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How Clipping Warnings Help to Minimize the Impact of Clipping on 6 Series and 6 Series B MSO Oscilloscopes

TECHNICAL BRIEF

Clipping is an undesirable condition on oscilloscopes, and it is essential to understand how it impacts test and measurement setups when analyzing hardware, capturing waveform data, and performing automated measurements. Signal clipping can result in a distorted waveform on the oscilloscope display and cause measurement inaccuracies or signal fidelity loss. By understanding how an oscilloscope handles clipping, designers can make informed decisions regarding their test setup and ensure accurate measurements during testing. This technical brief introduces the clipping concept, clipping indicators and warnings, and how to avoid clipping on the Tektronix 6 Series and 6 Series B MSO.

Traditionally, engineers reduced the vertical scale on digital oscilloscopes to examine finer waveform details. However, setting the vertical scale too low can cause larger portions of the input signal to exceed the oscilloscope's input range, resulting in signal clipping or distortion. This situation is called signal clipping (or just clipping). Specifically, clipping happens when the raw input signal contains samples or points above the maximum input range of the digital oscilloscope analog-to-digital converters (ADC) and the vertical settings. However, clipping can also occur when the waveform exceeds any limit along the signal path, even during digital signal processing.

Figure 1 shows how clipping displays on a Tektronix MSO64B as a warning indicator in the channel badge. There is a red "Clipping" indicator on the Channel 1 badge at the bottom, and the automated measurements for Channel 1 show a red "Neg clipping" warning. These warnings inform the user that the input signal contains samples exceeding the digital oscilloscope's vertical scaling and ADC range settings.

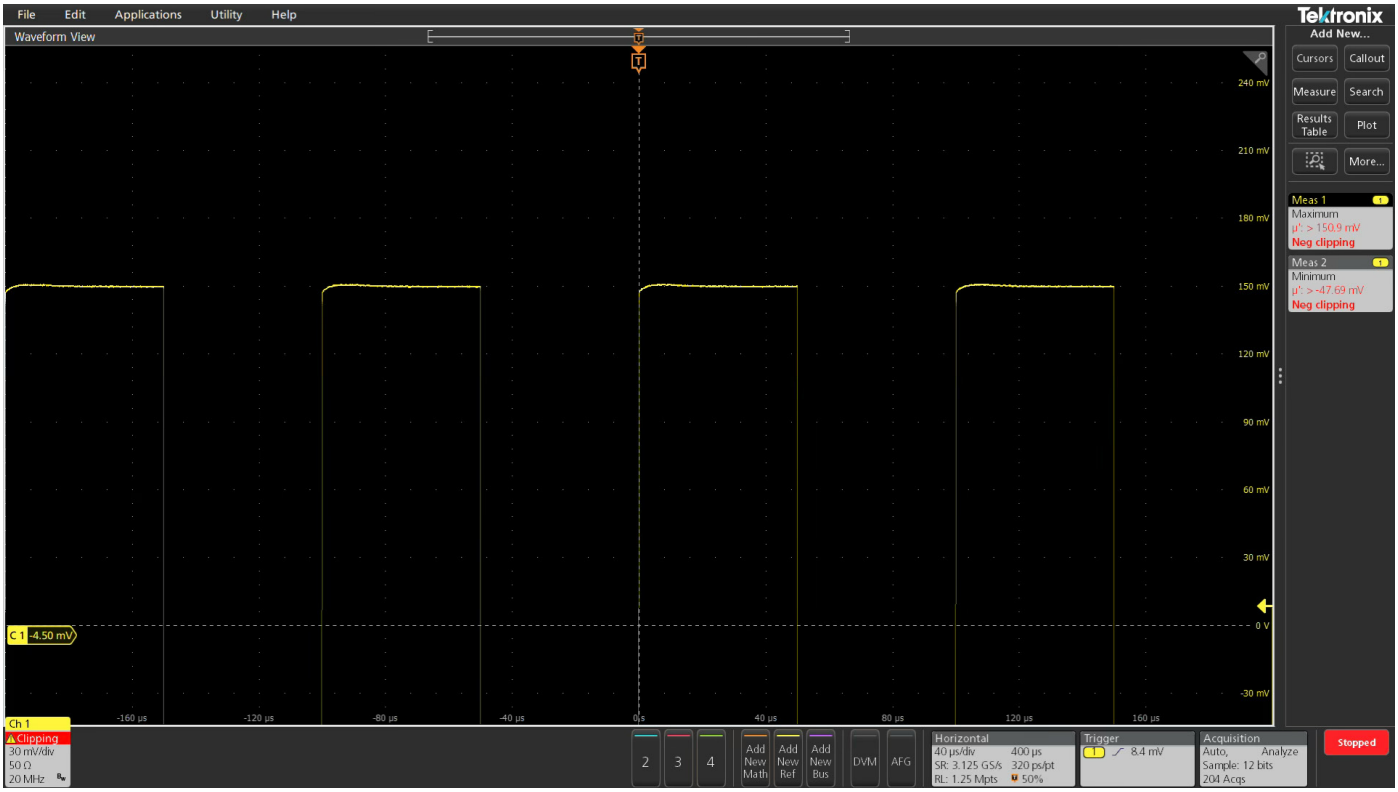

Figure 1 - Clipping demonstrated on Tektronix oscilloscopes, both in the channel badge and automated measurements.

By default, Tektronix oscilloscopes DO NOT allow users to disable or modify clipping warnings and indicators. These alerts are crucial for minimizing safety risks and preventing potential instrument damage when measuring high voltages, currents, or power. Furthermore, they notify users when measurement results may be unreliable, leading to measurement inaccuracies.

6 Series Clipping Indicators

Tektronix oscilloscopes provide two visible clipping warnings. These clipping warnings tell the user when the input signal exceeds the oscilloscope input range, causing a waveform to clip in the waveform view. The most direct and reliable approach is to observe the red "clipping" warning displayed on the channel badge at the bottom of the waveform view (see **Figure 2**). Additionally,

- Clipping warnings appear even when the viewable waveform does not contain any visible clipping. This means there is at least one instance of signal clipping detected in the acquisition.
- Clipping warnings remain present when acquisitions have stopped. In Tektronix digital oscilloscopes the ADC continuously samples even when the waveform view is paused.

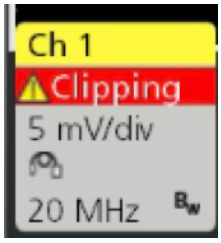

Figure 2 - Clipping warning in Channel 1 badge.

Automated measurements also have clipping warnings. When measurement qualifiers detect invalid inputs or waveform points, a red "pos clipping" or "neg clipping" warning appears in the measurement badge. **Figure 3** shows examples of these warnings. "Pos clipping" refers to a situation where the signal is being clipped above the ADC range, while "Neg clipping" indicates that the signal is being clipped below the ADC range.

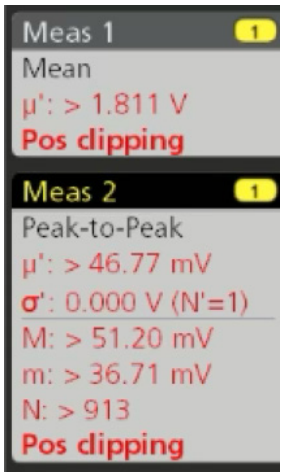

Figure 3 - Clipping warning in measurements badges based on current acquisition

Tektronix oscilloscope clipping warnings are software-generated flags in the oscilloscope signal path. **Figure 4** shows a generalized signal path diagram for the Tektronix 6 Series Oscilloscope. The channel badge clipping warning is tied to the 12-bit ADC at the Analog Front End of the Oscilloscope. The ADC possesses a fixed input range, and the Analog Front End will vertically scale the input to fit within the ADC input range. The channel badge clipping

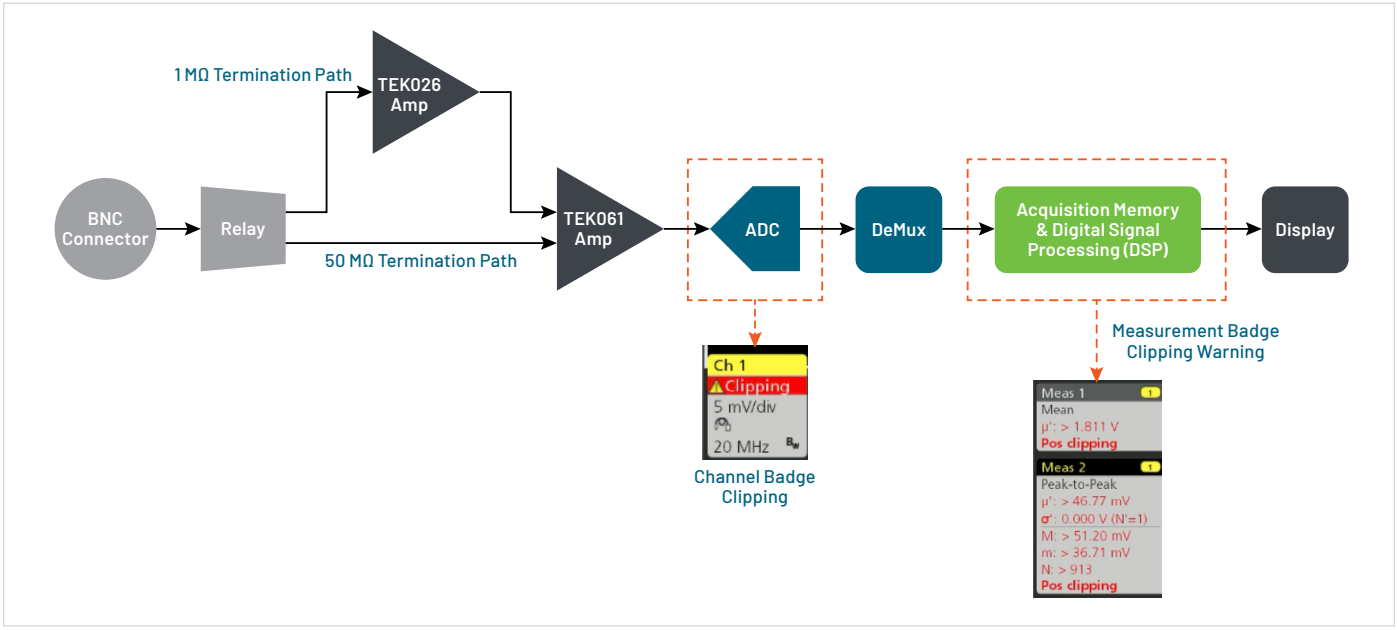

Figure 4 - The different clipping warnings and how they are tied into the 6 Series signal path. The TEK026 and TEK061 are custom Tektronix ASICs in the 1 MΩ and 50 Ω signal paths respectively.

warning is intentionally placed at the ADC to alert the user when clipping is detected before digitizing the analog input as the input moves along the signal path to be displayed. This prevents relying on the waveform being displayed and informs the user to make the necessary adjustments to avoid clipping at the ADC. Without this warning at the ADC, there is potential for the oscilloscope to display a distorted waveform when the input exceeds the ADC input range (i.e. saturation), leading to incorrect waveform representation.

Further down the signal path, waveform data is stored in memory (acquisition memory). Automated measurements operate on stored waveform data. Suppose the measurement qualifiers detect invalid inputs beyond the vertical scale settings (symbolically written as NaN or "Inf") in the data. In that case, the automated measurement badge will display a clipping warning similar to the one pictured in **Figure 4**.

When clipping occurs during acquisition, it is represented as NaN (Not a Number). For .csv and .MAT files, a NaN is represented as "Inf" or "-Inf", indicating positive or negative clipping, respectively. Although not the most direct indication of clipping, waveform data should be carefully examined for any occurrences of clipped waveform data as clipping waveform data could produce misleading or incorrect measurement results.

The Tektronix 6 Series and 6 Series B MSO contain analog (hardware) front-end and DSP (i.e. software) filtering. The 6 Series uses both hardware and DSP filtering to achieve significant low-noise performance for high bandwidths and finer vertical scales. The 6 Series hardware filtering is performed at the oscilloscope's analog front end (before the ADC). The software filtering operates farther down the signal path (after the ADC). It is critical to understand these details when a waveform on the display may not appear to be clipped but a clipping warning is displayed.

Figure 5 shows a noise waveform generated by a Tektronix AFG31000. The noise input is measured on an MSO64B with all 4 channels set to 50 Ω termination. The rest of the channel settings are shown in Table 1. Channels 1, 2, and 4 results correctly correlate the waveform to the channel badges' status. However, Channel 3 shows a clipping warning in the badge, yet the waveform does not visually appear to be clipping.

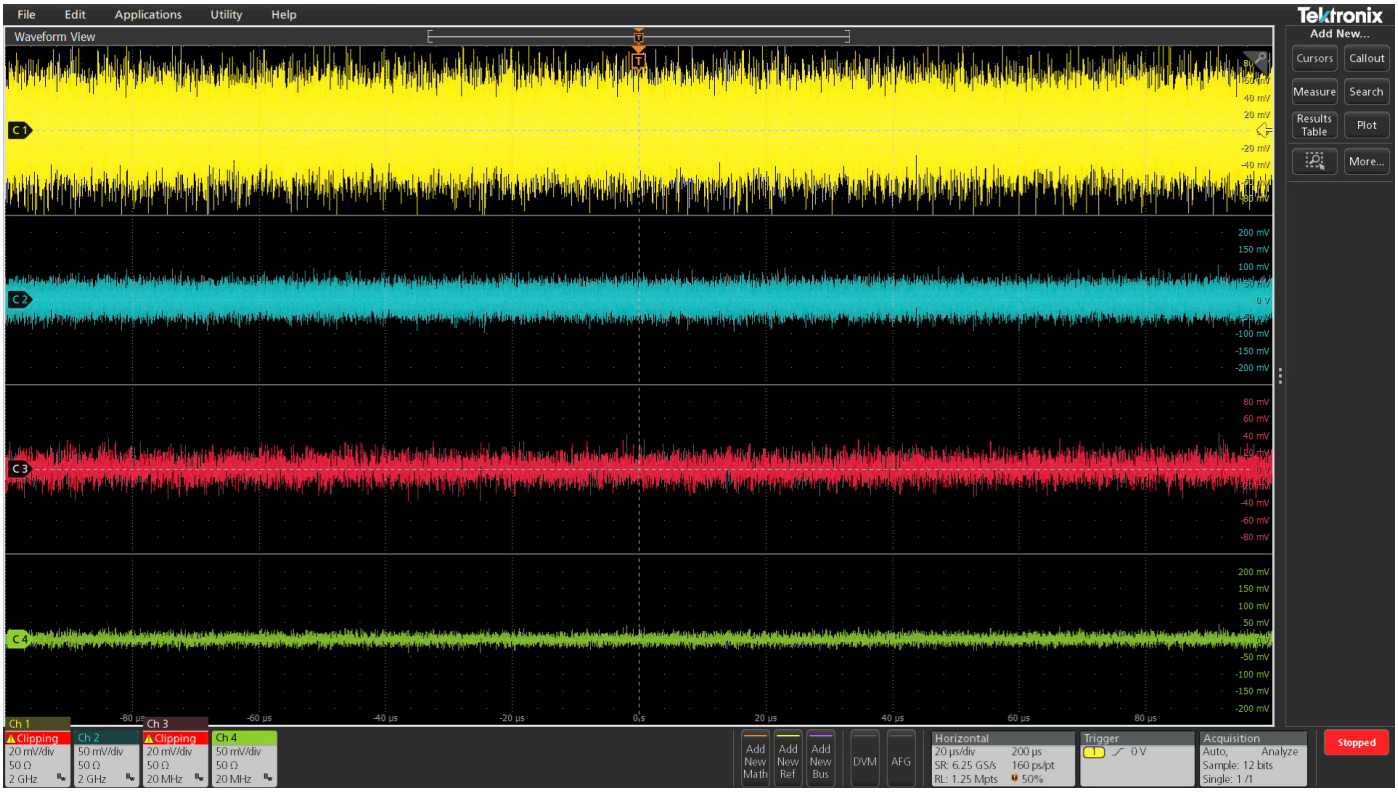

Figure 5 – Channels 1 to 4 on an MSO64B showing the noise input from an AFG31000 Arbitrary/Function Generator. The 20 MHz bandwidth filter on Channel 3 is applied after the ADC. Thus, it reduces the displayed amplitude of the signal but does not eliminate the ADC overrange.

Channel	V/div	Bandwidth	Visible Clipping	Clipping Warning
1	20 mV/div	2 GHz (no filter)	●	●
2	50 mV/div	2 GHz (no filter)		
3	20 mV/div	20 MHz (digital filter)		●
4	50 mV/div	20 MHz (digital filter)		

Table 1. Channel settings used to illustrate clipping warnings in Figure 5.

This phenomenon is due to the interaction between the ADC, the 50 Ω termination, and the DSP filtering. For lower noise performance, the 50 Ω termination signal path does not use the TEK026 amplifier for signal conditioning in the 6 Series MSO (refer to **Figure 4** for architecture details). Moreover, the selectable 200 MHz or 20 MHz channel bandwidth limits are implemented as DSP filters which are applied after the ADC in the signal path. This allows the ADC to process the input signal with fewer components and scaling elements, essentially viewing the raw input. As a result, if the input signal amplitude is outside of the ADC's input range, the ADC may saturate and initiate a clipping warning on the channel badge. Simultaneously, the input signal moves along the signal path, where it is digitized, filtered, stored in memory, and displayed. This could visually appear as though the waveform is not clipping, yet the channel badge warns the user of clipping.

Even though the clipping warning and waveform on the display seem to give different indications, this design is intentional to achieve low noise performance at finer Volts/Div on the 6 Series. The TEK026 amplifier is not used in 50 Ω termination input since it has a lower bandwidth and higher noise floor than the TEK061 amplifier. These performance specifications are not ideal for the higher fidelity 50 Ω path. Therefore, only the TEK061 is in the 50 Ω input in the analog front end. This decision prevents additional noise and maintains signal integrity for the 50 Ω input. The 6 Series also uses DSP filtering for 200 MHz and 20 MHz bandwidths.

DSP filtering has improved cutoff accuracy and consistent performance over time compared to analog filtering. Using 200 MHz or 20 MHz DSP filtering reduces high-frequency noise in the 50 Ω input and prevents aliasing without adding components that could increase noise levels and degrade signal integrity.

Oscilloscope probes must also affect clipping. Most digital oscilloscopes have a 50 Ω and 1 MΩ signal path (the impedance being the termination of the path). Some modern oscilloscope channels can automatically set the signal path termination based on the connected probe. The Tektronix 6 Series has 50 Ω and 1 MΩ signal paths, and depending on the probe attached, different signal paths are enabled and, therefore, affect clipping behavior.

Figure 6 shows a Tektronix MSO64B with a TPP1000 passive probe attached to Channel 1 and a TDP1000 High Voltage Differential probe attached to Channel 2, with both channels' bandwidth set to 1 GHz. This figure demonstrates how a 1.2 V peak-to-peak noise signal input shows the channel badge and measurement badge clipping for both channels (i.e. both probes).

Dropping the channel bandwidths to 20 MHz has a dramatic effect on clipping behavior. As shown in **Figure 7**, Channel 1 (TPP1000) shows no clipping, while Channel 2 (TDP1000) shows clipping in the badges even though both visually appear not to be clipping. This phenomenon is due to the signal path taken for each channel. Channel 1 (TPP1000) uses the 1 MΩ signal path containing the TEK026 amplifier path. At the same time, Channel 2 (TDP1000) uses the 50 Ω signal path and does not contain the TEK026 amplifier. The TEK026 has the effect of properly conditioning and scaling the input enough to fit within the ADC input range and eliminates clipping warnings at the front end.

Note: In **Figures 6 and 7**, the symbol in the Channel 1 badge indicates a passive probe using the 1 MΩ signal path with the TEK026 configured with a 250 kΩ termination.

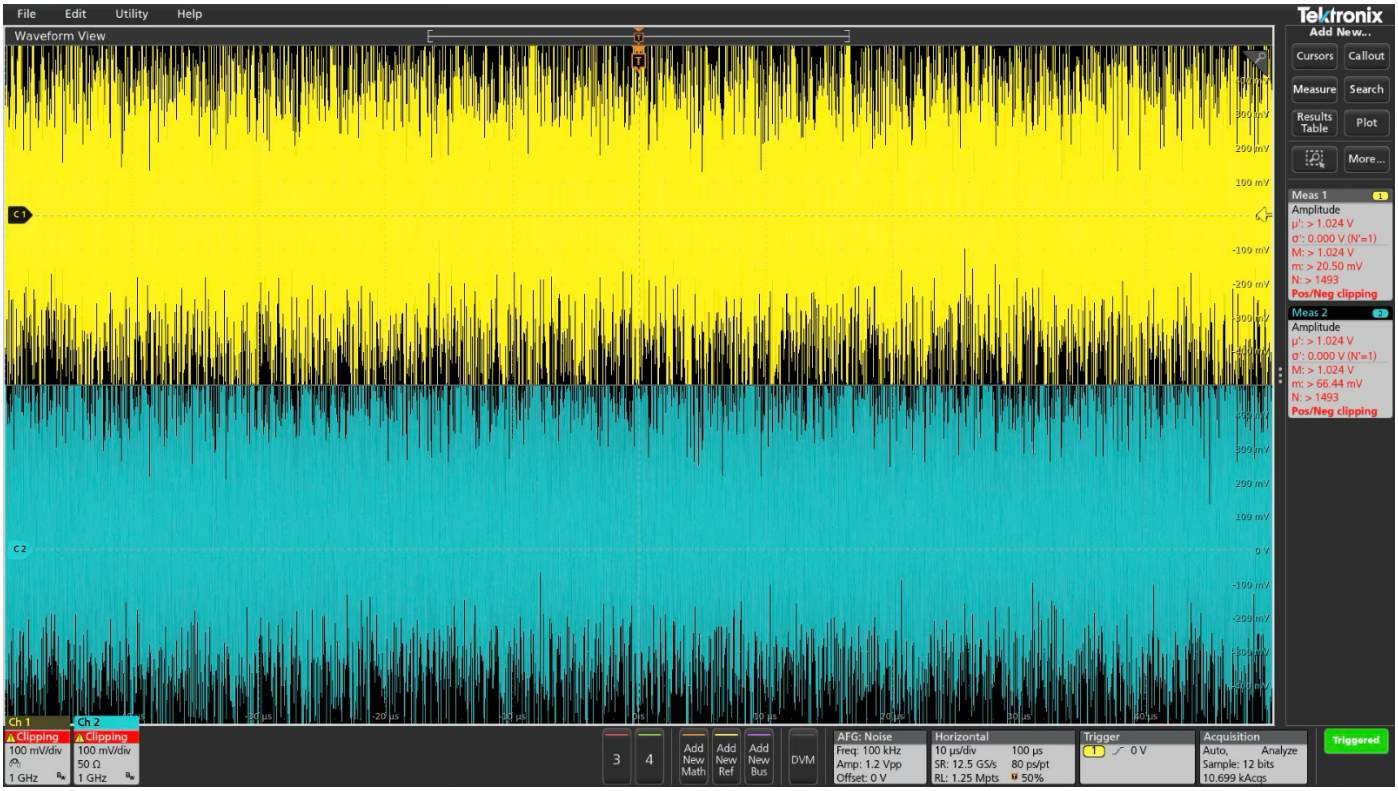

Figure 6 - Channel 1 with TPP1000 probe and Channel 2 with TDP1000 probe. Both channels have a 1 GHz Bandwidth Limit.

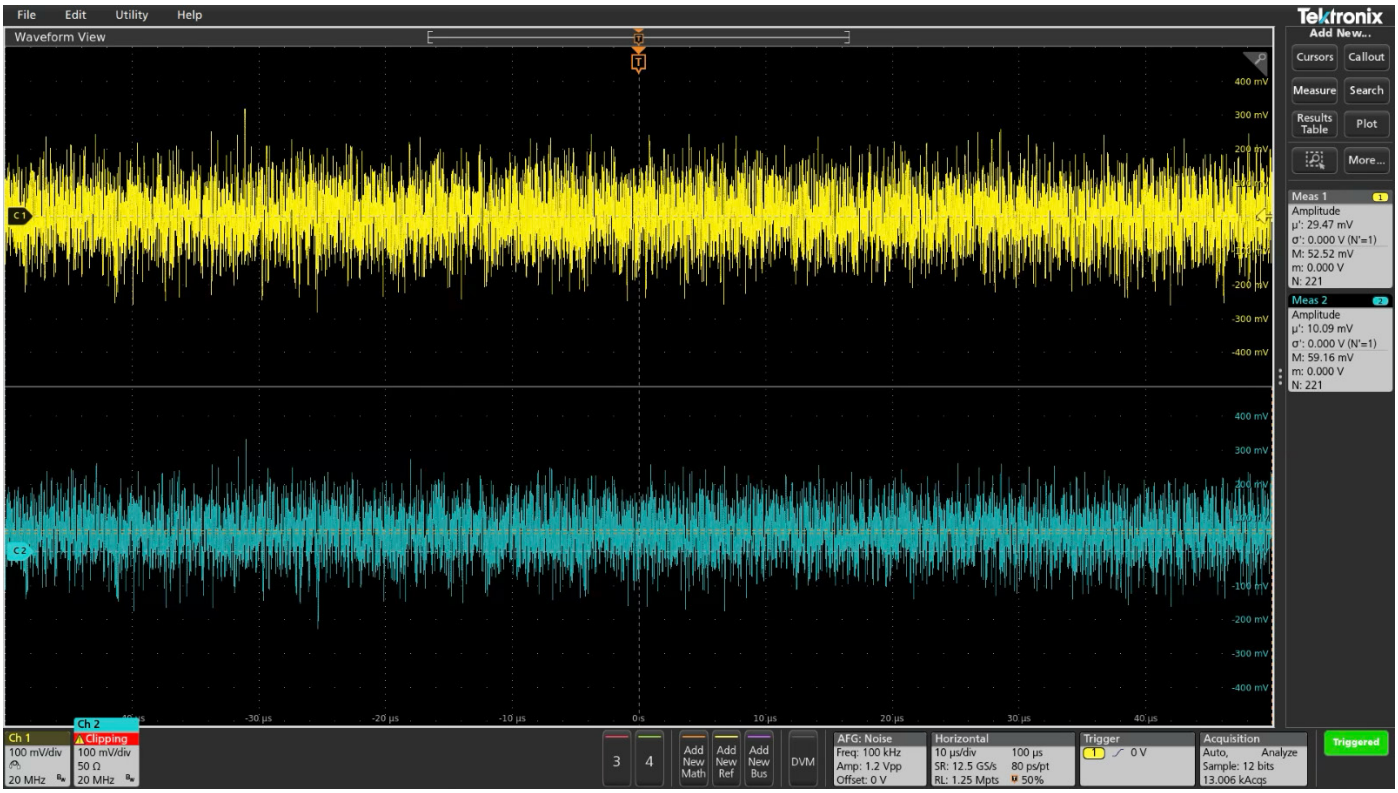

Figure 7 - Channel 1 with TPP1000 passive probe and Channel 2 with TDP1000 differential probe. Both channels have 20 MHz bandwidth limit, but the TPP1000 uses the 1 MΩ signal path while the TDP1000 uses the 50 Ω path.

How to Avoid Clipping

The best practice to avoid clipping is to increase the vertical scaling, i.e. adding more Volts/Div, and adjusting the vertical position so the signal's amplitude range fits within the input range of the oscilloscope. Adjusting the vertical scale and position will attenuate, amplify, and/or offset the input signal into the ADC on digital oscilloscopes. This action ensures that the signal is appropriately scaled to fit the ADC's range.

Using the smallest vertical scale that keeps the signal on the display without clipping is the best way to achieve finer measurement resolution without saturating the ADC while maintaining measurement integrity. The Tektronix 6 Series MSO Specification and Performance Verification document details various specifications and their accuracies in relation to changes in vertical scaling, including DC Gain accuracy, DC Offset accuracy, and Overdrive Recovery time. Together, these specifications and performance details help the user understand the impact that vertical scale changes and clipping can have on their measurements. Tektronix advises oscilloscope users to avoid signal clipping whenever the signal input is beyond the input range of the oscilloscope to prevent signal distortion, inaccuracies in measurements, and instrument damage.

Using Zoom to See Details

Traditionally, inspecting waveform details involved decreasing the vertical scaling. However, this approach can lead to signal clipping when overdriving the oscilloscope input. Luckily, Tektronix oscilloscopes provide standard zooming and panning features separate from the horizontal and vertical scale controls. This feature allows users to investigate waveform details without clipping waveforms or changing any waveform scales. With zooming and panning features, a user can examine waveform details without intentionally clipping signals and jeopardizing measurement accuracy. Oscilloscope users can maintain the waveform resolution while being able to investigate waveform details on display.

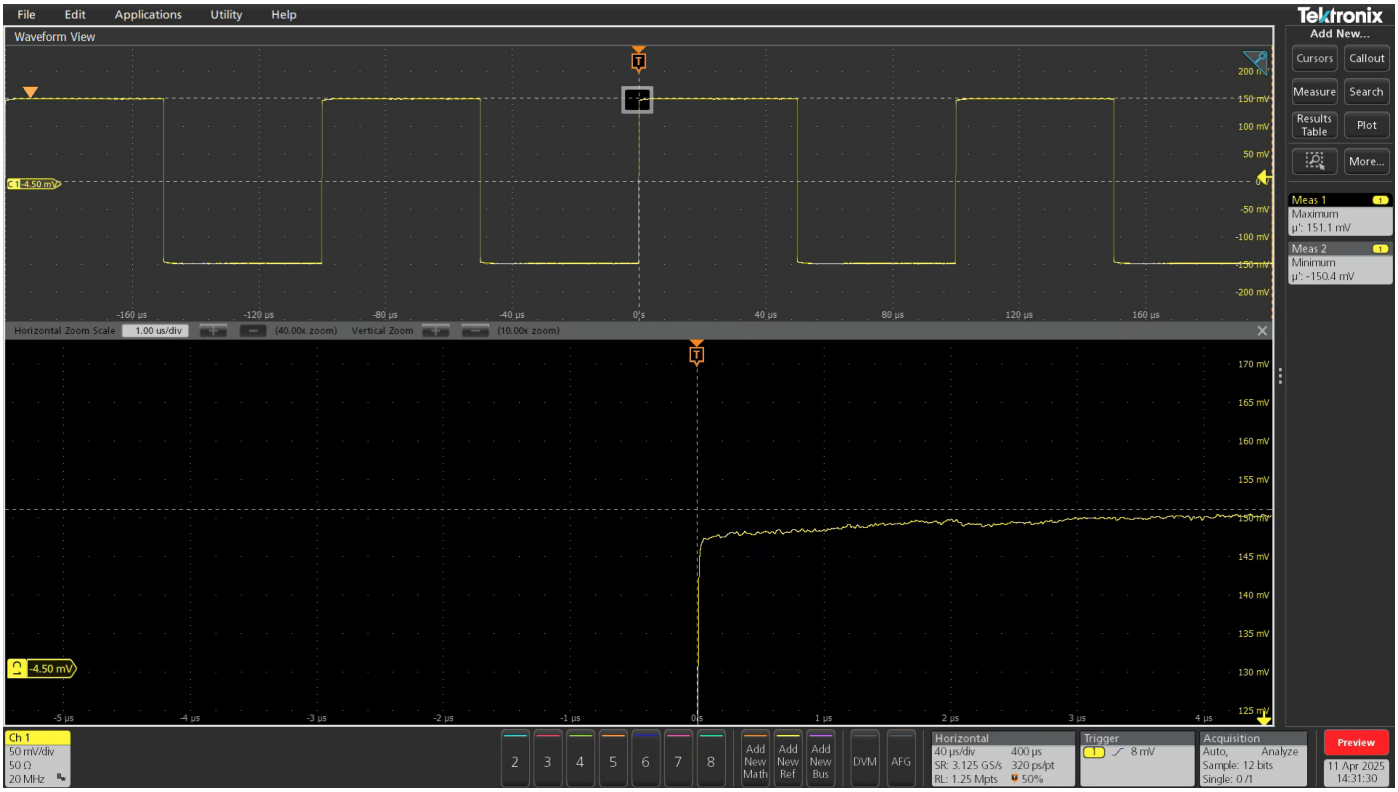

Figure 8 – Zooming and panning used on Channel 1 to examine waveform details without changing the horizontal or vertical scaling.

Intentional Clipping and Potential Pitfalls

In some situations, reliable measurements are possible even when the oscilloscope is clipping. However, this activity involves a relatively in-depth understanding of the input signal and the expected oscilloscope output results. This situation may also involve considering specifications from the 6 Series MSO Specifications and Performance Verification document, such as the Overdrive Recovery time, and understanding how this time will affect measurement results.

For example, **Figure 8** shows the MSO64B internal AFG generating a 1 V peak-to-peak, 100 kHz sine wave input to Channel 1 of the oscilloscope. Notice that the channel badge shows the clipping warning, and the waveform is visibly clipping. A maximum measurement is active on the waveform and doesn't show any warnings. For a 1 V peak-to-peak sine wave with a 0 V offset, we would expect the maximum measurement result to be roughly 0.5 V (500 mV). The measurement is 518 mV, close to our expectations when considering the clipping impacts. Depending on the testing constraints, these results may be adequate for the designers, test engineers, or intended application. In general, though, measurement results and accuracies are not guaranteed when intentionally clipping the oscilloscope and may deviate from the datasheet specifications.

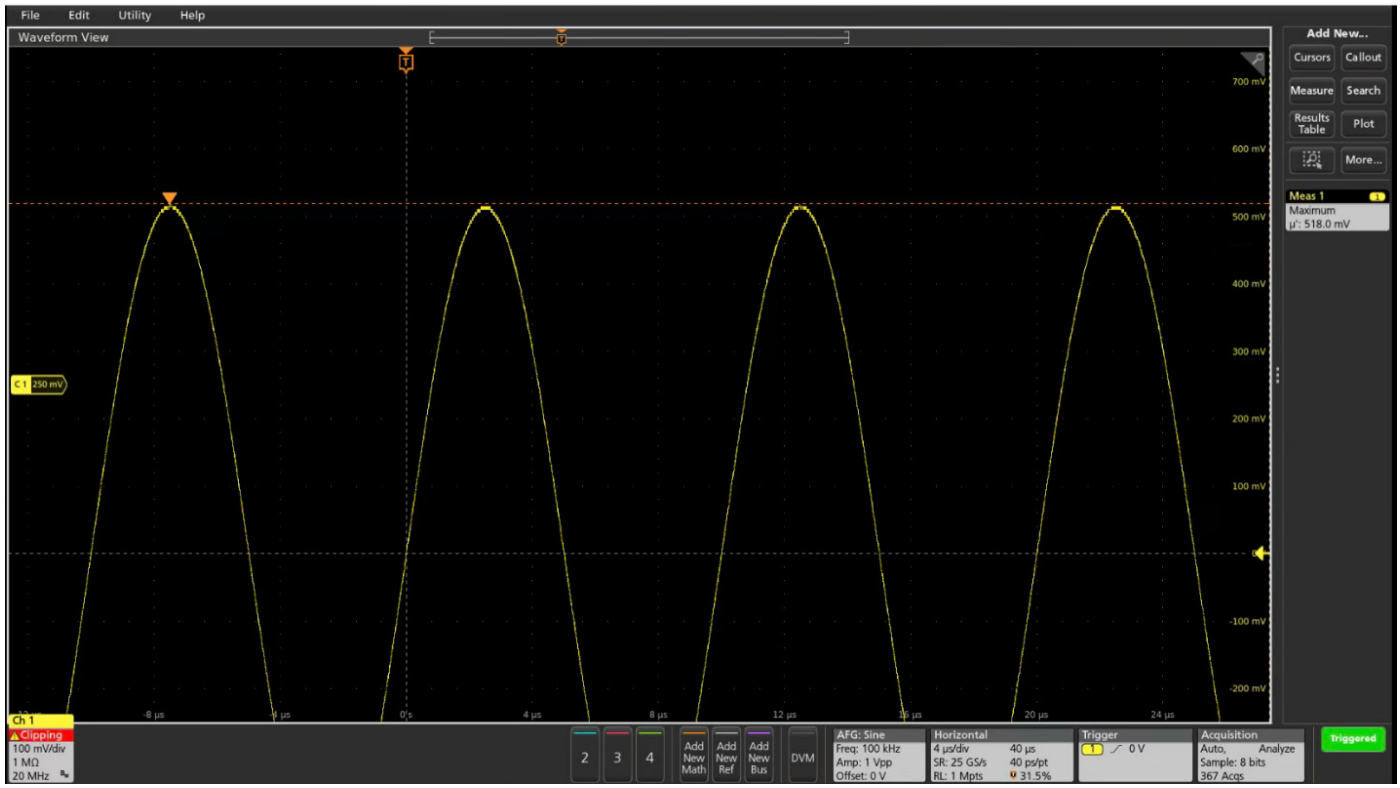

Figure 9 – Channel 1 measuring a 1 V peak-to-peak sine wave with intentional clipping and a maximum measurement being taken.

Summary

Oscilloscope clipping warnings play a significant role in ensuring user safety, preventing instrument damage, and verifying measurements and waveform results. This technical brief covered the background of oscilloscope clipping and how the 6 Series and 6 Series B MSO user interface shows clipping warnings. Additionally, this brief looked at some examples of oscilloscope clipping and methods to correct clipping issues, such as adjusting the vertical scaling or using zoom and panning features on the 6 Series. Recognizing what clipping looks like, how it affects measurements, and how to correct it can help designers and test engineers achieve verified waveform results, accurate automated measurements, and guarantee measurement integrity.

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