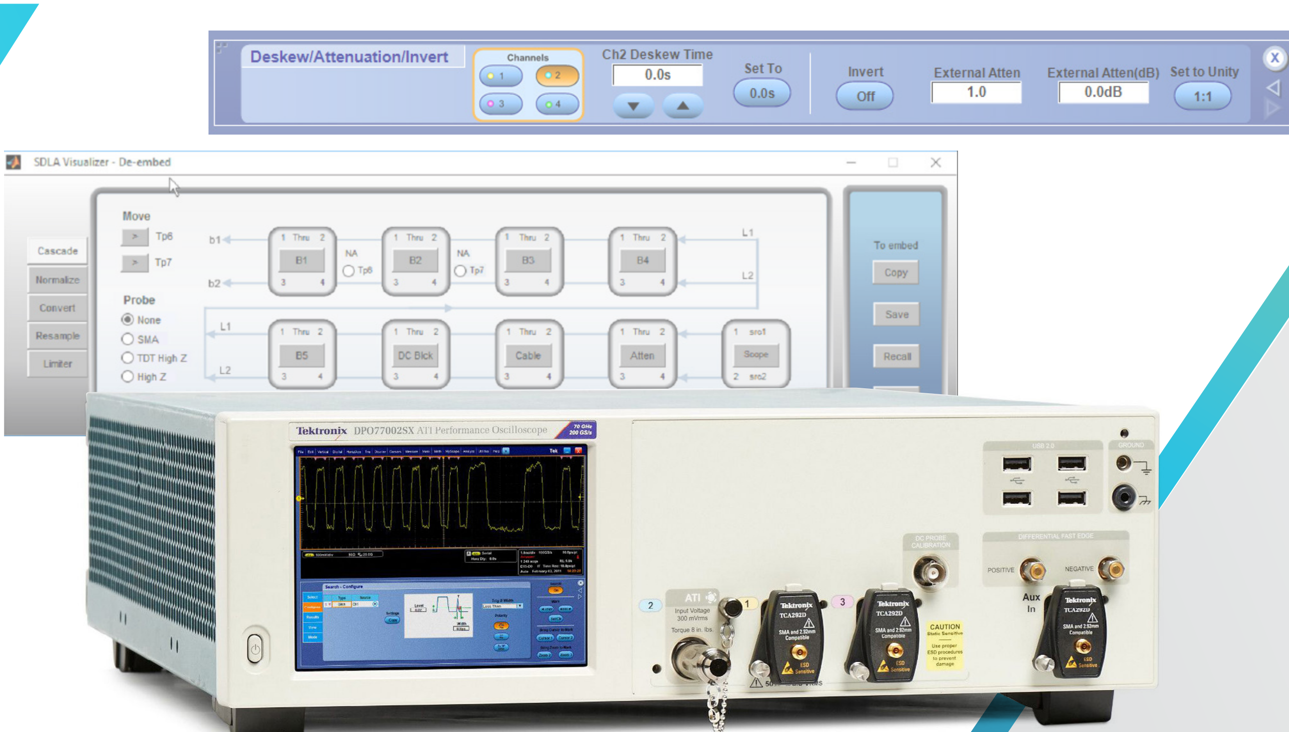
Using an Attenuator with Oscilloscopes

WHITE PAPER



Tektronix

Types of Oscilloscope Channels

Tektronix provides two types of oscilloscope acquisition channels on MSO/DPO70000 and DPO70000SX series real-time oscilloscopes. These channel types are:

- TekConnect channels, up to 33 GHz bandwidth, sample rate up to 100 Gs/sec, internal switchable attenuators which change based on user V/div setting. Applicable to MSO70000C/D/DX, and DPO70000SX models.
- Asynchronous Time Interleave (ATI) channels up to 70 GHz bandwidth, sample rate of 200 Gs/sec. These ATI inputs support 300 mV single-ended signals directly, and larger swing signals with external attenuators. Applicable to DPO70000SX models ≥ 50 GHz.

Typical Use of Attenuator Stages

Traditional oscilloscope channels use an internal switchable attenuator matrix to support various V/div settings. Attenuator values are controlled via switching relays based on various V/div settings from the user through front panel controls, GUI changes, or programmatic interface (PI). Different value attenuators are switched into the acquisition path depending on the vertical scale. Implementations may have 1 up to N stages depending on pre-amp gain input range and desired attenuation steps. TekConnect inputs on DPO70000SX oscilloscopes implement a 1-stage variable attenuator. For illustration purposes a three-stage example is shown in **Figure 1**.

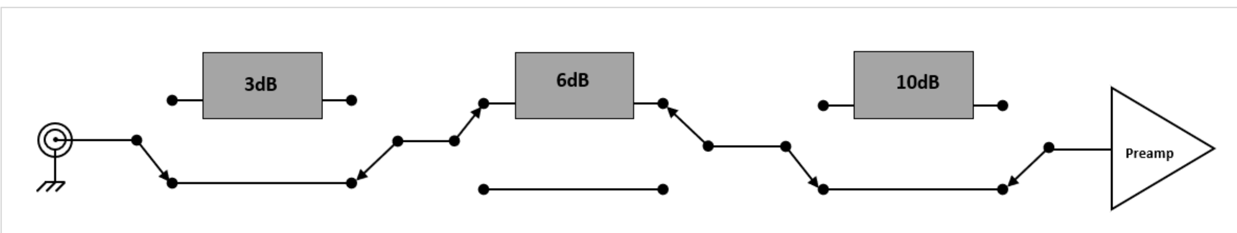


Figure 1 - Three stage internal attenuator switch matrix.

Another approach used in Tektronix' high-bandwidth ATI channel architecture is to connect the signal input directly to the pre-amp. In this case, no relays nor switched attenuators are present in the signal path, keeping signal fidelity as high as possible. This ATI signal path shown in **Figure 2** below.

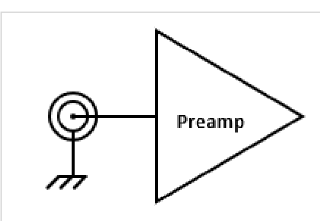


Figure 2 - Tektronix DPO700000SX Series high bandwidth ATI inputs connect directly to the pre-amp input, preserving signal fidelity.

TekConnect channels: Internally switched attenuators provide best ease-of-use via internally controlled matrix, but this comes with a downside of optimizing best attenuator value to maximize signal fidelity of your signal. At scope bandwidths ≤33 GHz this trade-off is less critical than for higher bandwidths.

ATI channels: Mechanical or electronic attenuators can degrade over time. They also increase repair time and cost since components need to be integrated onto the acquisition board. External attenuators can be chosen, installed, and swapped out for a fraction of the cost with little down time. The user can match the attenuator value selected to the application, signal characteristics, and test pattern to optimize V/div scaling vs noise as shown in **Figure 3** below. If an attenuator is damaged or wears out it can be replaced without removing instruments from the test environment.

Figure 3 shows a plot of noise measured across voltage FULL-SCALE SETTING range. One oscilloscope using external attenuators is shown in blue, compared to another oscilloscope using internal six-stage switchable attenuation shown in red. Notice the peaks in each noise curve. These peaks indicate where an attenuator value is changed. For the red curve, internal switches change the signal path thru attenuators, as shown in **Figure 1**. For the blue curve, external attenuators are changed by hand on the front of the scope channel. In each case, peaks are evident when attenuator value is changed. However, these peaks are lessened on the blue curve for external attenuator case, resulting in less vertical noise. Further, you will notice the natural shape of the amplifier relative to each inflection where a different attenuation value was set. A flatter curve is better, resulting in higher fidelity across the voltage range with less noise.

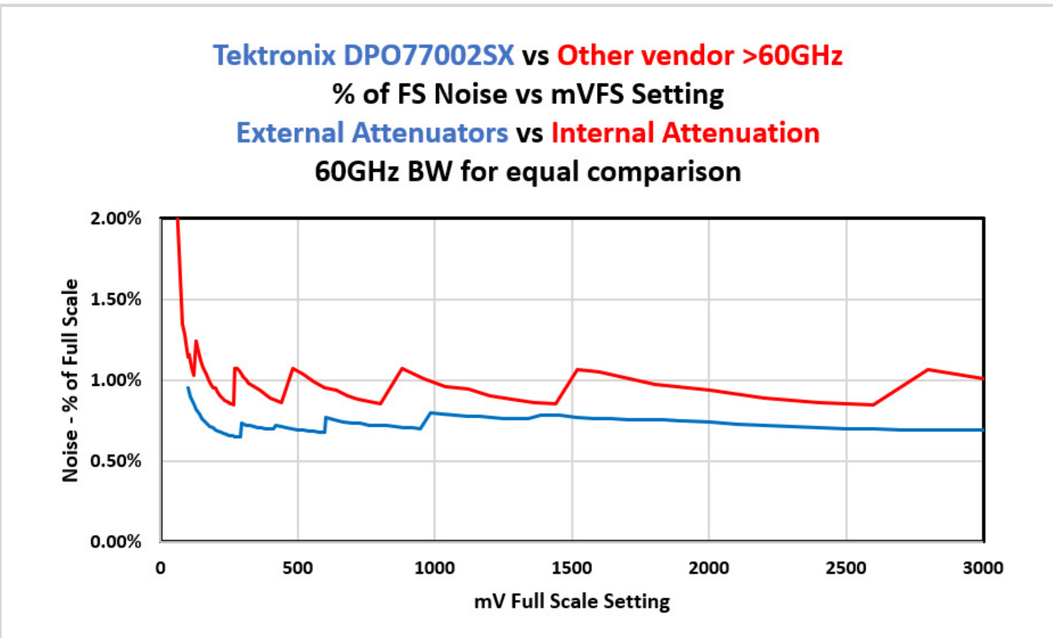


Figure 3 - Noise as a percent of full-scale voltage range on Tektronix DPO77002SX versus other vendor's >60 GHz Oscilloscope

External Attenuator Details

During development of the high-bandwidth ATI acquisition channel architecture, Tektronix performed extensive market research for applications requiring bandwidths ≥50 GHz. Primary use cases were ultra-fast high-speed serial data (PCI Express® and Ethernet), wireless/RF, coherent optical, and physics research. Each application has its own specific signal characteristics: test patterns, AC versus DC coupling, single-ended versus differential, voltage swing, and bandwidth response. Tektronix determined that a simple, high-fidelity acquisition system with user-selectable attenuators yielded best results over the applications requiring high bandwidth acquisitions.

Thus, high-bandwidth ATI channels require external attenuators. The user selects attenuator values with appropriate attributes when single-ended peak-to-peak signal swing is ≥ 300mV. Tektronix offers accessory kits containing precision 1.85mm high bandwidth (+67GHz) calibration-grade attenuators from Anritsu. These attenuators should be installed in the signal path of a DPO70000SX high-bandwidth ATI channel. Tektronix provide three kits to choose from shown in **Figure 4**. One kit is required per acquisition channel.

Tektronix Part Number	Description
DPO7RFK1	3 dB, 6 dB, 10 dB, and 20 dB attenuator kit with 1.85 mm connectors, characterized to 70 GHz. Includes serial numbers and S-parameters for each attenuator.
DPO7RFK2	Includes the contents of DPO7RFK1 plus 67GHz DC Block and 4 adapters for attaching to 1.85mm (V) and 2.92 mm (K) connectors.
DPO7RFK3	RF channel timing de-skew kit, 65 GHz, 1.85 mm. Kit includes a high-performance power divider and 1.85 mm male-male connector adapter.

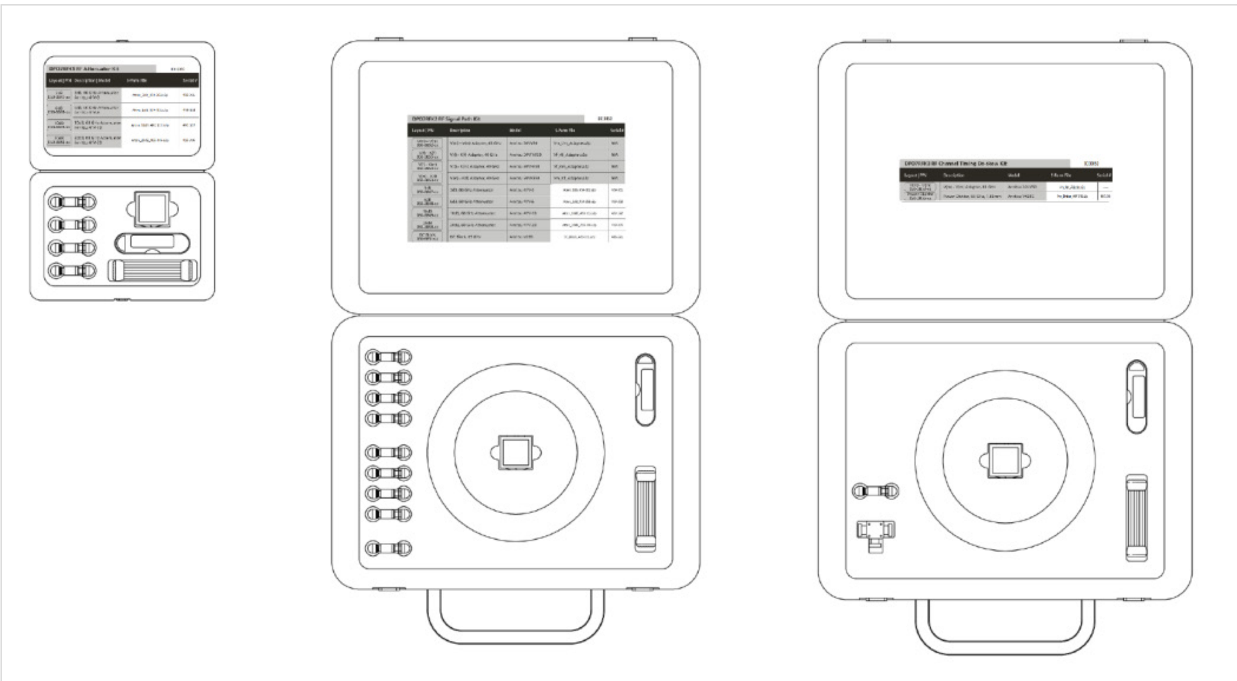


Figure 4 - DPO7RFK Kits from left to right: DPO7RFK1, DPO7RFK2, DPO7RFK3.

Placement of External Attenuators

Ideal physical placement of external attenuators will depend on your application and use case. External attenuators may be placed near the DUT, in-line with other components such as DC blocks. Attenuators may also be placed directly on the front-end of each high-bandwidth ATI channel input.

NOTE: *If using adapters for 2.92 mm (K) or 2.92 mm cables, these coax connector types have lower bandwidth capability and will limit the higher frequency signal content reaching the oscilloscope for acquisition.*

How Does the Oscilloscope Know an Attenuator is Installed?

There are two methods for oscilloscope attenuator compensation.

METHOD #1: Once an appropriate attenuator value (dB) for the signal has been determined and attenuator installed, the user should enter the attenuator dB value into the oscilloscope for compensation (VERTICAL drop-down menu → ATTENUATION → <*enter dB value for each channel*>). This method is easy and fast and may be implemented manually or via programmable interface. The attenuator value entered will automatically be applied to V/div scaling of the acquisition channel and promulgate to all internal scope functions: triggering and measurements. This is described in the direct attenuator compensation section below.

METHOD #2: The user may perform a full de-embed of attenuators, DC blocks, cables, switches, and adapters in the signal path. De-embed of these components is based on modelled or measured s-parameters and is a more precise way to compensate for non-linear frequency dependent losses as well as any reflections. This method is more time consuming and requires the user to create de-embed filter files that are applied thru math functions in the oscilloscope. This is described in the de-embedding section below.

Direct Attenuator Compensation

When quality cables are used and only linear loss of the attenuator is considered for testing purposes, the user should set the oscilloscope to compensate directly for the attenuator (dB). This is done via the VERTICAL menu under ATTENUATION. When the attenuator value is entered into the menu, the oscilloscope will automatically adjust the V/div scaling for acquired and saved data. **Figure 5** below shows the VERTICAL configuration menu. Attenuator value is entered into the cell labelled **External Atten(dB)**.

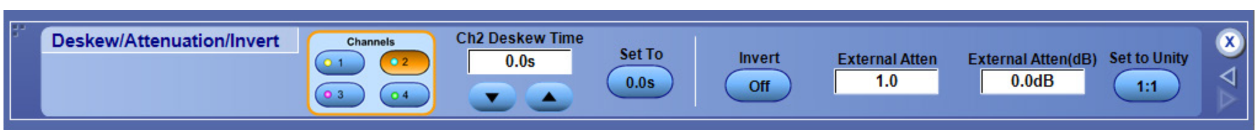


Figure 5 - Direct input of external attenuation value into scope channel settings.

De-embedding

For a more precise accounting of all losses and reflections due to cables, attenuators, switches, and any other elements in the signal path, it is recommended to use a de-embed filter. This filter can correct for frequency dependent losses and impedance mismatches found in complex interconnects, allowing the user to maximize accuracy and signal fidelity.

To aid in this process, attenuator kits sold by Tektronix come with a USB stick that include s2p 2-port measured s-parameter files. These s2p files may be imported into Tektronix Serial Data Link Analysis (SDLA64) software to create de-embed filters. **Figure 6** below shows an example of an external attenuator and other required interconnects to deliver the signal from the DUT to the oscilloscope. The user should match the physical layout and ordering of the components and de-embed the losses, reflections, coupling, and other effects of these components being connected in the signal path. The order of components entered should match the physical connection so that reflections are accounted for correctly. The highlighted circles in **Figure 6** and **Figure 7** show how this is entered into SDLA64 for de-embed.

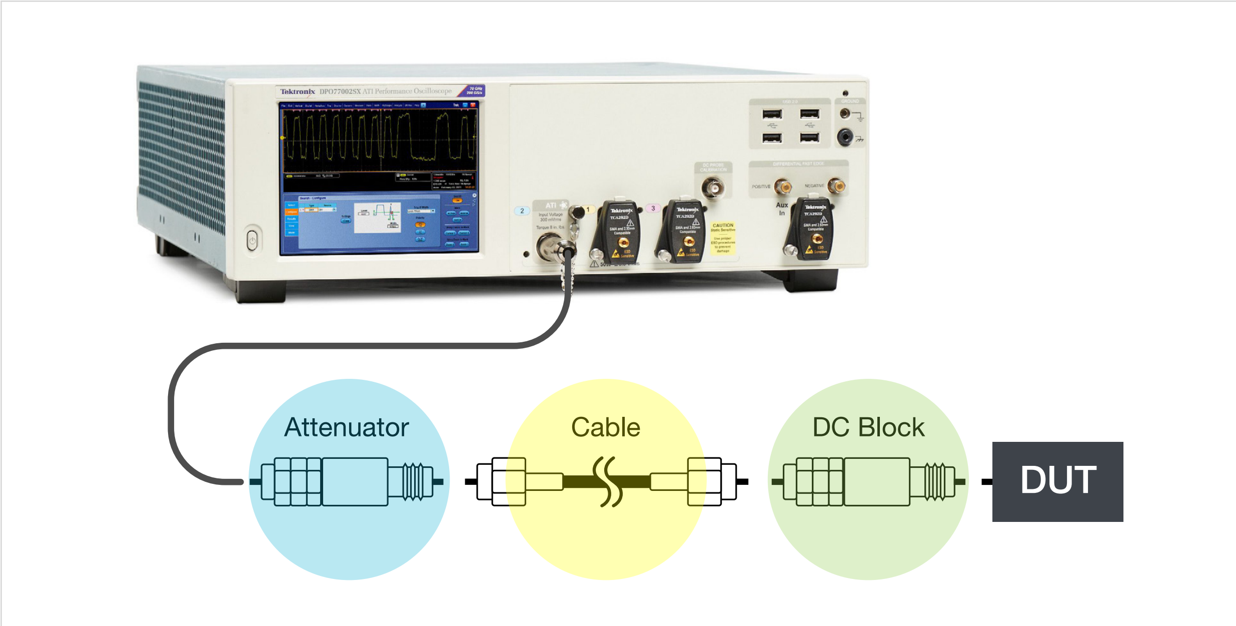


Figure 6 - Components to be modeled in SDLA for de-embed.

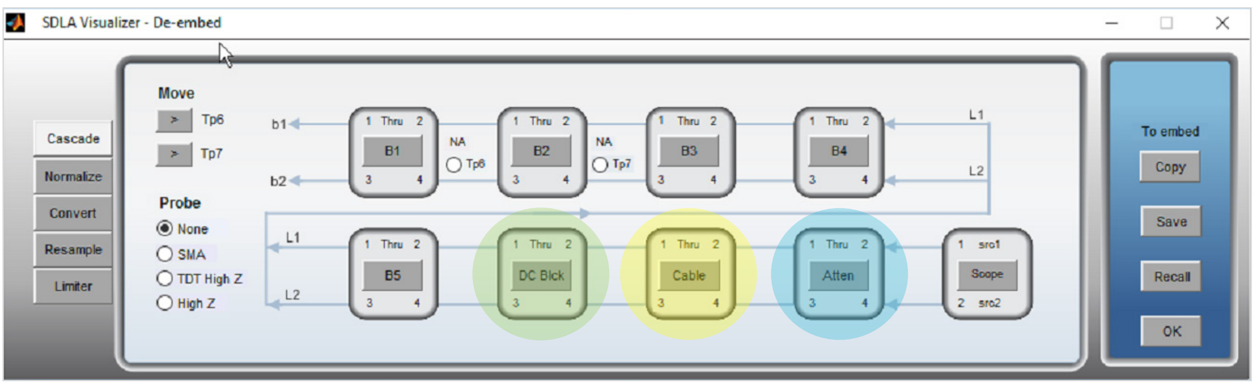


Figure 7 - Components modeled in SDLA.

How Do You Select the Correct Attenuator Value?

Attenuators are available in many different values. You may choose single dB steps or larger steps depending on your testing needs. High-bandwidth ATI input channels on Tektronix DPO70000SX oscilloscopes natively support up to 300 mV single-ended signal swings with no external attenuation. If your single-ended signal is larger than 300 mV (600 mV differential), an attenuation value should be determined to best fit your max signal swing. High-bandwidth ATI channels support a 3:1 pre-amp gain adjustment via V/div settings for fine vertical adjustments.

For high-speed serial applications such as PCI Express, a 6 dB attenuator is recommended for high-bandwidth ATI channels to meet all signal swing combinations from 2.5 Gb/s NRZ up to 64 GT/s PAM4. 6 dB attenuation supports characterization, margin, and compliance testing across all PCI Express data rates and test patterns. If portions of your test plan involve testing higher frequency patterns (toggle, 52UI jitter, 0303) where these patterns produce a smaller voltage swing, the attenuator value may be reduced appropriately for that test pattern if desired.

Table 1 shows commonly available attenuator values, and voltages supported by these attenuator values in your test setup. Voltage values shown are for single-ended capture on each individual channel input of the oscilloscope and should be doubled for differential swing signals.

General guidance:

- Compare Full Scale voltage vs. attenuator value in **Table 1** below.
- Choose the smallest attenuator value that supports highest required voltage.

Example: PCIe® Gen6 normal swing mode specifies 800mV (Min) to 1000 mV (Max) differential voltage swing ($V_{TX\text{-}DIFFPP}$, BASE spec table 8-6). This equates to 400mV (Min) to 500 mV (Max) single-ended swing ($V_{diff}/2$). Enter **Table 1** below with 500 mV single-ended voltage value. A 5 dB attenuator would be ideal since it supports 178 mV to 535 mV, slightly above 500 mV (Max). However, there are two reasons why it would be better to choose a 6 dB attenuator in this case:

- Precision 5 dB attenuators do not come in the DPO7RFK attenuator kits.
- 6 dB attenuators provide voltage margin above 500 mV (Max), with a single-ended voltage range of 200 mV up to 600mV (diff range of 400 mV to 1200 mV).

Note: For PCIe Gen6 reduced swing signaling mode (BASE spec section 8.3.3.10), consider <6 dB attenuators for smaller V_{diff} swings.

Attenuator Value	Full Scale Voltage Range	Attenuator Value	Full Scale Voltage Range
None	100 mV to 300 mV	7 dB	223 mV to 670 mV
1 dB	112 mV to 336 mV	8 dB	251 mV to 755 mV
2 dB	126 mV to 378 mV	9 dB	281 mV to 845 mV
3 dB	141 mV to 424 mV	10 dB	316 mV to 950 mV
4 dB	158 mV to 476 mV	11 dB	353 mV to 1.06 V
5 dB	178 mV to 535 mV	12 dB	396 mV to 1.19 V
6 dB	200 mV to 600 mV	20 dB	1 V to 3 V

Table 1 - Full-scale range of DPO70000SX High Bandwidth ATI input with external attenuators.

Attenuator values shown in blue are included in attenuator kits from Tektronix.

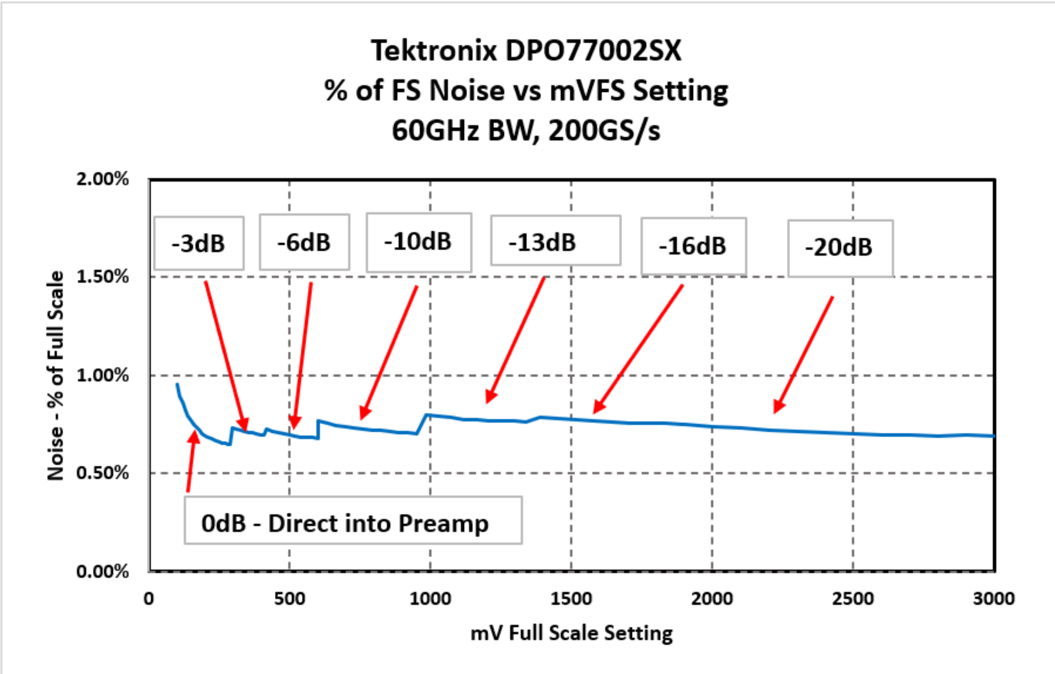


Figure 8 - Baseline noise as a percentage of full-scale input voltage range with common external attenuator values.

Compliance Software

Tektronix provides transmitter and receiver compliance software for many high-speed serial applications. The TekExpress automation framework allows the user to either specify attenuator values directly or provide de-embed filters for use in the compliance workflow. This dual mode approach allows the user to choose between the two attenuator compensation methods described above and ensures best signal fidelity and accuracy when making measurements in accordance with a specification.

Figure 9 and **Figure 10** below show the Tektronix PCI Express Gen6 transmitter software, and locations where the user would specify the external attenuator value.

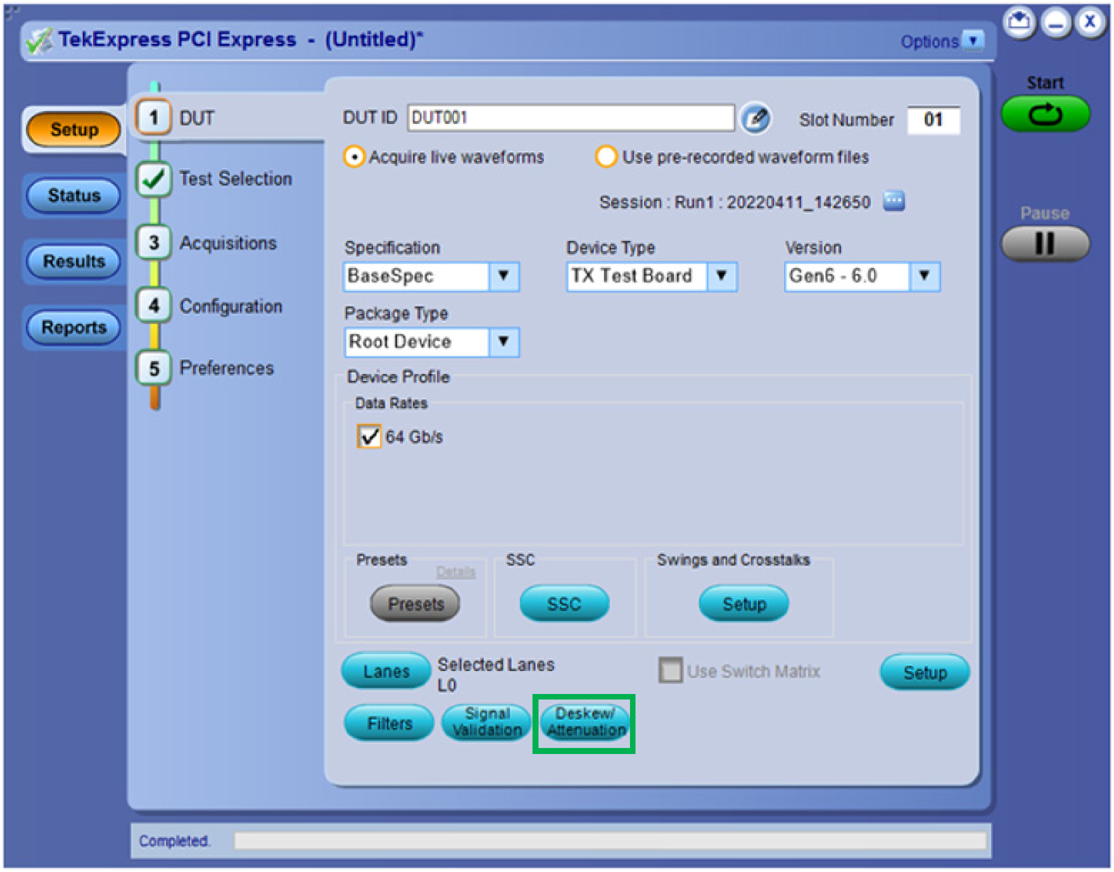


Figure 9 - Click the Deskew/Attenuator button in TekExpress PCIe Gen 6 Tx software to open the external attenuation settings.

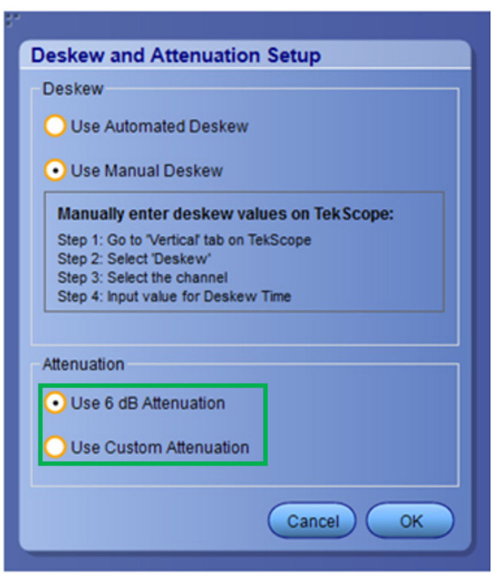


Figure 10 - Configure external attenuation setting.

Summary

Using attenuators to pre-condition incoming signals before acquisition in an oscilloscope channel is common practice. When technology and signal fidelity requirements allow, attenuators may be placed inside the instrument and switched automatically by user interface controls. When finer control of the signal quality attributes is needed, external attenuators in conjunction with other components such as DC blocks and adapters are added. Tektronix DPO70000SX series oscilloscopes' high-bandwidth ATI channels rely on external attenuation to provide the best combination of signal fidelity, ease of use, low noise across V/div settings, and optimization for many applications. This led to a simpler acquisition channel design which keeps the input signal path as short and clean as possible during the digitizing process. The user has ultimate control of the type, quality and attenuation value that best fits their measurement needs.

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