measured. If the test fixture is driven by a TDR pulse generator and terminated with a sampling oscilloscope channel input, then probe pulse response and probe loading effects on an input pulse can both be measured.

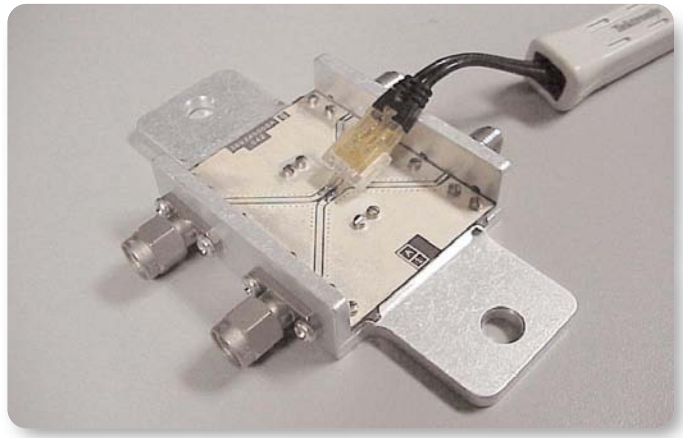


Figure 10. *P7380 Differential Signal Test Fixture with Solder-down Tip-Clip.*

Although there are many metrics that could be examined in characterizing the measurement fidelity of an oscilloscope probe, the following list includes the key signal response parameters for a differential probe:

– High bandwidth

– Linearity

– Low noise

– High CMRR

– Gain accuracy

The P7380 probe, with its 8 GHz bandwidth, supports accurate characterization of first generation serial data signals at 2-3 Gbps rates, can be used to measure cleanly second generation serial data signals at 5-6 Gbps rates, and is useable at 10 Gbps rates. Although the P7380 probe has been designed specifically for use with real-time oscilloscopes like the TDS6804B, which supports the TekConnect probe interface, the most accurate probe measurement performance is obtained with higher bandwidth sampling scopes. Use of the 80A03 TekConnect Probe Adapter with a TDS8200 Sampling Oscilloscope allows the P7380 probe performance to be displayed most accurately and will be used for most of the time domain response screenshots.

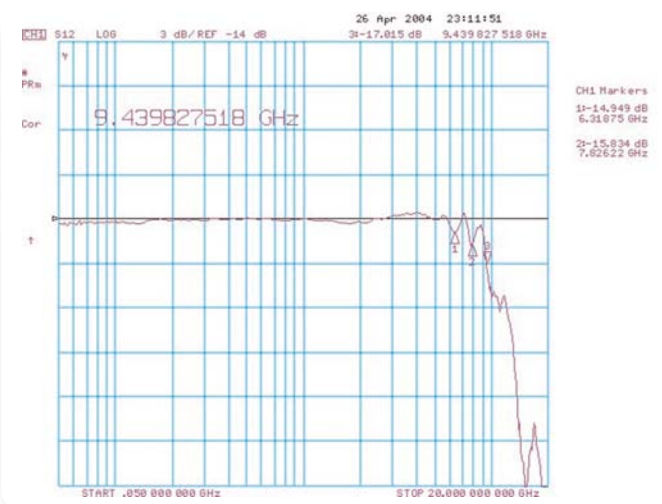
The high bandwidth of the P7380 active probe must be supported not only by its buffer amplifier, which drives the meter-long output cable, but also by the probe input attenuator. The P7380 Z-Active probe input attenuator is designed with high performance hybrid circuit technology to support high bandwidth operation. The miniature probe head assembly contains the series elements of the probe attenuator network and was made physically small using hybrid circuit technology. The probe head series hybrid is also laser-trimmed to match the signal differential paths and to trim the attenuation factor to match the attenuator shunt hybrid. The probe head series hybrid is shielded and enclosed in a plastic housing to protect the probe tip button contact interface and the soldered extension cable launch. The probe tip amplifier housing contains the attenuator shunt hybrid that terminates the extension cable and interfaces to the probe buffer amplifier. The probe shunt hybrid contains the shunt elements of the probe attenuator network and is laser-trimmed to match the signal differential paths and to trim the attenuation factor to match the attenuator series hybrid.

The linearity of the P7380 probe is primarily a function of the probe buffer amplifier, since the probe input attenuator is a passive linear network. The P7380 probe exhibits excellent linearity over its specified dynamic range, but becomes highly non-linear and eventually saturates when overdriven. In order to support a wider dynamic range than is possible with the 5X input attenuator network alone, the probe buffer amplifier ASIC contains an internal 1X/5X gain switch. Because of the wide bandwidth of the P7380 probe, low noise performance is also a critical parameter for the probe ASIC. The advanced SiGe process used to produce the P7380 probe ASIC provides not only wide bandwidth performance but also low noise when provided with sufficient amplifier bias current. The P7380 probe amplifier module is designed to provide thermal management of this required probe ASIC power dissipation.

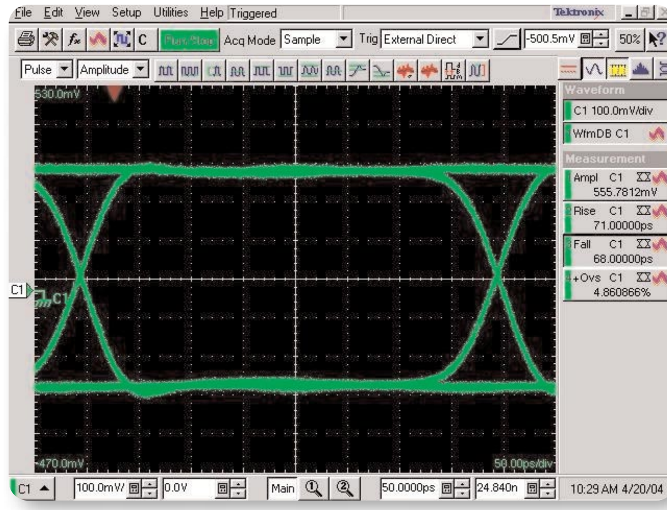
Because the P7380 probe is designed for differential signal measurements, probe CMRR is also a key parameter for preserving the measurement fidelity of differential signals. High CMRR requires careful matching and balance of the two differential input paths. If the two differential paths are not well matched, mode conversion problems can result in conversion gain between common mode input signals and differential mode input signals. Careful matching is required in the attenuator series hybrid, the attenuator shunt hybrid, the probe amplifier ASIC, and all signal interconnections. The sophisticated P7380 probe ASIC also contains internal common mode monitoring and balancing circuitry to maximize CMRR performance.

A final key probe measurement fidelity parameter is gain accuracy. There are a number of elements to gain accuracy, including DC gain accuracy, gain flatness over frequency, and pulse response aberrations. DC gain accuracy is usually specified as the best-fit slope of a linear regression of output voltage mapped against input voltage over most of the dynamic range. The DC gain accuracy specification should include worst-case variation over the operating temperature range. The P7380 probe ASIC contains internal calibration adjustments for DC gain and zero offset to enhance measurement fidelity in both the 5X and 25X attenuator settings.

Although it is desirable for probe gain to be constant over most of the frequency range, it is a fact that gain will decrease for signals approaching the bandwidth frequency. Since the P7380 Z-Active probe architecture has several different operating regions, with a



▶ **Figure 11.** *Typical P7380 Gain Frequency Response.*



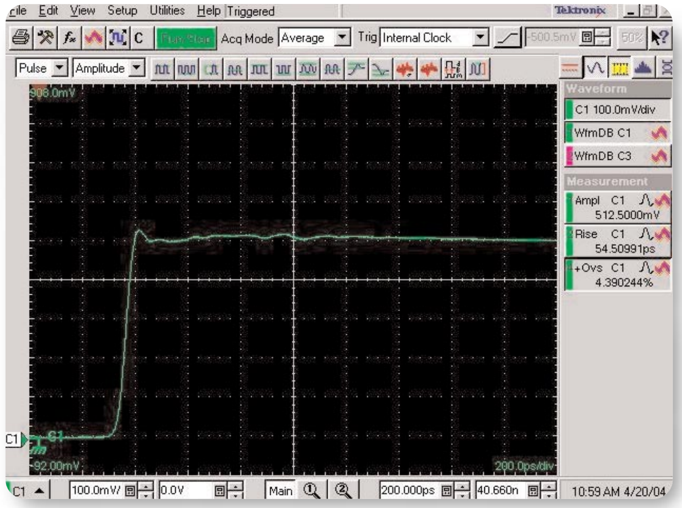
▶ **Figure 12.** *Typical P7380 Eye Pattern Response (50 ps filter).*

distinct model for each region, gain flatness requires the same attenuation factor in each region. As noted previously, the high value resistive divider in the P7380 DC model had an attenuation factor of 5X. In the case of the P7380 LF model, the compensated attenuator also had an attenuation factor of 5X with matching attenuator series and shunt section time constants, for a constant gain over the LF model frequency range. Similarly, for the P7380 HF model, the Z_0 probe attenuator had an attenuation factor of 5X, which was set primarily by a resistive divider, after transitioning from an RC divider at the low frequency end of the HF model range.

Because of the Z_0 probe attenuator, the gain response of the Z-Active probe architecture should be flatter at high frequencies than a more conventional compensated attenuator with damping resistor. The compensated attenuator with damping resistor gain response will not be as flat because of the RC filter action inherent in the structure. A frequency response plot showing typical gain variation with frequency for a P7380 probe is shown in Figure 11. The gain rolloff with frequency near the bandwidth limit is a complex interaction between frequency response limitations of both the passive input attenuator network and the active probe ASIC. The gain of the probe ASIC has also been boosted at high frequencies specifically to compensate for known cable losses in the meter-long probe cable due to skin effect and dielectric losses.

Although a frequency response plot like that in Figure 11 might show a very flat gain amplitude response to almost the bandwidth limit, it does not guarantee an ideal pulse response. In fact a very sharp gain rolloff rate is usually indicative of a pulse response with excessive ringing and aberrations. The missing factor not shown in Figure 11 is the gain phase response with frequency. An ideal pulse response requires a linear phase variation with frequency or constant group delay. The pulse response of the P7380 probe has been designed to minimize aberrations as much as possible, while still preserving a 10-90% risetime less than 55 ps. In addition to the use of a damping resistor in the Tip-Clip attachment adapters and the damping effect of the Z_0 probe resistive divider, the extension cables have been designed with lossy cable to help damp out cable reflections due to imperfections in the cable termination. Figure 12 shows a typical eye pattern response of the P7380 probe to a fast risetime step with a 50 ps risetime (10-90%) filter.

The pulse response of the P7380 probe has been carefully designed for low aberrations and minimal ringing even with very fast risetime input signals. Figure 13 shows the excellent quality of the P7380 pulse response to a 35 ps risetime (10-90%) input signal, which is significantly faster than the specified 55 ps risetime (10-90%).



▶ **Figure 13.** *Typical P7380 Pulse Response (35 ps rise time differential input signal).*

One of the more significant improvements in probe performance resulting from the new Z-Active probe architecture is reduced probe loading at high frequencies. Because of the P7380 probe architectural differences compared to more conventional probe structures, however, some of the traditional methods of specifying probe loading are no longer useful (see side article on AC Probe Loading). The commonly used measure of probe AC loading performance, input capacitance, for example, is no longer an adequate indicator of the P7380 loading performance. Although the input capacitance of the P7380 probe is almost an order of magnitude higher than a comparable conventional probe, the embedded Z_0 probe in the P7380 Z-Active architecture holds Z_{MIN} (the minimum probe input impedance over its full frequency range), higher than a conventional probe. In addition, although the P7380 input capacitance causes an input impedance breakpoint at a lower frequency than a conventional probe, the embedded Z_0 probe

AC Probe Loading

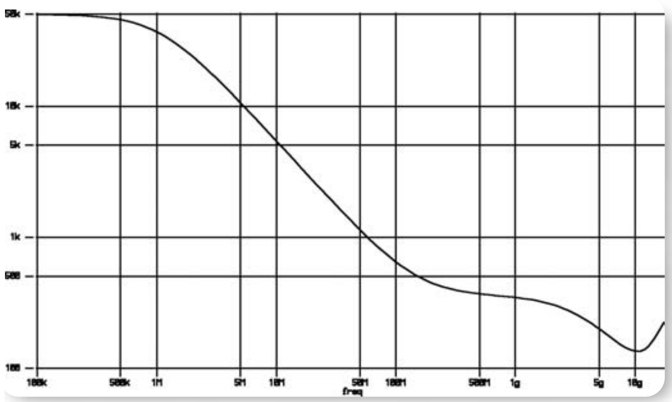
Connecting a probe to a circuit in order to make a measurement results in an interaction between the input impedance of the probe and the impedance of the circuit. This interaction is referred to as probe loading and can affect not only measurement fidelity, but possibly even the operation of the circuit. An ideal probe would exhibit no circuit loading, but any realistic probe must draw some amount of signal current in order to develop a measurable signal voltage. Minimizing the amount of probe loading is an important measure of probe quality. Understanding probe loading specifications is very important in selecting the best probe for a measurement application.

Probe loading has traditionally been specified using a simplistic RC model. The DC input resistance of the simple RC model is a measure of probe loading on the DC component of the signal source. In general, high DC input resistance is a desirable probe characteristic. Most common passive probes have a 10M ohm input resistance and most high performance active probes have a DC input resistance greater than 20K ohms. Although the DC input resistance of most common active and passive probes is high enough to be considered insignificant, there are some exceptions. The DC input resistance of a Z_0 probe, for example, is 1K ohm or less, which will generally result in some degree of measurement error and may load the signal source enough to cause signal distortion. The new class of SMA input probes is also different, since they are designed to provide a broadband resistive termination in a differential 100 ohm transmission line environment (see P7380SMA probe sidebar).

The input capacitance of the simple RC model is similarly a measure of probe loading on the AC components of the signal source. Low input capacitance, which is equivalent to high AC input impedance, is a desirable probe characteristic. Unlike probe DC input resistance, however, probe input capacitance is almost always a significant element in probe loading of high frequency signals. Achieving low probe input capacitance is a very difficult design task, particularly since probe interconnect capacitance increases the effective probe input capacitance. The effect of probe structure results in a relatively flat input impedance response over most of the gigahertz frequency range.

The input impedance of the P7380 probe varies with frequency as shown in Figure 14. The DC loading of the P7380 probe is very light due to the embedded high impedance compensated attenuator in the Z-Active probe architecture. As can be seen in the simplified DC model in Figure 7, the P7380 probe DC input impedance is 100K ohms differential and 50K ohms single-ended. This high input impedance is constant from DC to near the LF model breakpoint frequency of about 1 MHz.

The input impedance of the P7380 probe rolls off at a 20 dB/decade rate over the P7380 probe LF model frequency range of about 1 MHz to 100 MHz. This drop off in input impedance arises from the shorting effect of the compensated attenuator bridging capacitance as frequency increases as shown in the simplified P7380 LF model in Figure 8. Even though the P7380 probe input impedance is dropping off over the LF model frequency range, the impedance level is still relatively high, and probe loading is still light in the LF model frequency range. Although the P7380 probe input impedance rolls off in the same manner as a conventional compensated attenuator probe, the higher input capacitance of the P7380 Z-Active probe architecture results in the impedance rolloff beginning at about 1 MHz rather than 10 MHz for a comparable conventional architecture probe.



▶ **Figure 14.** *Typical P7380 Input Impedance Frequency Response (single-ended).*

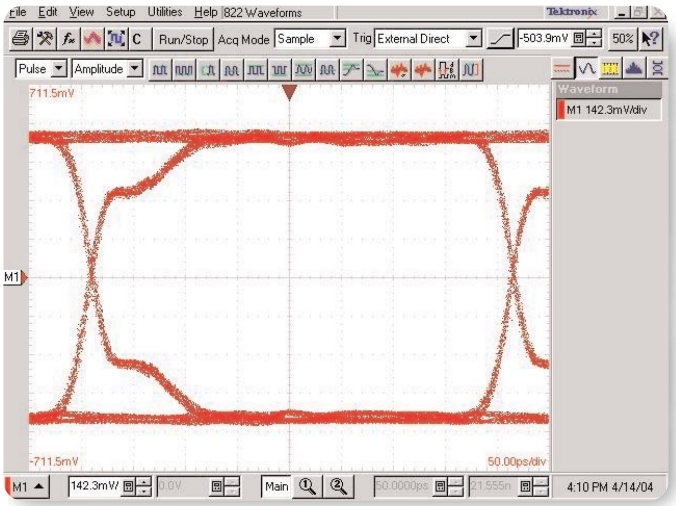
input capacitance is to reduce probe input impedance as signal frequency increases, as shown in Figure 4 (see page 6). Also shown in Figure 4 is the break-point frequency where the probe input impedance begins to decrease due to the input capacitance: FBKPT = (1/2*π*RIN*CIN).

The input capacitance of a quality, high impedance passive probe is about 10 pF, which results in a probe input impedance of 160 ohm at 100 MHz. The input capacitance of a quality, high frequency single-ended probe is about 1 pF, which results in a probe input impedance of 160 ohm at 1 GHz. The low impedance caused by probe input capacitance, which typically becomes significant at frequencies well below the probe bandwidth, requires the addition of damping resistance at the probe input pins. This damping resistance is designed to establish a lower limit on probe input impedance and to reduce resonant effects that result from inductance in the probe inter-connect network. The size of the damping resistance that can be added to the probe input, however, is generally limited to about 100 ohms, because of the effect the damping resistance has on limiting bandwidth with a conventional probe input network.

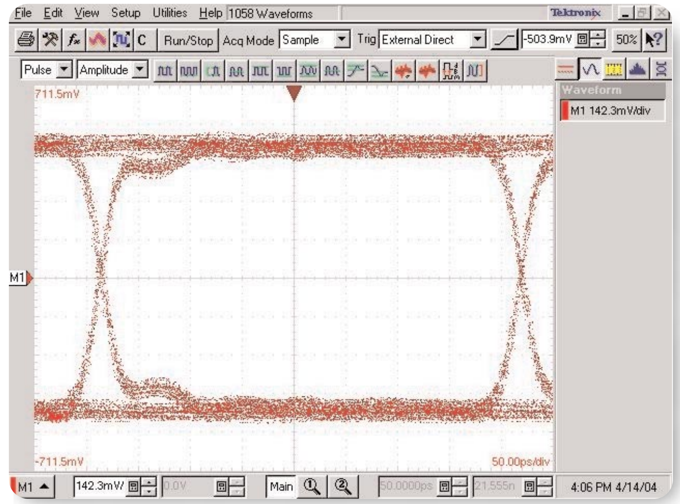
Although theoretically the addition of damping resistance should add a second high frequency breakpoint to the input impedance frequency response plot show in Figure 4, damping resistance is not generally specified as part of probe performance. One reason for this is the dominant impact of probe and interconnect parasitics at gigahertz frequencies. It can thus be seen that the use of input capacitance to characterize AC probe loading for gigahertz frequency probes is simply not adequate. This is particu-larly true for the new Z-Active probe architecture, where the seemingly high input capacitance fails to indicate the improved probe loading performance. The true measure of probe AC loading performance is probe input imped-ance at the measured signal frequency. Since most real-world signals contain a multitude of frequency harmonics, a plot of typical probe input impedance with frequency is probably the most complete measure of probe AC loading performance. A separate input impedance frequency response plot should also be provided for each standard probe interconnect structure, because of the effect of interconnect parasitics on probe input impedance.

At the upper frequency end of the LF model frequency range, the Z-Active architecture transitions from a conventional compensated attenuator structure to a Z_0 probe attenuator structure. The input impedance of a Z_0 probe attenuator, like that shown in the simplified P7380 HF model in Figure 9, should be flat with frequency until parasitic elements not shown in the model reduce the impedance. Although the differential input impedance calculated from the simplified Z_0 probe model should be about 1.2K ohms, the actual performance of the P7380 probe shown in Figure 14 is much less than that value. This significant difference results partly from the use of a very simplified model for the embedded Z_0 probe and partly from the effect of the probe input interconnect parasitics. Rather than burdening the Z-Active probe architecture description with complicated design details, a simplified version of the P7380 probe design was used. Practical design details in the P7380 probe design, which will not be described in this paper, account for about half of the reduction in input impedance compared to the simplified model. Although these practical design details may have contributed to a somewhat lower probe input impedance, they are also key to significantly improved signal fidelity. The other major contributor to reduced input impedance, particularly the drop at the highest frequencies, is probe interconnect parasitics. Parasitic interconnect inductance and capacitance tend to reduce probe input impedance from the ideal theoretical minimum and set a practical limit on high frequency probe loading. It should be noted, that even though the input impedance may not exactly match the simplified model performance, the P7380 probe input impedance in the gigahertz frequency band is still higher and flatter than that of more conventional probe designs.

One possible alternative to a complete frequency response plot of input impedance is an indication of minimum input impedance, valid over the full probe bandwidth. Although the use of Z_{MIN} to characterize probe AC loading performance is much better than specifying input capacitance, it is also important to understand whether single-ended or differential response is being described. Because of the increased use of differential signaling, the use of differential probes is also on the increase. Since a differential probe can be used to make either single-ended or differential measurements, the probe input impedance can be specified in single-ended or differential mode. The DC input resistance will be twice as large in differential mode as in single-ended mode. Similarly, if input capacitance is specified, the probe input capacitance will typically be about half in differential mode what it is in single-ended mode. Although it might be expected that the differential mode Z_{MIN} is also twice the value of the single-ended mode Z_{MIN}, that is not always the case, because of probe and interconnect parasitics that tend to reduce the probe input impedance at very high frequencies.



▶ **Figure 15.** *Conventional Probe Pulse Response Loading.*



▶ **Figure 16.** *P7380 Probe Pulse Response Loading.*

The effect of probe input impedance on a high-speed pulse signal can be seen by observing time domain transmission (TDT) response plots produced using the probe test fixture shown in Figure 10. The impact of probe loading on the TDT response of a more conventional probe is shown in Figure 15. The step aberration on the TDT response due to probe loading is primarily caused by the conventional probe input capacitance. The charging of the probe input capacitance delays the full rise of the input signal pulse step. It is possible, by integrating the area under the normal pulse step that is affected by the probe loading and scaling the result correctly, to calculate the probe input capacitance. The TDT response shown in Figure 15 indicates the impact that probe loading would have on a signal propagating down a terminated transmission line. It should be clearly understood that the TDT response shown in Figure 15 does not represent the measured signal response displayed by the probe. A well-designed probe will try to compensate for the effect of probe loading and indicate as accurately as possible the transmitted or unloaded signal response, as was shown in Figure 12.

The impact of P7380 probe loading on the same signal used to make Figure 15 is shown in Figure 16 for comparison. It can be seen in comparing the two figures that the apparent loading of the P7380 probe is less than that of the more conventional probe. It might seem odd at first that the P7380 probe, which has a significantly larger input capacitance, should have a smaller step aberration than the more conventional probe. The source of this surprising benefit is the isolation of input capacitance of the P7380 probe by the embedded Z_0 probe series resistance. The effect of the P7380 probe's input capacitance can be seen on the TDT response plot in Figure 16 as a small effect at the top of the pulse waveform that persists for a much longer time. The P7380 probe loading on a fast pulse step is lighter than a more conventional probe because of the P7380 probe's higher Z_{MIN}. The loading of the P7380 probe Z-Active architecture effectively trades off less energy extracted at the pulse edge for a smaller loading effect over a longer time period. This approach is somewhat analogous to the approach taken in spread spectrum designs for reducing EMI noise spikes by spreading out the noise energy over a broader frequency spectrum so it appears to have less effect. The small size of the long term loading effect does not significantly impact signal measurements.

Another possible contributor to increased probe loading, particularly at very high frequencies near the probe bandwidth and beyond, are probe interconnect parasitics. A key contributor to the improved electrical performance of the P7380 probe is the new Tip-Clip design for probe attachment. The family of interchangeable Tip-Clip adapters has been designed not only for flexibility in probe application, but also for optimum input signal response and minimum interconnect parasitics. The reduced interconnect parasitics compared to earlier adapter designs for more conventional probes results in improved signal fidelity and better signal response match with most of the different Tip-Clips. The reduced interconnect parasitics also allow the solder-down Tip-Clips to be soldered to the circuit-under-test and left in place after the probe head is disconnected, without significant adapter-only loading. The adapter-only loading of a properly installed Resistor Tip-Clip or Short Flex Tip-Clip should be only about 0.1 pF. This is comparable to the small input capacitance of a well-designed high frequency Z_0 probe.

The P7380 Probe Attachment—A New Tip-Clip Design

Although the electrical performance of an oscilloscope probe is critical to its use in a measurement application, it is really only part of the story. For an oscilloscope probe to be useful in a measurement application, it must also be able to make physical and electrical connection to the circuit being measured. Traditionally a single-ended probe's physical connection to a circuit is made with the sharp metal pin at the probe tip, with the electrical connection being completed by attaching a probe ground lead to the circuit. In the case of traditional differential probe use, a ground lead connection is generally not necessary, but the two probe tip pins have to both be attached to the circuit differential signal nodes. No matter the style of probe being used, the physical attachment of a probe to a circuit can have a significant effect, and often even a dominant effect, on measurement electrical performance. The impact of probe attachment on electrical performance has become a more critical issue with higher speed signals, which are more sensitive to probe interconnect parasitics. The P7380 probe attachment design uses a new approach that optimizes both the physical interconnect to the circuit under test and the overall probe measurement electrical performance.

Recent measurement application requirements have influenced the P7380 probe attachment design approach, which is significantly different than the traditional probe tip pin approach. These new measurement requirements include the following issues:

– Increasing circuit density

– Decreasing component size and signal path pitch

– Increasing need for differential measurements

– Higher frequency signals, requiring lower interconnect parasitics

– Need for greater flexibility in attachment method

The P7380 probe attachment design uses a new interchangeable Tip-Clip design approach to try to deal with each of these new measurement requirements.

As was shown in the probe head drawing in Figure 1, the P7380 probe head is physically small and lightweight and attached to the probe tip buffer amplifier with a pair of flexible extension cables. The electrical connection to the P7380 probe head is made with a pair of gold-plated button contacts on the end of the probe head housing. These button contacts provide the electrical interface to a family of Tip-Clip adapters that allow for flexibility in connection for different probe attachment applications. The different Tip-Clip designs all have a common basic shape and mounting scheme as is shown in the exploded view in Figure 17. The Tip-Clips have a U-shaped plastic bail structure with the bottom of the bail providing the electrical interface to the probe head and the sides of the bail providing the mechanical mounting of the bail to the probe head. Retention features have been included on the sides of the P7380 probe head and on the sides of the Tip-Clip bail to hold the Tip-Clip in place, once it has been snapped on. A slide-release mechanism has also been incorporated into the design to aid in releasing the attached Tip-Clip.

The P7380 Tip-Clips have been designed to provide a high frequency electrical interface for differential signal input with very low parasitics. Since parasitic inductance is primarily a function of electrical interconnect length, the Tip-Clips have been designed to minimize interconnect length. The higher performance Resistor Tip-Clip and Short-Flex Tip-Clip, for example, both use 8 mil diameter leaded resistors for solder connections to the circuit-under-test. The interconnect

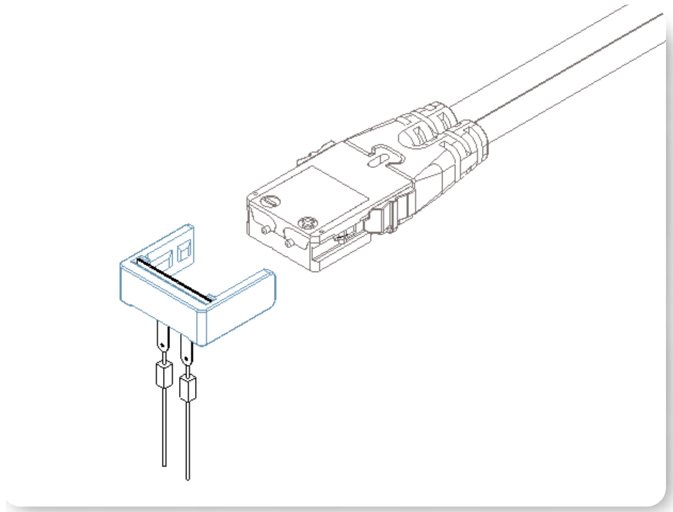


Figure 17. *P7380 Tip-Clip Mounting Structure (Exploded View).*

length between the P7380 probe head button contacts and the resistor body is less than 0.1 inch, by design. The resistor lead length between the resistor body and the soldered circuit connection should also be cut to less than 0.1 inch length for best performance. Since parasitic capacitance is also affected by interconnect length as well as the location of adjacent metal surfaces, keeping the Tip-Clip interconnect length short also helps to reduce parasitic capacitance. The use of small-value, embedded resistors in each of the Tip-Clips also helps to improve electrical performance by damping out resonant effects caused by interconnect parasitics. Since the solder-down Tip-Clips can also be left in circuit, with the P7380 probe head disconnected, minimizing interconnect parasitics in the Tip-Clip interface helps to minimize undesirable loading of the circuit by permanently attached Tip-Clips.

In cases where the probe interconnect lead length must be extended to attach to circuit nodes in a physically confined area, where the probe head will not fit, longer length Medium-Flex and Long-Flex Tip-Clips are available. The use of these longer Flex Tip-Clips is preferable to simply extending the lead length of the damping resistors, since the damping resistors should be located close to the attached circuit nodes for best damping performance and isolation of interconnect parasitics. The length of the signal paths in the Flex Tip-Clips has also been carefully matched for best differential signal measurement performance. Similarly, the lead length and placement of the embedded damping resistors should be carefully matched for best performance. The consequence of the added interconnect lead length with the Long-Flex Tip-Clip, in particular, is slightly reduced measurement signal bandwidth. The relatively modest decrease in signal rise time and the small resonance in the response, even with the parasitic inductance of the Long-Flex Tip-Clip, is a pleasant surprise. The consistent response of the P7380 probe with the variety of different Tip-Clips is an important consequence of the Z-Active probe architecture. The best probe performance however will always be obtained with the minimum interconnect lead length.

The Tip-Clips are designed for easy interchangeability at the P7380 probe head, so that different Tip-Clip styles can be used with the same probe. The Tip-Clips can be removed and replaced by hand or by using a Tip-Clip Ejector tool. This easy interchangeability also allows a single P7380 probe to be moved relatively easily between a group of solder-down Tip-Clips on a circuit board. The low cost of the P7380 Tip-Clips and their low interconnect parasitics allow Tip-Clips to be permanently attached to measurement nodes during circuit board testing. The left-in-circuit loading of a resistive Tip-Clip with minimum lead length is about 0.1 pF. The probe interconnect stubs inside the Tip-Clip bail are also isolated from the attached circuit nodes by the Tip-Clip damping resistors. The currently available Tip-Clips for the P7380 probe include the following:

Resistor Clip Assemblies

– 8 mil Resistor Tip-Clip

– 20 mil Resistor Tip-Clip

Flex Clip Assemblies

– 8 mil Short-Flex Tip-Clip (0.080 inch trace length)

– 8 mil Medium-Flex Tip-Clip (0.200 inch trace length)

– 8 mil Long-Flex Tip-Clip (1.00 inch trace length)

– 20 mil Short-Flex Tip-Clip (0.200 inch trace length)

– 20 mil Medium-Flex Tip-Clip (0.500 inch trace length)

– 20 mil Long-Flex Tip-Clip (1.00 inch trace length)

Handheld Adapter Clip Assemblies

– Handheld Tip-Clip (with variable spacing from 130 mil to 20 mil pitch)

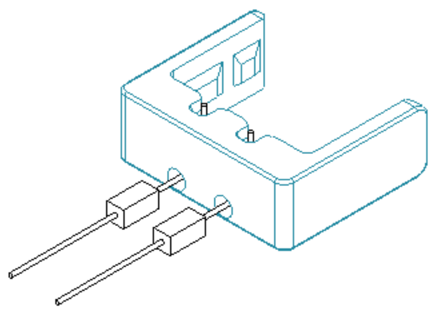


Figure 18. *P7380 Probe Resistor Tip-Clip.*

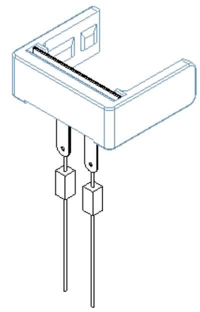


Figure 19. *P7380 Probe Flex Tip-Clip.*

The Resistor Tip-Clip adapters are designed to supply a solder-down, differential interconnect out the end of the Tip-Clip bail. Two different axial-lead resistor sizes are available, either small 1/16 watt, 8 mil diameter resistors or somewhat larger 1/8 watt, 20 mil diameter resistors. The resistor leads pass through holes in the bottom of the Tip-Clip bail, so that the resistor body is flush with the bail surface. The inserted resistor leads then wrap over a non-conductive elastomer pad embedded behind the bottom bail surface and are glued to retention slots in the bail. The purpose of the elastomer pad is to force good electrical contact between the P7380 probe head button contacts and the inserted, wrap-around resistor wire leads. This electrical contact is made once the Tip-Clip bail is snapped into place on the P7380 probe head housing. There are latching features designed into the P7380 probe head housing and the Tip-Clip bail mounting arms. The resistor leads that extend out from the resistor body on the bottom of the Tip-Clip bail should be cut to between 50 and 100 mils and soldered to the circuit-under-test for best probe measurement performance (Note: The 8 mil diameter resistor body is 0.075 inch long, which can be used as a rough gauge for cutting the resistor lead to an optimum length). If cut too short, then soldering to circuit nodes becomes difficult and if not cut short enough, electrical performance will suffer. For best differential measurement performance, the lead length of the resistors should be matched and the resistor lead dress should be well balanced.

The Flex Tip-Clip adapters are designed to supply a solder-down, differential interconnect out the side of the Tip-Clip bail. The Flex Tip-Clip adapters use a common plastic bail for capturing a Kapton flex circuit assembly, which provides a differential interconnect path between the probe head button contacts and the solder-down attachment resistors. Three different flex circuit lengths, with two different axial-lead resistor sizes, are available. The Flex Tip-Clip bail has a pair of narrow grooves cut into the bottom bail surface for aligning and retaining the flex circuit assembly. A pair of ears on the probe head end of the flex circuit assembly slide into the grooves on the bail surface. A slot in the flex circuit also fits over an alignment post on the bail to provide alignment between the probe head button contacts and the gold–plated flex circuit pads. A non-conductive elastomer pad is also captured between the bottom bail surface and the flex circuit assembly, which forces good electrical contact between the probe head button contacts and the flex circuit gold-plated pads. A matched pair of etched traces on the flex circuit assembly completes the transmission path between the gold-plated pads and plated-through holes for the solder-down resistors. As with the Resistor Tip-Clips, for best differential measurement performance, the lead length of the solder-down resistors should be well matched and the resistor lead dress should be balanced. The Short Flex Tip-Clip exhibits the best signal fidelity of any of the Flex Tip-Clips, because it has the lowest interconnect parasitics. Its performance should be very similar to a properly installed Resistor Tip-Clip. The Medium Flex and Long Flex Tip-Clips will show somewhat poorer signal fidelity and reduced probe bandwidth, because they have longer interconnect paths and increased parasitics. The reduction in performance is surprisingly slight, however, because of the Z_0 probe-like response at high frequencies of the new P7380 probe architecture. Flex Tip-Clip performance details can be found in the P7380 Probe User Manual.

The Handheld Tip-Clip is designed specifically for use with the P7380 Handheld Adapter. The P7380 Handheld Adapter is a removable clamshell design that allows the P7380 probe head, extension cable assembly, and probe amplifier module to be conveniently combined into a more conventional hand-held probe package. The use of the same probe head and extension cables in the P7380 Handheld Adapter as is used in the solder-down Tip-Clip adapters results in virtually the same signal fidelity and probe loading

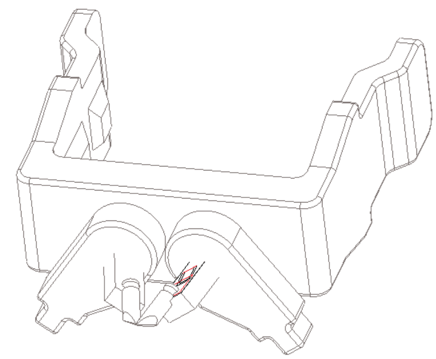


Figure 20. *P7380 Probe Handheld Tip-Clip.*

performance as the solder-down adapters. This is a significant improvement over some competitive approaches that use different cable assemblies for different adapter styles. The Variable-Spacing Tip-Clip extends out the end of the P7380 Handheld Adapter for connection to differential signal contact points over a variable spacing range from 130 mils down to 20 mils. The Handheld Tip-Clip spacing is adjusted by rotating lever arms that are integrated into the tip structure.

One of difficulties commonly faced with the use of conventional rigid pin differential probes is the lack of mechanical compliance between the differential probe tips and a pair of circuit contacts. The P7380 Handheld Adapter has significantly improved mechanical compliance through the use of elastomeric pads embedded in the adapter clamshell. The elastomeric pads provide a flexible holder for the P7380 probe head that acts to adjust and balance the contact forces between the differential probe tips and the pair of circuit contacts as force is applied against the P7380 Handheld Adapter housing. The P7380 Handheld Adapter housing also contains features designed for ease of use in articulated-arm fixtured probing.

Summary

This paper has described a novel Z-Active probe architecture, first implemented on the P7380 differential probe. The Z-Active probe architecture combines the performance of a conventional high impedance, compensated attenuator probe at frequencies below about 100 MHz with the performance of a Z_0 probe at higher frequencies. By combining the best characteristics of these two conventional probe structures, the Z-Active probe architecture provides improved high frequency electrical performance. The high bandwidth and flat pulse response of the P7380 probe demonstrates the excellent measurement integrity possible with the Z-Active architecture. The reduced probe loading of the P7380 probe and its relatively constant input impedance in the gigahertz frequency band also demonstrates the excellent probe loading performance possible with the Z-Active architecture.

The Z-Active probe architecture and its implementation in the P7380 probe also addresses probe interconnect problems that have occurred because of increasing circuit density and higher frequency signals. The embedded Z_0 probe structure in the Z-Active probe architecture enables the P7380 implementation to feature a small probe head with flexible extension cables. The compact and flexible probe input, combined with the innovative Tip-Clip interconnect design, gives the P7380 probe improved interconnect electrical performance and greater flexibility in interconnect application. The cost effective Tip-Clip design supports improved interconnect electrical performance by minimizing interconnect parasitics and by embedding damping resistance in the various interconnect adapters. A variety of Tip-Clip adapters also enables the same P7380 probe to be utilized in solder-down, handheld, and fixtured probe applications.

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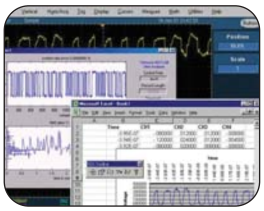

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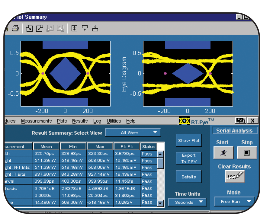

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