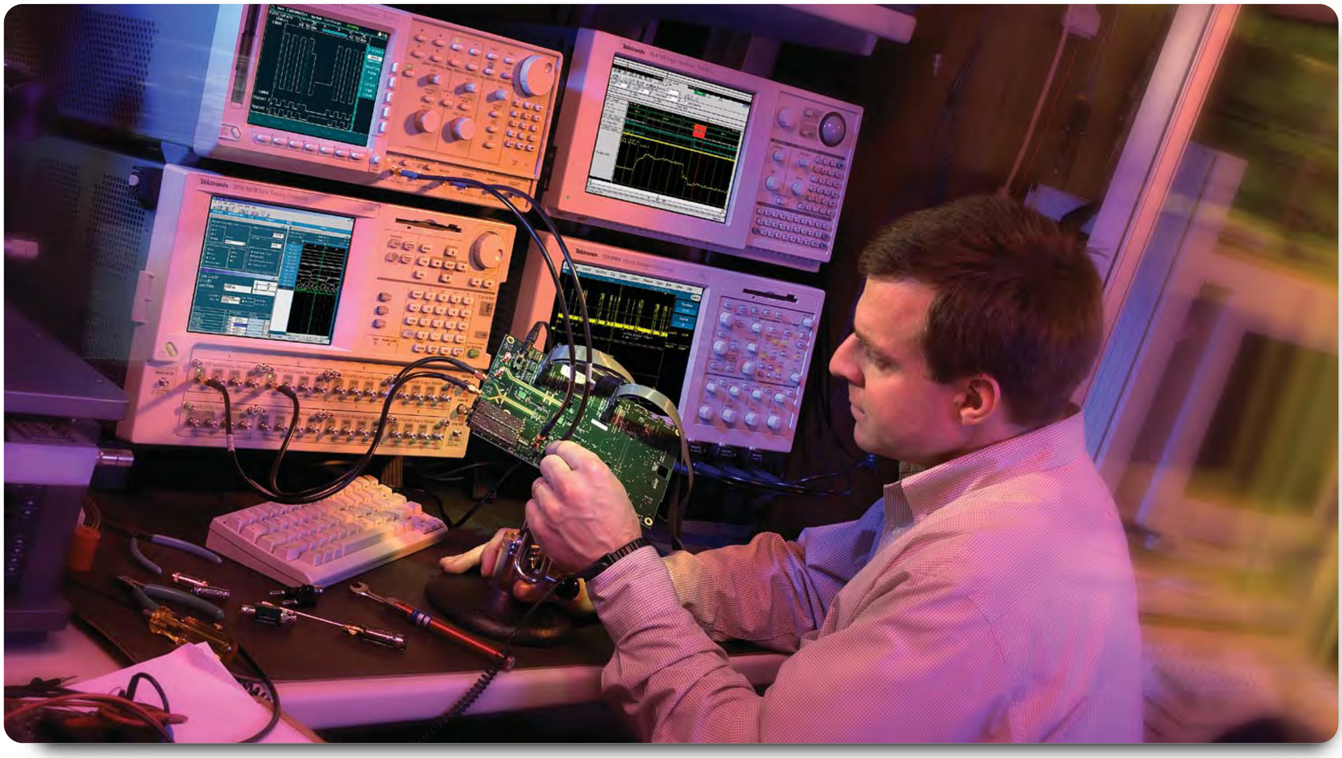
Utilizing DSP to Optimize Real Time Oscilloscope/ Probe System Performance



Real-time (RT) oscilloscopes have employed DSP (digital serial processing) filters to optimize magnitude and phase response and extend bandwidth beyond the analog -3 db bandwidth for several years. These same techniques are now extended to the oscilloscope probe tip. The resulting system response yields improved signal fidelity and often lower noise.

A detailed explanation of various DSP filtering techniques is covered in the white paper "DSP in High Performance Oscilloscopes" by John Pickerd of Tektronix (www.tek.com). This application note will not attempt to repeat the analysis done by Mr. Pickerd. It will cover the extension of these techniques to the latest generation of Tektronix active probes, demonstrating the system level performance improvements and benefits of user selectable probe DSP filters.

Why Employ DSP Filters in Probing Applications?

In today's world of high speed digital design, the characteristics of digital signals is vitally important in reliable robust product design. Maintaining signal fidelity through the acquisition system, including any probes, is a crucial requirement. While no probes offer ideal response, the combination of DSP and advances in hardware and ASIC design have enabled

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significant advances in probe signal fidelity. DSP opens several avenues to improved performance:

- It is possible to implement more complex processing algorithms in the digital domain. Filters that would be impractical in hardware are often readily implementable with DSP. One example is the ability to provide a selection of filters specific to individual probe tips.
- DSP filters do not require any additional hardware or circuitry in the probe head. The probe head can remain physically small for optimum usability and performance.

Thus, through the use of DSP, it is possible to significantly improve overall system response. DSP also enables a wide variety of filters tailored for specific applications without compromising the probe form factor and usability.

The Tektronix Approach to Probe DSP

Tektronix support of DSP to the probe tip is a direct extension of the techniques used in RT oscilloscope bandwidth extension and bandwidth enhancement. This enables a consistent, intuitive user selection of DSP choices. As with RT oscilloscope DSP, the user retains the ability to turn off probe DSP filters. A major focus of the implementation of oscilloscope and probe filtering is consistent response, channel to channel and scope to scope. DSP filter selections are as transparent and easy to use as possible.

Linking Oscilloscope and Probe DSP Filter Choices

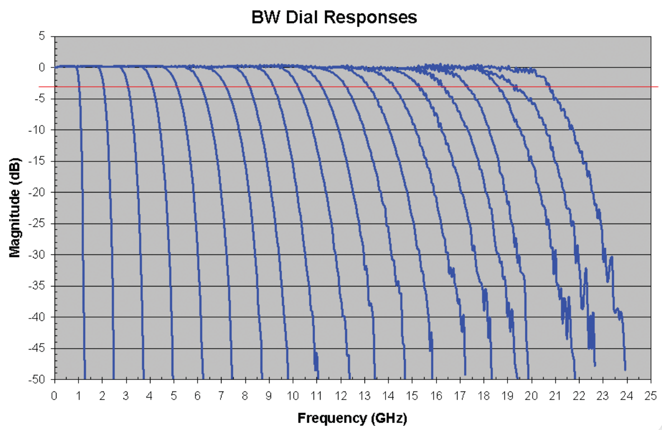
Tektronix RT oscilloscopes and probes employ 3 basic response correcting filters, all sharing some common characteristics. They are bandwidth enhance (BWEh), bandwidth extend (BWE), and bandwidth Limit (BWL). All three of these filter types are implemented as linear phase FIR (finite impulse response) filters with frequency response down approximately 60 db at 1.2 times the filter -3 db bandwidth. Each of these filters further tailor the frequency response as described below.

Bandwidth Enhance (BWEh): The BWEh filter is designed to correct for non-ideal oscilloscope or probe/oscilloscope response variations within the analog bandwidth of the system. This is accomplished by characterizing each oscilloscope channel and attenuator settings, and characterizing the nominal response of various probe and tip responses in a 50 Ω environment. From these characteristics a linear phase FIR filter for each unique combination of oscilloscope channel, probe and probe tip is created. The system response is designed to be as flat as possible in the frequency domain, then rolling off rapidly to attenuate out of band signals.

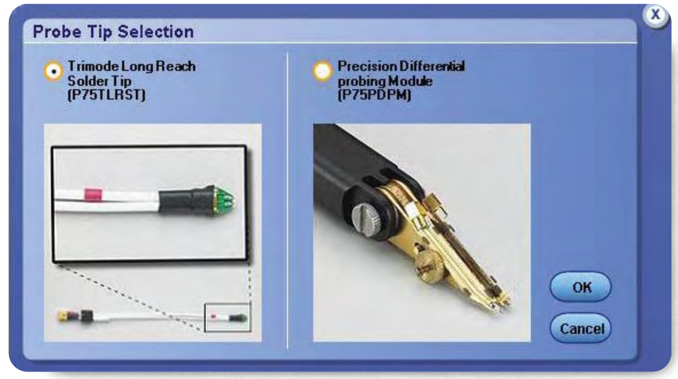
Bandwidth Extend (BWE): The BWE filter is similar to the BWEh filter with one exception. The BWE filter extends the system bandwidth beyond the analog system bandwidth. For example, the Tektronix P7380A with the Medium Flex Small Resistor Tip-Clip™ has a typical analog bandwidth of 7 GHz. The BWE filter increases the bandwidth to 8 GHz typical while maintaining flat frequency response and linear phase.

Bandwidth Limit (BWL): The BWL filter is a linear phase low pass filter with response similar to the BWEh filter with the addition of user selectable upper bandwidth. In the implementation employed in the Tektronix DPO/DSA70000, the bandwidth is selectable at 500 MHz or in 1 GHz steps from 1 GHz to the maximum instrument or probe bandwidth. Bandwidth limit filters are applied to the acquired digitized signal. This eliminates out of band noise contributions from the probe and the oscilloscope acquisition system. For example, when a P7240 4 GHz probe is attached to the DPO/DSA70164 16 GHz oscilloscope, the 4 GHz BWL filter will provide 4 GHz system bandwidth while reducing the system out of band noise.

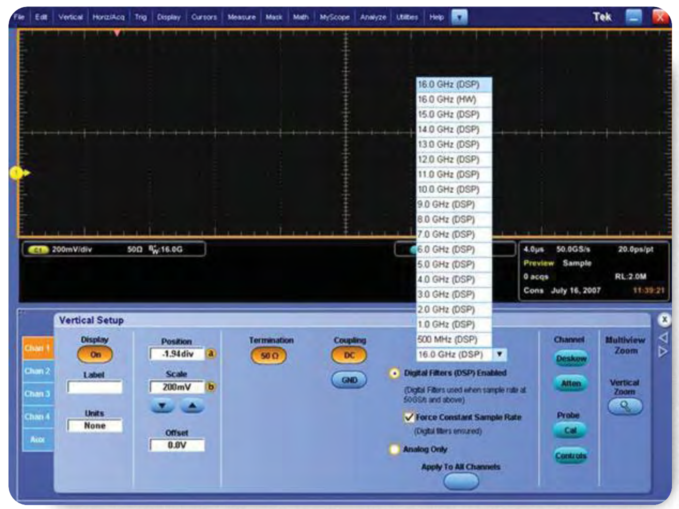
The response of the BWL filters is shown in Figure 1. The response of the BWEh and BWE filters are very similar, with the upper -3 db point determined by the host instrument or probe bandwidth.



▶ **Figure 1.** Typical bandwidth limit filter response for the DPO/DSA70000 oscilloscopes.



▶ **Figure 2.** P7500 Series Probe tip selection menu.



▶ **Figure 3.** P7516 bandwidth selection menu.

This selection of filters provides a powerful arsenal of filter capability to improve the signal fidelity of measurements.

Probe DSP Selection and Use Examples

Let's look at two typical use cases and see how easy probe DSP is to use and what the benefits are.

Eye Diagram Example

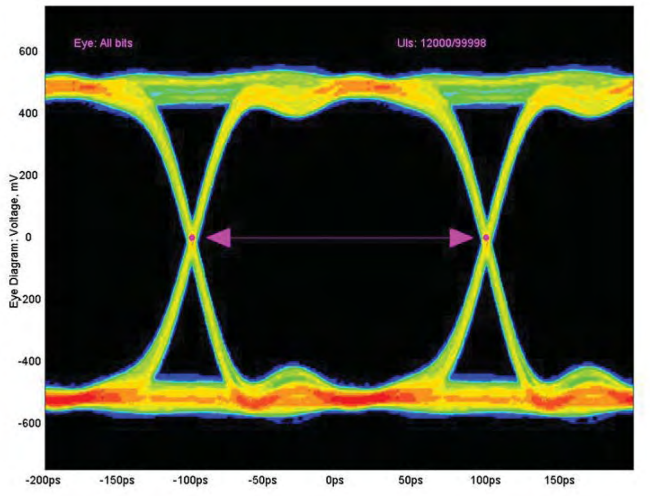
The first example is a 5 Gb/s eye diagram typical of high speed serial applications. In this case the reference source is an Advantest D3186 Pattern Generator with a Picosecond Pulse Labs 50 ps rise time limiter generating a 5 Gb/s serial stream. The acquisition system consists of a DSA71604 and P7516 16 GHz TriMode™ probe and the TDSRT-Eye™ package.

P7500 Series Probe Tip Selections

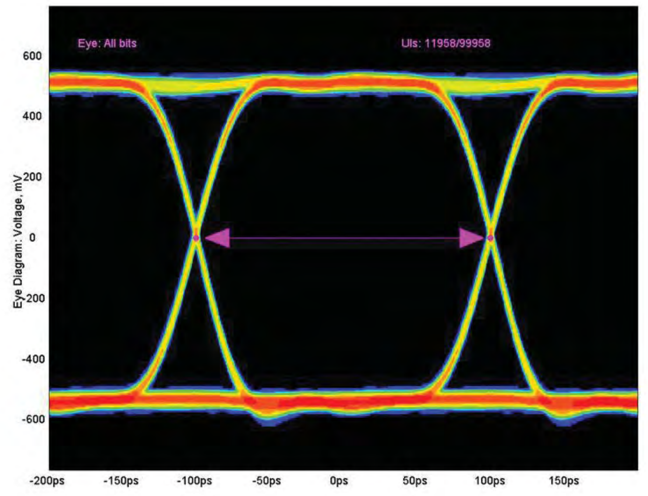
The first thing to notice when connecting the P7500 probe is the selection menu for the tip attached to the probe. Figure 2 shows the menu choice for the two tips; P75TLRST (TriMode Long Reach Solder Tip) or P75PDPM (Precision Differential Probing Module). In this case the P75LRST tip is selected. The menu automatically appears the first time a P7500 probe is plugged-into the oscilloscope. It can be accessed via Vertical > Probe Controls > Setup > Probe Tip > Diagram.

Next, we can select our DSP options using the oscilloscope vertical menu, Vertical > Vertical Setup > Bandwidth. Choices include Analog Only mode or a variety of DSP filters from 500 MHz to 16 GHz. The choices are shown in Figure 3.

In the first case, response is set to Analog Only (no DSP). Now let's examine eye diagrams using the DSA71604 and P7516 16 GHz probe.



▶ **Figure 4.** P7516/P75LRST 5 Gb eye diagram without DSP filter.



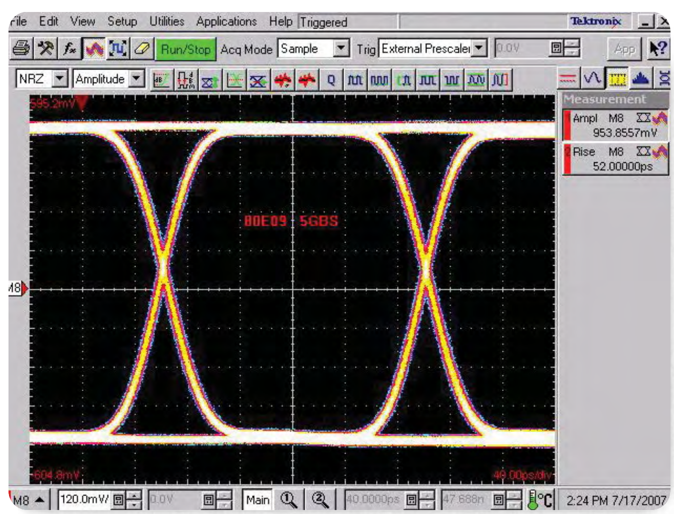
▶ **Figure 5.** P7516/P75LRST 5 Gb eye diagram with 16 GHz BWEh DSP filter.

While the eye is quite clean, there is still a noticeable amount of noise, and some overshoot and ringing present on the acquired signal (Figure 4).

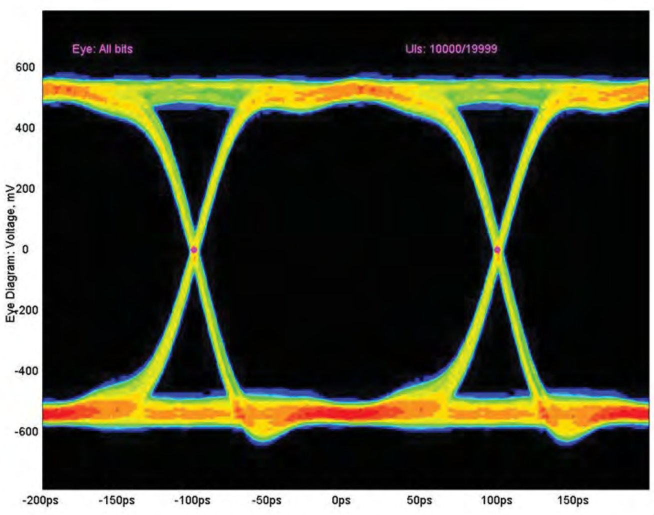
Next, let's look at the same signal, this time with Probe DSP turned on (16 GHz DSP) in Figure 5. The advantages of DSP are clearly visible. DSP improves the step response and reduces the ringing and overshoot. There is also a noticeable reduction in noise resulting in a better eye opening.

Let's compare this eye diagram with the eye diagram captured by a sampling oscilloscope as a “golden reference”. Figure 6 shows the same signal connected directly to the Tektronix DSA8200 sampling oscilloscope with the 80E09 30 GHz electrical sampling module (Figure 5). Note that the RT scope eye diagram using DSP compares very favorable to this “golden reference” eye diagram.

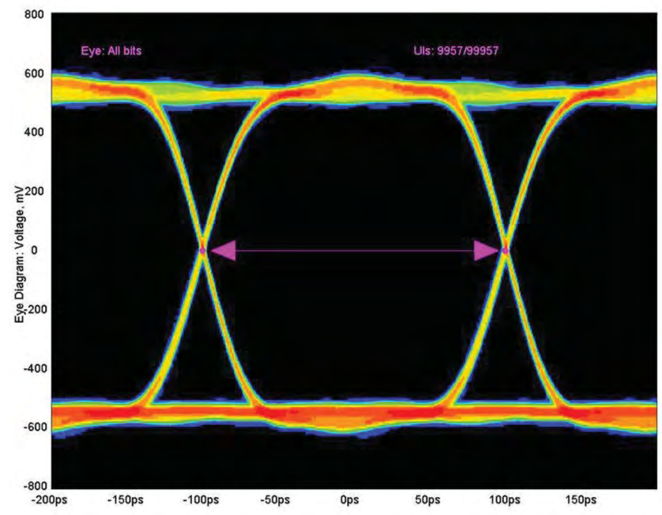
Next, let's repeat the same comparison, this time with the P7516 16 GHz probe and P75PDPM tip (handheld adapter). First, the eye diagram without DSP (Figure 7).



▶ **Figure 6.** DSA8200/80E09 golden reference 5 Gb eye diagram.



▶ **Figure 7.** P7516/7P5PDPM 5 Gb eye diagram without DSP filter.



▶ **Figure 8.** P7516/7P5PDPM 5 Gb eye diagram with 16 GHz BWEh DSP filter.

The results are similar to the P75TLRST. Now let's look at the same eye diagram with 16 GHz DSP bandwidth selected (Figure 8). Again the improvements in signal fidelity and noise are dramatic and compare favorably with the "golden reference" eye diagram.

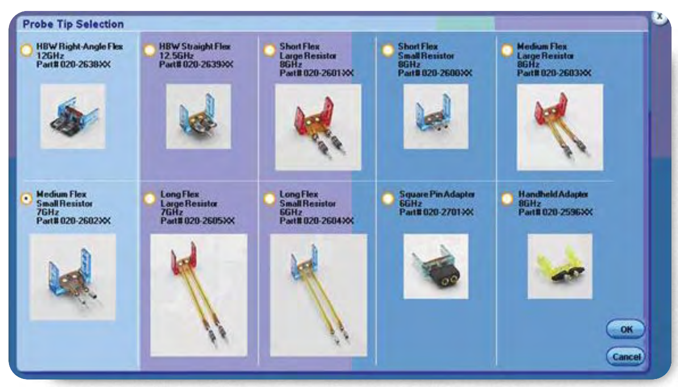
Troubleshooting Example

Next, let's cover a typical troubleshooting example using the Tektronix DSA71604 16 GHz oscilloscope and P7380A 8 GHz probe with a solder in tip.

P7380A Probe

Again, the first thing to notice when connecting a P7380A probe is the tip selection menu (Figure 9). Note that the menu automatically appears the first time a P7300 probe is plugged-into the oscilloscope. It can be accessed via Vertical > Probe Controls > Setup > Probe Tip > Select.

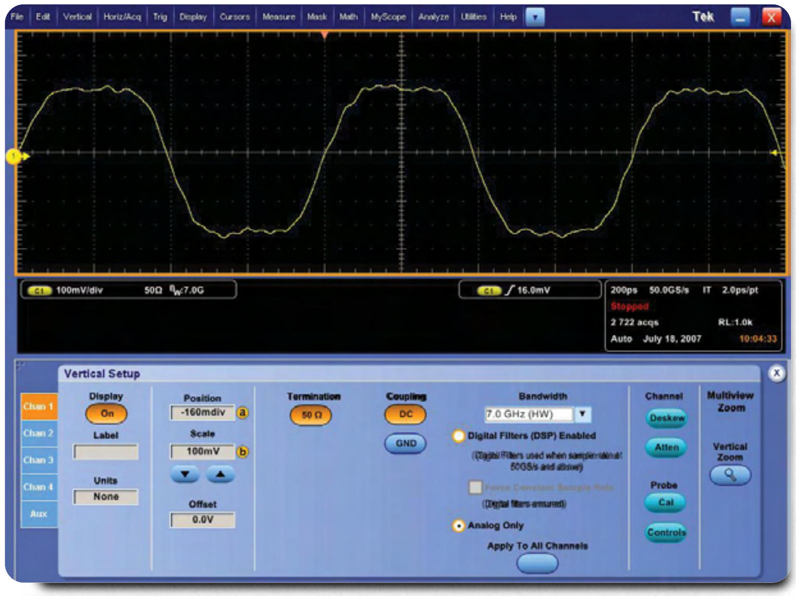
In the example that follows we will use the Medium Flex Small Resistor Tip-Clip. This tip offers a good compromise between ease of use and signal fidelity, an important consideration during board troubleshooting.



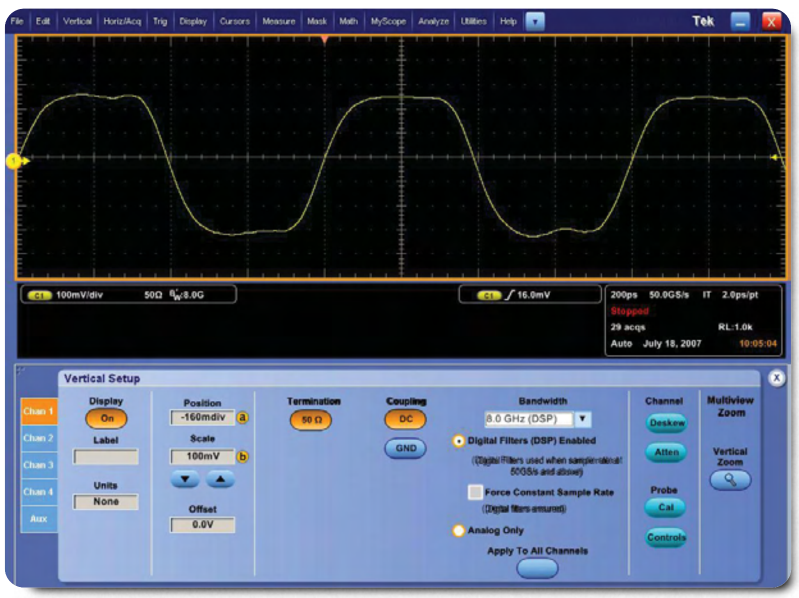
▶ **Figure 9.** Tektronix P7380/80A ProbeTip Selection Menu.

The tip selection menu indicates this probe/Tip-Clip combination has 7 GHz hardware bandwidth. Once the tip is selected, the bandwidth menu appears. The bandwidth menu can also be access via Vertical > Vertical Setup > Bandwidth. The bandwidth menu selections include choices of Analog Only and 500 MHz through 8 GHz bandwidth with DSP selected.

Now let's look at a 2.5 Gb/s data signal from a test board with this probe and tip, with and without DSP. This is a PCI Express signal, which should have 5th harmonic frequency components to about 6.25 GHz. Here we are using an 8 GHz probe with a 7 GHz tip on a 16 GHz oscilloscope.



▶ **Figure 10.** 2.5 Gb/s PCI Express signal and Tektronix P7380 Medium Flex Small Resistor Tip-Clip without DSP filter.



▶ **Figure 11.** 2.5 Gb/s PCI Express signal and Tektronix P7380 Medium Flex Small Resistor Tip-Clip with 8 GHz BWE DSP filter.

First, let's see what the signal looks like with no DSP by selecting Analog Only in the bandwidth selection menu (Figure 10).

Next, let's look at the same signal with 8 GHz DSP bandwidth selected (Figure 11). With the probe DSP filter turned on, there is less noise and improved signal fidelity. This is a result of the improvements in frequency response due to the BWE filter, and the noise reduction from bandwidth limiting of the overall acquisition to 8 GHz. This provides excellent signal fidelity from an easy-to-use solder-in tip.

Should I Use Probe DSP All the Time?

The eye diagram and troubleshooting examples demonstrated how DSP can improve signal fidelity. But there are a few cases when using probe DSP may not be appropriate. For these cases, you can turn DSP on or off. Four cases where DSP may not be appropriate are:

- **Use of excessively long leads on solder-in accessories**. The DSP algorithms for the probe solder – in accessories assume a short (<0.075 inch) connection between the end of the resistor on the solder-in accessory and the connection to the DUT. If your solder-in connection has excessively long lengths of wire from the resistor to the DUT, you may experience excessive ringing and loading that DSP may not be able to correct.
- **Custom Interconnect.** If you have developed a unique DUT interconnect solution using customized accessories, there will not likely be a DSP filter appropriate for the specific interconnect. In this case turning off DSP is highly recommended.
- **Impedance Mismatch.** The probe DSP algorithms, and probe calibration assumes the source impedance of the device under test is 50 Ω. For 50 Ω transmission lines, such as copper serial data transmission, this provides an optimal solution. However, as the source DUT source impedance deviates from 50 Ω, the accuracy of the probe BWEh or BWE filter is degraded. For environments that vary significantly from 50 Ω, probe DSP should be used with the impedance mismatch in mind.

Tips for Minimizing Noise Contributions from the Probe and Oscilloscope.

Tektronix Probe	P7516	P7513	P7313
Bandwidth (typical)	>16 GHz	>13 GHz	>12.5 GHz
Differential Input Range	± 0.75V (5x) ± 1.75V (12.5)		± 0.625V (5x) ± 2.00V (25x)
Offset Voltage Range	+2.5V/-1.5V (Diff) +4.0V to -2.0V (A, B, Comm)		+4.0V to -3.0V
Common Mode Input Range	+4.0V to -2.0V		+4.0V to -3.0V
Noise	4.2mV RMS	4.8V RMS (5X)	3.5mv RMS (5x)
	6.1mV RMS	5.5mV RMS (12.5x)	8.4mV RMS (25x)

▶ **Table 1.**

The table below highlights several key relationships between probe noise, bandwidth, and attenuation.

First, notice that the probe noise is a strong function of probe attenuation. Choosing 25x attenuation vs. 5x attenuation will result in more than double the noise.

In general, a probe offset voltage range and common mode input range are not functions of attenuation. Only the input dynamic range is affected by attenuation selection. Select the lowest attenuation that covers the input voltage swing of your signal. Then use the oscilloscope's volts/div selection to adjust the display as needed.

Second, bandwidth limit (BWL) can be your friend. Note that the P7513 has lower noise than the P7516. This is largely due to the lower bandwidth of the P7513. This same reduction in noise can be realized by selecting 13 GHz bandwidth on the oscilloscope when using the P7516. Noise approximately scales as the square root of bandwidth. Doubling the bandwidth will increase noise by about 40%!

With the DPO/DSA70000 series oscilloscopes system, bandwidth can be set at 500 MHz, and in 1 GHz steps from 1 GHz to full instrument or probe bandwidth. This provides the ability to minimize system noise by selecting a system bandwidth adequate to cover the signal of interest, eliminating the out-of-band noise contributions to the acquired signal. In general, selecting a bandwidth of 3 to 5 times the fundamental frequency of the digital signal of interest is a good compromise between capturing important harmonic content, and minimizing noise.

- **Applying custom DSP Filters or Interpolation.** You may want to apply your own DSP algorithms to filter or interpolate the acquired data. In this case, you may prefer the non-processed sample points from A/D. The Tektronix application note “Arbitrary FIR Filter Theory, Design and Application” (www.tek.com) discusses DSP filter design in more detail.

Summary

Real Time (RT) oscilloscopes have employed DSP filters to optimize magnitude and phase response and extend the bandwidth beyond the analog -3 db BW for several years. This capability is now available all the way to the probe tip.

Allowing the user to turn DSP on or off provides the ultimate in flexibility. You can still apply your own DSP algorithms, or turn off DSP filtering when using non-standard or custom accessories.

The wide selection of bandwidth limit filters provides the flexibility to use the highest bandwidth probes and oscilloscopes on lower bandwidth signals and “dial back” the bandwidth for lower noise. Or, use the bandwidth dial to “match” the measurements made on a lower bandwidth system.

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