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# Enabling Low Noise Measurements on Signals Transmitted Over Lossy Channels

## How novel QuietChannel™ technology in 7 Series DPO oscilloscopes makes low-noise measurements on de-embedded signals

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WHITE PAPER

## Abstract

De-embedding is a critical tool for removing the influence of cables, probes, fixtures and connectors when measuring signals carrying high speed data. However, de-embedding can also unduly boost instrument noise. This paper explains the challenges in de-embedding channel effects from high-speed signals, especially in terms of managing oscilloscope noise. It explains how a new approach, implemented in the 7 Series DPO oscilloscope, uses a patented combination of hardware and software to shape the noise floor of the oscilloscope to reduce the impact of instrument noise on de-embedded signals. Several experiments are described to illustrate the effects of this new QuietChannel™ technology, and how the benefit increases with channel length. A brief section on configuring the equalization is included.


## The Current Technology Gap

Measurement of high-speed serial signals, especially as part of standards testing, has required de-embedding to account for cables, packages, and boards since 10 Gb/s data rates were achieved. As data rates have increased the impact of channel loss has also increased and the ability of oscilloscopes to accurately represent the de-embedded signal has been limited by the noise of the digitizer. If the instrument had zero noise, then the original signal could be perfectly represented by de-embedding. Modern oscilloscopes have greatly improved noise floors, but instrument noise still causes significant error when amplified by a de-embedding filter.

For example, **Figure 1** shows the frequency content of a 20 Gb/s PRBS signal before and after channel loss. Measuring the edge rate and characterizing signal traits like pre-emphasis requires capturing higher frequency signal components.

**Figure 2** illustrates a basic model of an oscilloscope. Noise is modeled in several places. The noise at the input of the preamp is ahead of the gain and changes with the vertical scale of the instrument. The noise at the output of the preamp and the noise of the ADC typically don't change with the vertical scale of the instrument. At most vertical scale settings used for high-speed serial measurements, the gain of the preamp is low and the ADC noise dominates. The Scope DSP block in modern oscilloscopes applies filters and equalization to account for the signal path within the instrument. The Software De-embed block is a tool used to compensate for a lossy signal path external to the oscilloscope – including cables, connectors and traces. It typically uses S-parameters to describe losses in the external channel leading up to the oscilloscope input. In the case of the 7 Series DPO, Signal Integrity Modelling (SIM) software performs de-embedding to compensate for external signal path elements.

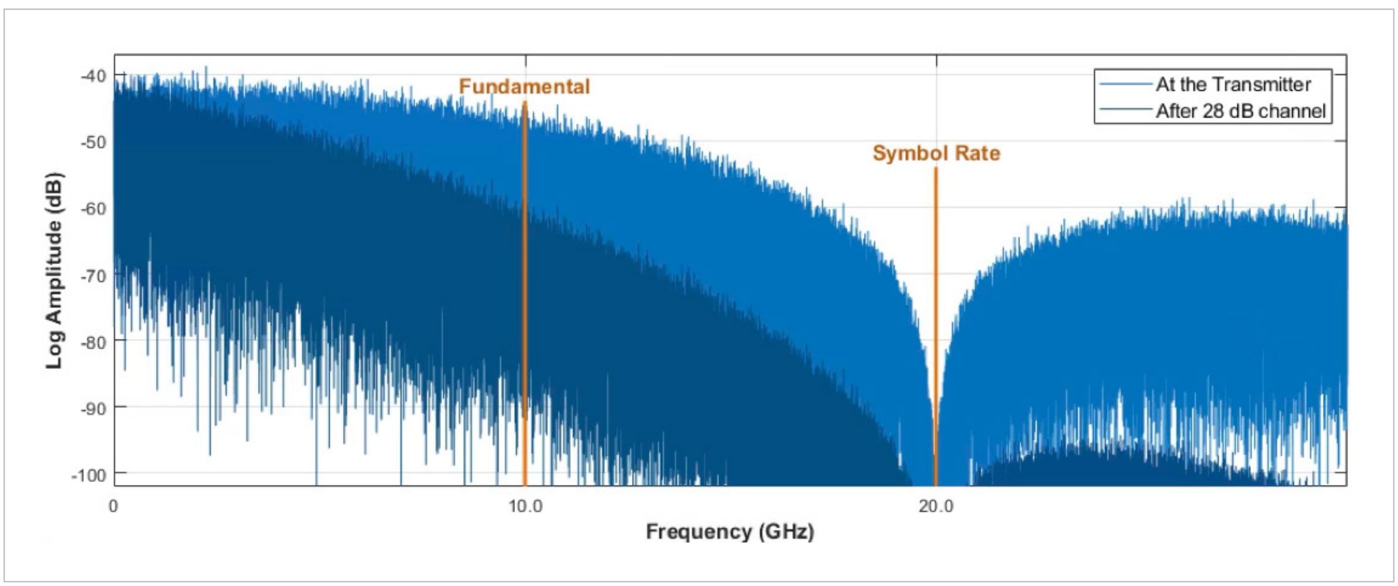


**Figure 1. Frequency content of a 20 Gb/s PRBS signal before and after channel loss.**

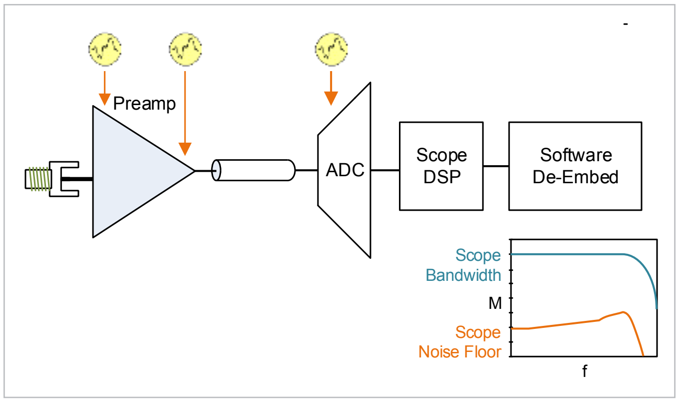


**Figure 2. Traditional oscilloscope signal path with software de-embed. In addition to boosting high-frequency signal power, de-embedding also boosts oscilloscope noise.**

The plot in the bottom right of **Figure 2** shows the bandwidth of the oscilloscope, and the oscilloscope noise floor as a function of frequency. Since channel loss is greater at higher frequencies, de-embedding generally boosts higher frequencies. This boost is applied not only to the signal but also to the instrument noise, resulting in a noise floor like the one in **Figure 2**. Note that the signal isn't distorted by the de-embed because the channel loss is applied and removed which balances out. The oscilloscope noise floor itself isn't affected by the channel loss. However, the oscilloscope noise is boosted by the de-embed, so the oscilloscope noise floor increases as frequency increases.

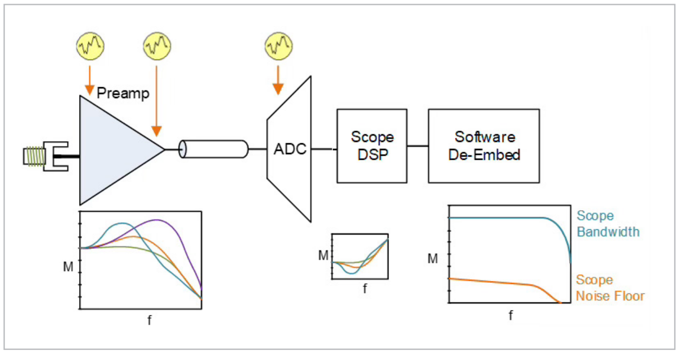


**Figure 3. Oscilloscope Noise with De-Embed and QuietChannel technology. Equalization in the preamp is reversed in the scope DSP, effectively shaping the noise floor of the oscilloscope.**

**Figure 3** is a model of an oscilloscope with QuietChannel technology implemented. In this case the preamp has been designed with selectable frequency responses that boost the signal's high frequency content. The transfer function is a form of continuous time linear equalization (CTLE), which is often used to correct for losses in transmission lines. After the ADC sampling, with the accompanying noise, the frequency response is flattened by applying DSP that is the inverse of the Preamp boosting. The plot on the bottom right shows the result — a flat oscilloscope bandwidth, but a noise floor that is shaped to be attenuated at higher frequencies.

## QuietChannel Technology Experiments

To demonstrate the effect of this technology, three experiments were performed and are described in this paper. The setup for the experiments includes a bit error rate tester (BERT) capable of 28 Gb/sec data. Pseudorandom binary sequences (PRBS) from the BERT are transmitted through a PCB made of Megtron 6 material with high-quality connectors and striplines of various lengths designed to create inter-symbol interference (ISI board). The differential signal is measured using two channels of a Tektronix 7 Series oscilloscope, the first oscilloscope to incorporate QuietChannel technology.

In all of these experiments Tektronix Signal Integrity Modeling (SIM) software was used to de-embed the loss of the PCB from the measured signals. Some standards apply continuous time linear equalization (CTLE) along with or instead of de-embed. These experiments didn't use CTLE but the effects of QuietChannel technology would be similar.

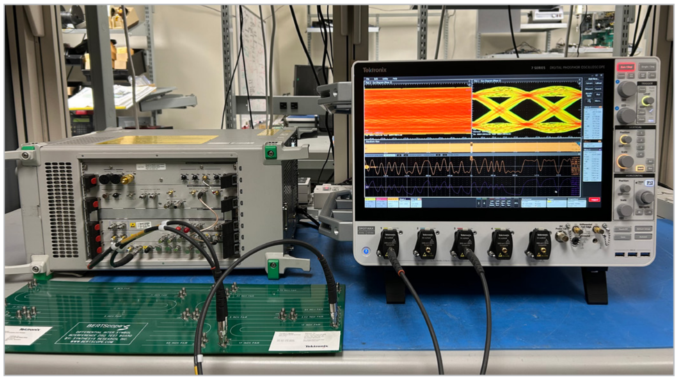

**Figure 4. Test setup for experiments. A BERT (left) is used to drive PRBS test signals through channel of different lengths. The 7 Series DPO with QuietChannel technology is used to measure the resulting signal.**

The first experiment is using 20 Gb/s data running through a 17-inch stripline. The insertion loss of this channel is shown in **Figure 5**.

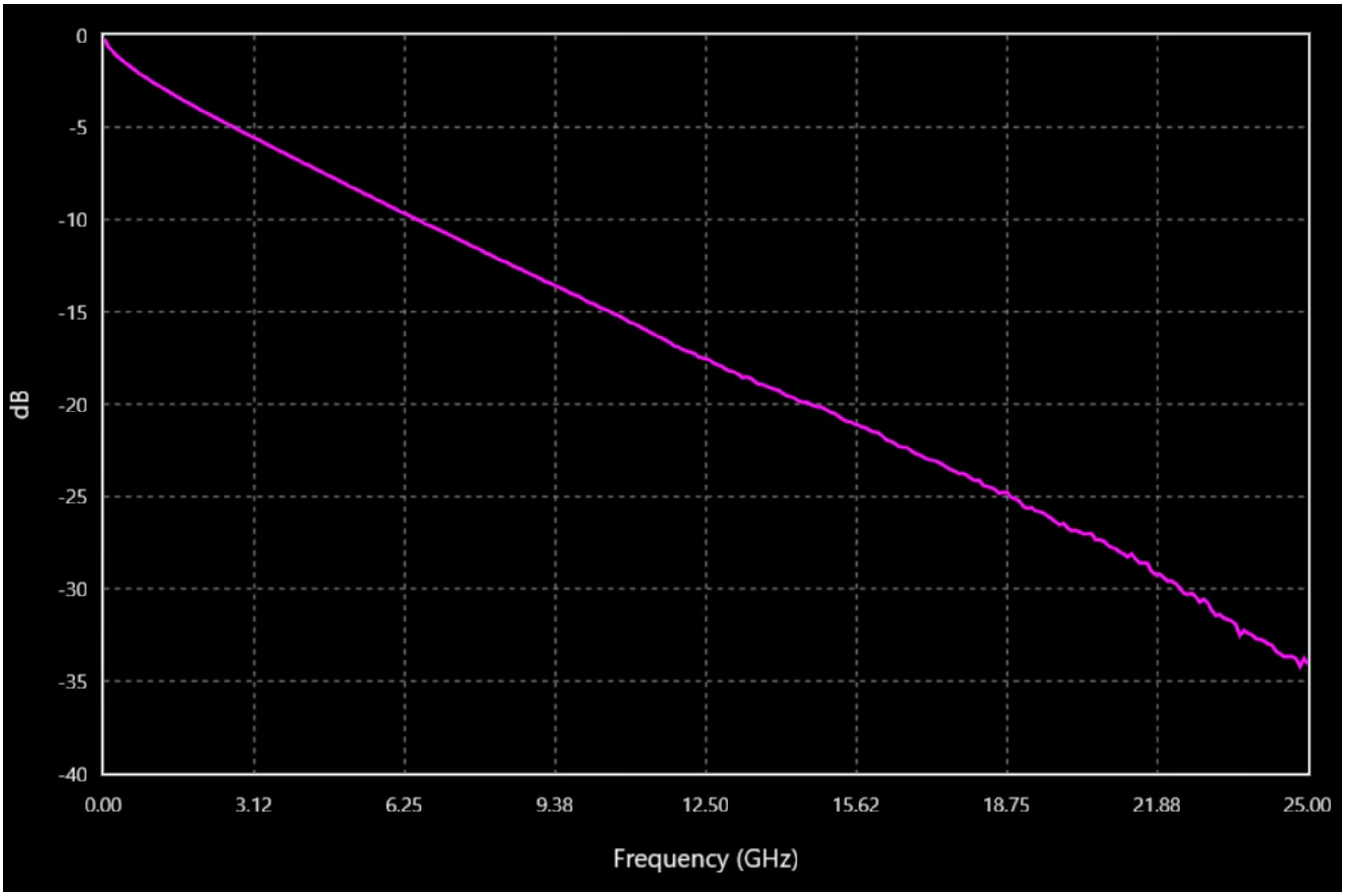


**Figure 5. Insertion Loss of the 17-inch pair on the ISI board.**

For our 20 Gb/s data rate that is about 15 dB of loss to de-embed at the 10 GHz fundamental frequency, but almost 30 dB at the 20 GHz bandwidth limit of the de-embed filter. **Figure 6** shows the measurement without QuietChannel technology. The bottom trace (purple) is for the differential pair without the de-embed. The orange trace above that is the de-embedded waveform created by SIM. The top left eye diagram is based on the differential pair without de-embed and is completely closed for these experiments. The top right waveform is the eye diagram of the de-embedded waveform with measurements 1 and 3 showing the jitter details.

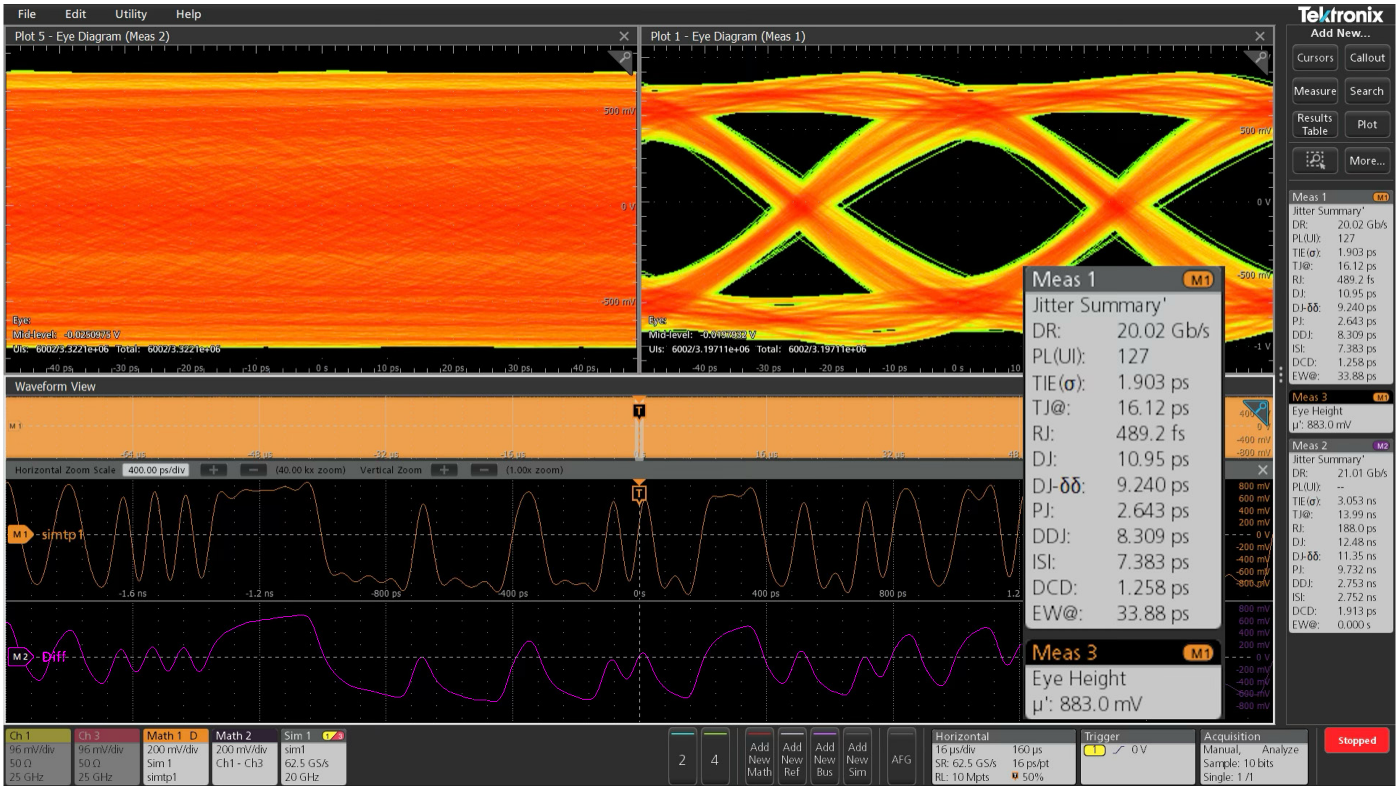


Figure 6. 20 Gb/s without QuietChannel technology through 17-inch trace.

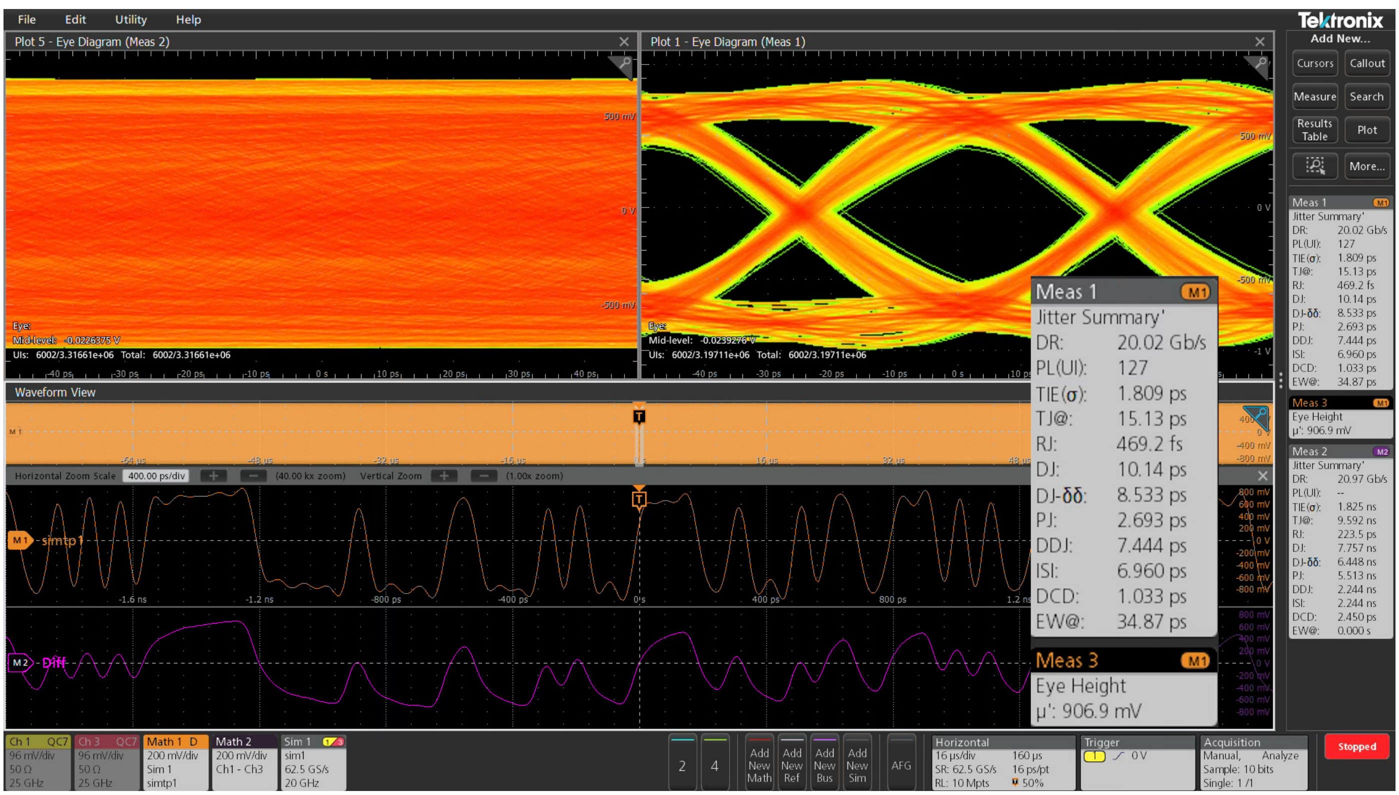


Figure 7. 20 Gb/s with QuietChannel technology through 17-inch trace. Eye height has increased by 3%.

**Figure 7** shows the same measurements with QuietChannel technology enabled. With the relatively short trace we see an improvement of 3% in eye height and 1% in eye width. That margin may not seem like much, but that could make the difference between passing or not passing compliance or a significant yield hit. The next experiments show how this impact increases with the channel loss.

This second experiment keeps everything the same but switches to the 24-inch long traces on the ISI board. **Figure 8** shows the loss has increased to 20 dB at the 10 GHz fundamental and near 35 dB at the 20 GHz SIM filter frequency limit. This is a relatively small increase in loss, but the effects of QuietChannel technology have become more pronounced. With higher data rates this kind of loss is very realistic and much lower than many channels. Modern standards support 25-30 dB loss at the fundamental compared to this 20 dB loss.

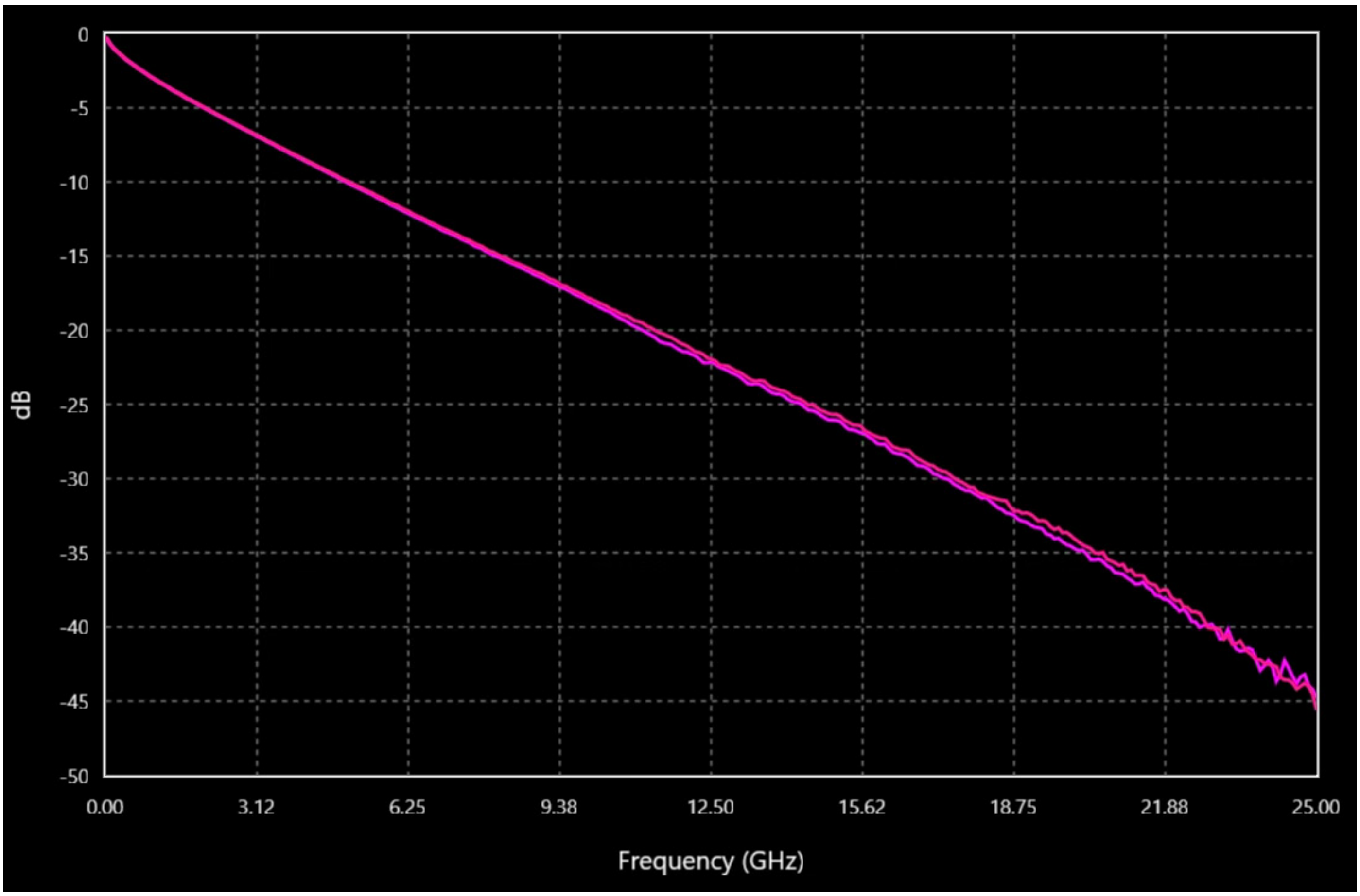


**Figure 8. 24-inch ISI Board Insertion Loss**

**Figure 9** shows screenshots of the eyes created without QuietChannel technology on the left and with QuietChannel technology on the right. Here we see an obvious difference in the eye diagram and the measurement shows a 31% increase in eye width and 34% increase in eye height. Notice that there is a drastic reduction in random jitter (RJ) of around 40%. The reduction in RJ comes from the lower noise, since noise converts to random jitter as fast edges are sampled.

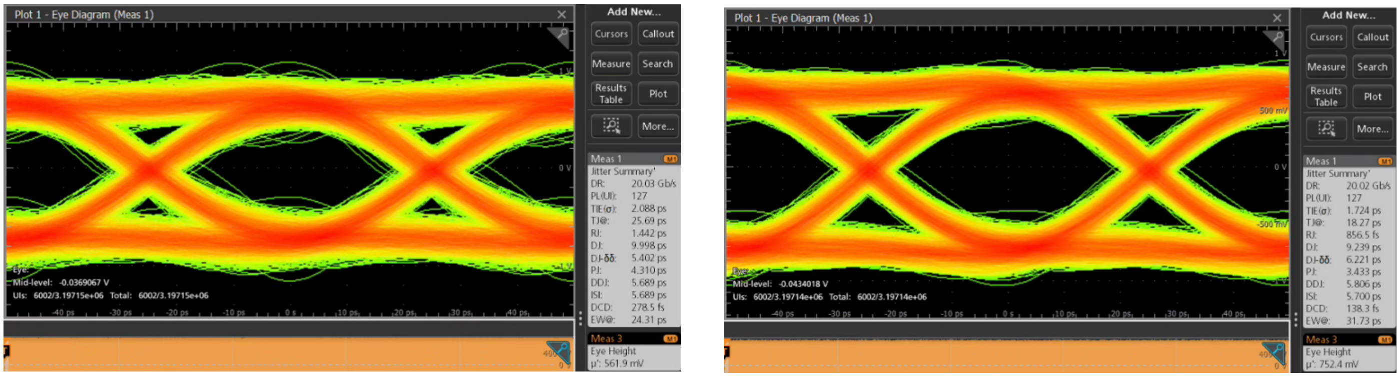


**Figure 9. 20 Gb/s de-embed of the same 24-inch trace. The eye diagram on the left was measured without QuietChannel technology and shows random jitter (RJ) of 1.4 ps. The eye diagram on the right was measured with QuietChannel technology and shows RJ of about 860 fs.**

To see why QuietChannel technology has such an effect we can look at an FFT of the signal and noise floor with and without QuietChannel technology. This third experiment uses a 16 Gb/s signal using the 31-inch long traces which have a loss of 20 dB at the 8 GHz fundamental and 35 dB at the second harmonic. In **Figure 10**, the Fast Fourier Transform (FFT) of Math 3 (red trace) shows the presence of the PRBS signal superimposed on the oscilloscope's inherent noise floor. The top FFT of Math 4 (green trace) shows the FFT of the SIM waveform that has de-embedded the channel loss. The signal and the noise are boosted by the same amount.

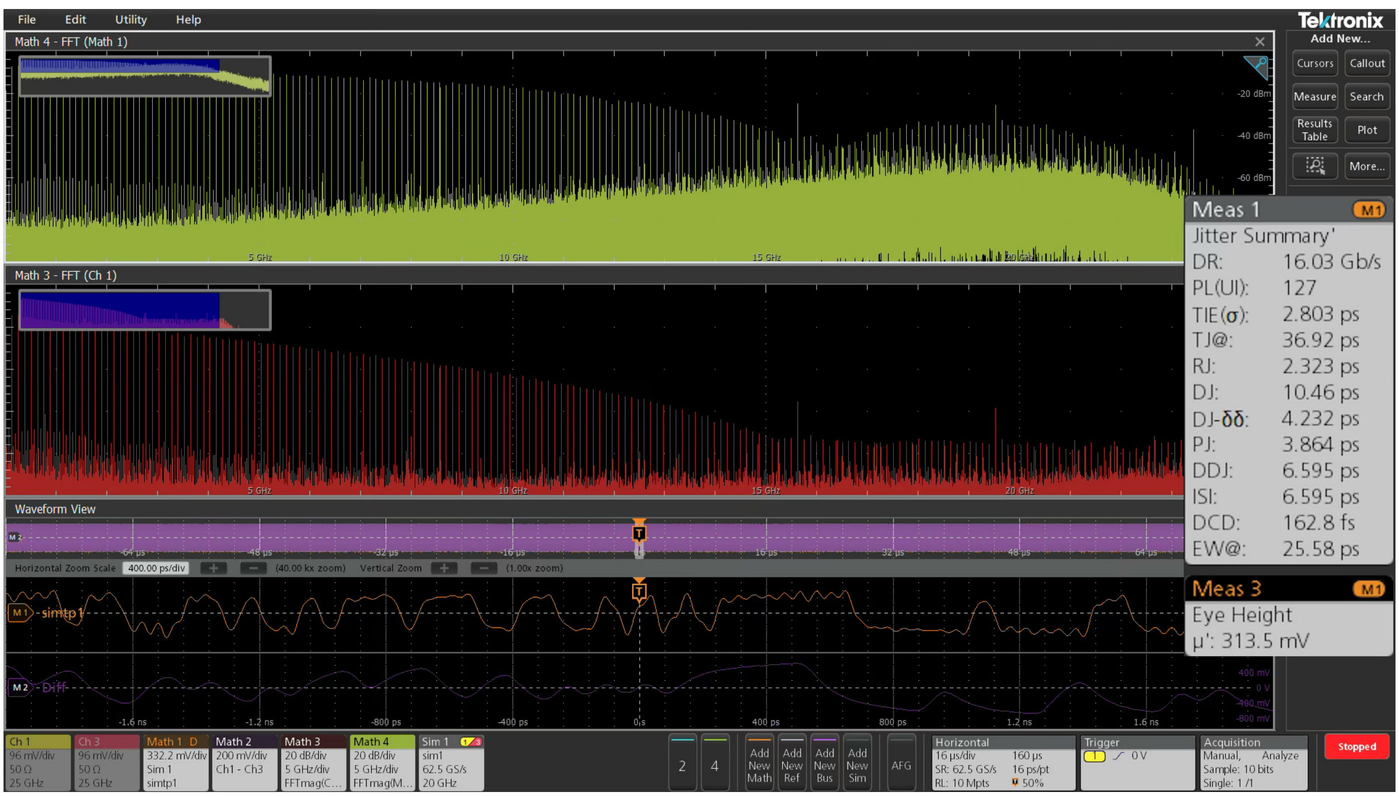


**Figure 10. FFT of a 16 Gb/s signal over 31-inch traces without QuietChannel technology.**

In **Figure 11** the eye height more than doubles, and that can be seen in the signal to noise ratio visible in the FFT. This is due to the noise shaping done by QuietChannel technology.

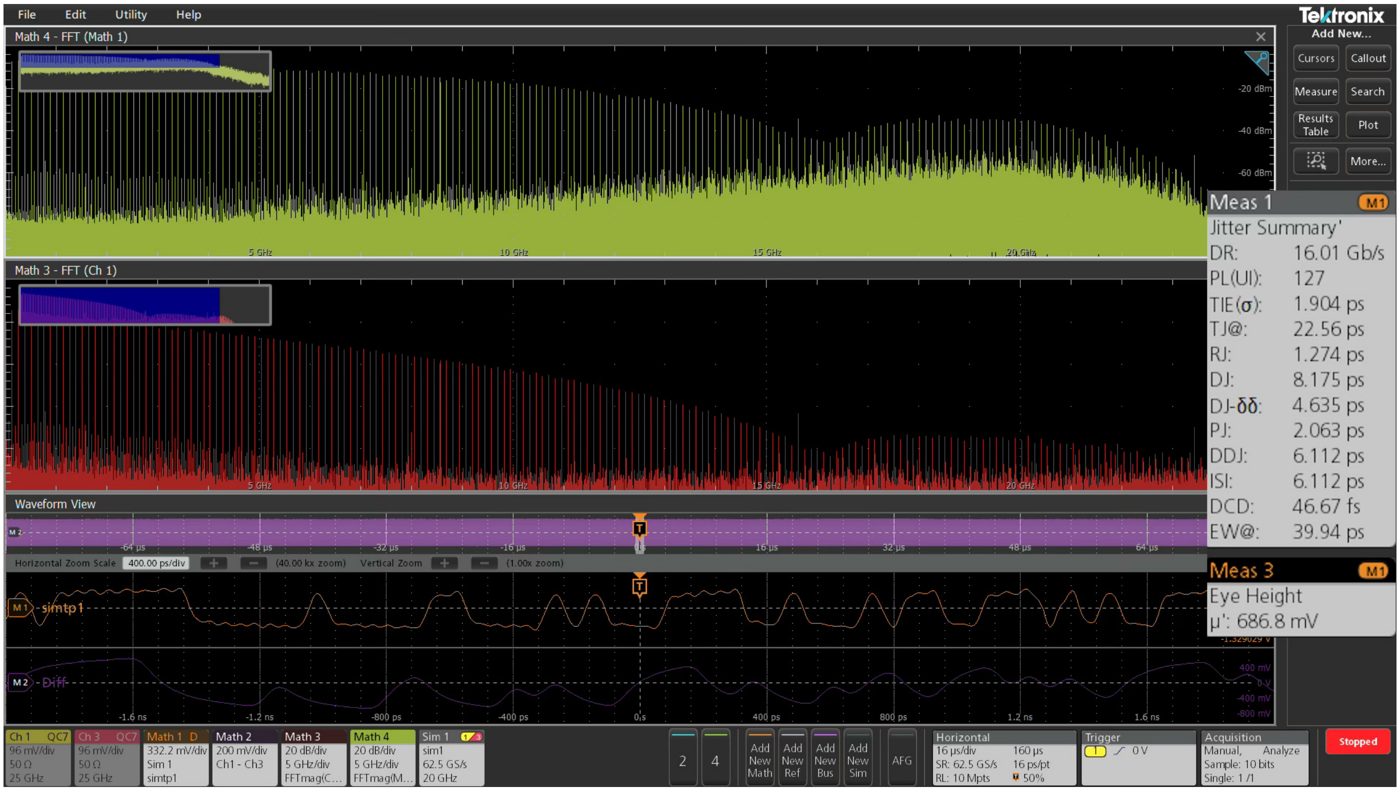


**Figure 11. FFT of a 16 Gb/s signal over 31-inch traces with QuietChannel technology activated. Eye height is more than doubled.**

**Figure 12** shows a zoom in of the FFT with QuietChannel technology turned off on the top and QuietChannel technology turned on at the bottom. The signal to noise ratio improves by about 5 dB because the oscilloscope noise floor is shaped at higher frequencies.

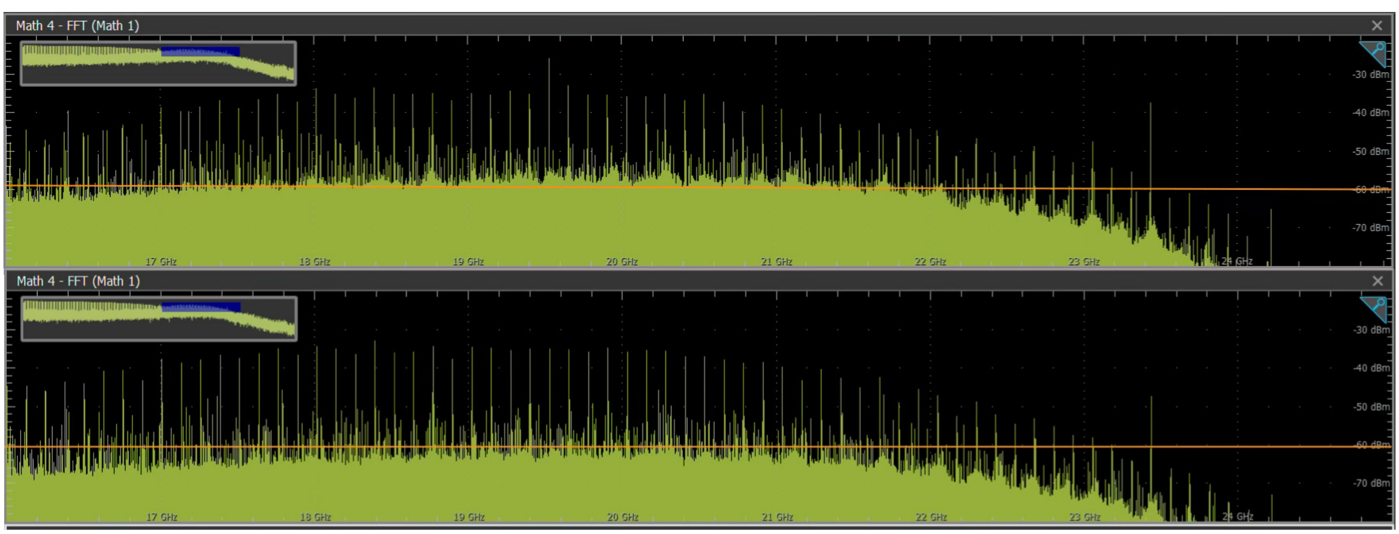


**Figure 12. FFT comparison without QuietChannel technology™ (top) and with QuietChannel technology (bottom).**

The noise shaping of QuietChannel technology can be used in many applications. For high-speed serial applications where de-embed is required, this is a revolutionary technology that enables a much more accurate view of the waveform at the transmitter.

## QuietChannel Technology Setup

7 Series DPO oscilloscopes are the first instruments to incorporate QuietChannel technology. The preamp ASIC in these products has 7 different QuietChannel technology settings that target different amounts and slopes of channel loss and bitrates. **Figure 13** shows the panel used to configure a channel on the 7 Series DPO.

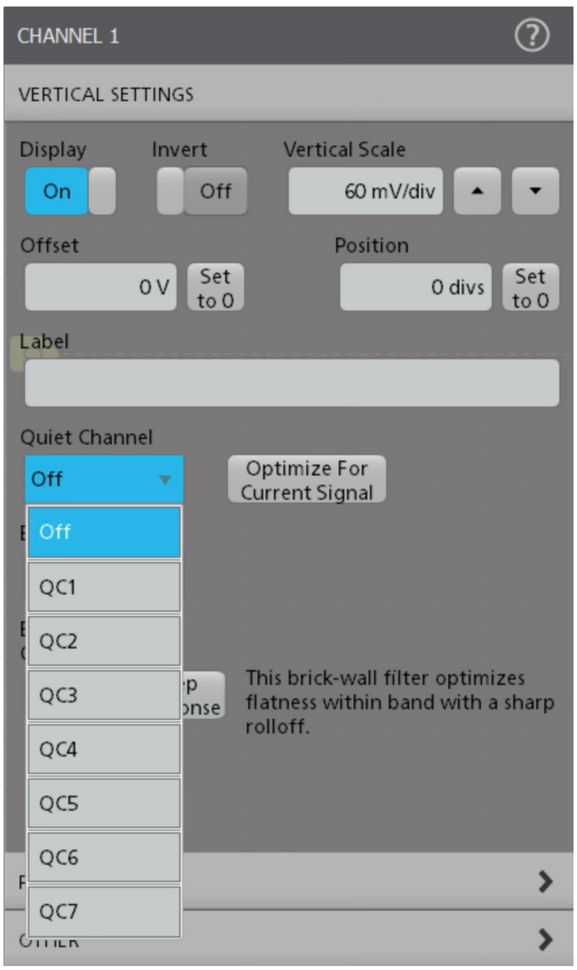


**Figure 13. QuietChannel technology settings.**

Figuring out which setting to use for a particular DUT can be challenging. The optimal setting may change with bit rate, drive strength, and pre-emphasis settings. The Optimize for Current Signal button optimizes the signal to noise ratio of the oscilloscope channel based on the current signal being measured. The oscilloscope software evaluates the signal to noise ratio at each QuietChannel technology setting including off. This enables the optimal setting to be found for current transmitter and channel conditions. The setting may also be configured manually to maintain consistent setups when testing multiple devices.

De-embedding is a critical tool for removing the influence of cables, probes, fixtures and connectors, when measuring signals carrying high speed data. In many cases it is required for testing for compliance to standards. However, de-embedding can also boost instrument noise, resulting in instrument noise negatively impacting test results. This paper has shown how this patented technology incorporated in the 7 Series DPO oscilloscope uses a unique combination of hardware and software to "shape the noise floor of the oscilloscope" and minimize the impact of instrument noise on de-embedded signals. Several experiments were performed to demonstrate the value of QuietChannel technology, especially when de-embedding lossy channels. For more information about the 7 Series DPO and QuietChannel technology, please visit tek.com.

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