Overcoming Overdrive Recovery on High-Speed Digital Storage Oscilloscopes

Application Note 1473

Who Should Read This Application Note?

This application note provides valuable measurement technique information for engineers and technicians that want to make the most accurate vertical and timing measurements possible using a high-speed, real-time Digital Storage Oscilloscope (DSO).

Introduction

When making critical signal integrity measurements of high-speed digital signals, it may be necessary to measure the small aberrations on the top and bottom of the signals. Examples of these measurements include overshoot, undershoot, and overall ripple. A common technique often employed by oscilloscope users to increase the effective resolution and accuracy of these types of measurements is to offset the signal under test and then increase the vertical sensitivity around the waveform portion of interest. This will spread out the small aberrations of the signal over a larger range of the scope's A/D converter.

This technique definitely improves the resolution of the measurement on the signal's small aberrations. Intuitively you might think that it also improves the accuracy. However, offsetting and expanding the signal over a wider range will drive major portions of the signal off-screen and beyond the dynamic range of the oscilloscope's input amplifier and A/D converter. When this happens, the scope's amplifier can be driven into saturation, causing waveform distortions.

There is a misconception that some oscilloscopes can tolerate overdrive conditions, whereas others cannot. This application note will show ripple measurements on a high-speed digital signal using 6 GHz, real-time oscilloscopes from two different vendors, Agilent Technologies and Tektronix, Inc. We will show the inaccuracy of these measurements when the scope's amplifier is overdriven, and then show the proper technique to make the same measurement accurately without overdriving the amplifier.

Problem: Overdriving the Scope Amplifier

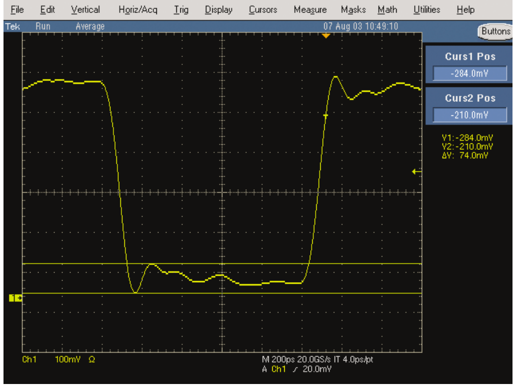
Figure 1 shows a 500 MHz clock signal captured using a Tektronix TDS6604 oscilloscope. In this case, the signal has been captured with the waveform scaled within the scope's 10 divisions of dynamic range. With approximately 5 divisions of peak-to-peak deflection at 100 mV/div, the entire waveform has been optimally scaled to be fully on-screen.

Even though full screen is 8 divisions high, the scope's 8-bit A/D converter is actually spread across 10 vertical divisions (2 divisions of the A/D's dynamic range are off-screen). Consequently, for this particular measurement we are using just half (7 bits) of the scope's 8-bit A/D converter. But if we are primarily interested in accurately measuring the peak-to-peak ripple on the bottom of this signal, then we are using an even smaller portion of the A/D converter. With the scope's voltage markers, we have measured the ripple on this signal to be approximately 74 mV peak-to-peak. However, we are only using about 7 percent of the scope's A/D converter range for this measurement, meaning that our measurement has a resolution of just slightly greater than 4 bits relative to the peak-to-peak swing of the ripple.

To improve the resolution and apparent accuracy of this ripple measurement, we have used the scope's vertical dc offset capability and then increased the vertical sensitivity to 20 mV/div in order to zoom in on the bottom portion of the signal (Figure 2). This should give us a 5X improvement in absolute measurement resolution.

When comparing the differences between the waveforms captured and displayed in Figures 1 and 2, we can see obvious distortions in the captured waveform in Figure 2. The first negative overshoot peak in Figure 2 now has less negative amplitude than later perturbations in the signal, as compared to our original measurement (Figure 1) with the waveform scaled to be fully on-screen.

It would be pointless to perform another peak-to-peak ripple measurement for comparison since we would be measuring signal aberrations caused by amplifier distortion, not real signal aberrations. Even though the resolution of the second measurement has been improved over our first measurement, the accuracy has been degraded due to driving the scope's input amplifier into saturation and thereby inducing signal distortions. Our original intent was to improve measurement resolution and accuracy with the second zoomed-in measurement. But in fact, this measurement technique has degraded our measurement accuracy.

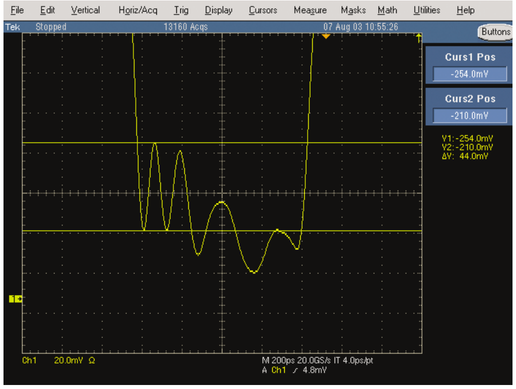


Curs1 Pos -284.0mV

Curs2 Pos -210.0mV

V1: -284.0mV
V2: -210.0mV
ΔV: 74.0mV

Figure 1. Ripple captured at 100 mV/div on a Tektronix TDS6604 scope.



Curs1 Pos -254.0mV

Curs2 Pos -210.0mV

V1: -254.0mV
V2: -210.0mV
ΔV: 44.0mV

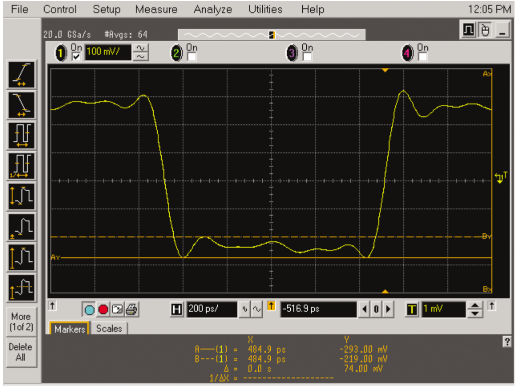
Figure 2. Ripple captured at 20 mV/div on a Tektronix TDS6604 with 5X resolution improvement and signal distortion due to an overdriven amplifier.

Solution: Keeping within the Specified Dynamic Range

The problem with this vertically expanded measurement is that we violated the dynamic range specification of the oscilloscope. Most vendors specify the dynamic range of their oscilloscopes. This specification is usually in the range of +/– 4 divisions to +/– 5 divisions (depending on the scope). For accurate and non-distorted measurements on high-speed digital signals, signals should not be scaled beyond the specified dynamic range of the oscilloscope. To insure that the signal is properly scaled within the dynamic range of the oscilloscope to avoid signal distortions, simply scale the signal for maximum peak-to-peak deflection, but still keep it fully on-screen.

Some scope vendors also specify overdrive recovery time (sometimes called “step response settling error”). Overdrive recovery is the time required for a signal to recover from distortion effects if the dynamic range of the scope is violated. For the Tektronix TDS6604, the specification states that overdriven signals will recover/settle to within 2 percent of their correct amplitude within 20 nanoseconds. But for high-speed digital signals, 20 nanoseconds can be a very long time. And for the measurement examples shown in this application note, 20 nanoseconds is much longer than the pulse itself. The negative width of this pulse is only 1 nanosecond wide. Basically, the overdrive recovery specification should be a warning to the user to never overdrive the scope’s input amplifier when making critical vertical and timing measurements on high-speed digital signals.

Let’s now look at these same measurements on an Agilent 54855A 6 GHz, real-time oscilloscope. Figure 3 shows this same 500 MHz clock signal properly scaled to be fully on-screen with a vertical sensitivity setting of 100 mV/div. Measuring the peak-to-peak ripple using the scope’s voltage markers, we again measure approximately 74 mV of peak-to-peak ripple. But with the signal scaled to be fully on-screen, we are using a relatively small portion of the A/D’s dynamic range to measure this ripple, which is the same situation we encountered on the Tektronix oscilloscope. So, let’s now expand the vertical sensitivity to 20 mV/div and see what happens on the Agilent scope.



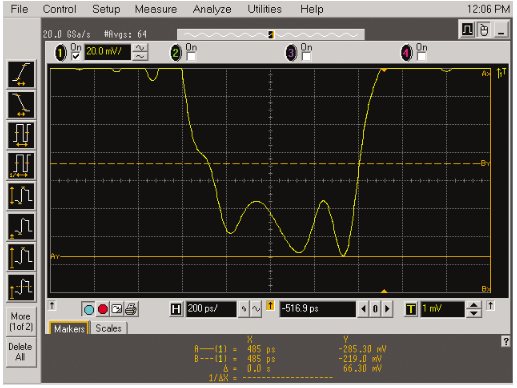
Channel 1: 100 mV/
H 200 ps/
-516.9 ps
T 1 mV

```
                X                 Y
A——(1) =  484.9 ps         -293.00 mV
B---(1) =  484.9 ps         -219.00 mV
      Δ =  0.0 s             74.00 mV
   1/ΔX = -------------------
```

Figure 3. Ripple captured at 100 mV/div on an Agilent 54855A scope.

As Figure 4 shows, overdriving the Agilent scope's input amplifier also causes visually detectable distortions in the captured waveform. Some of these distortions are caused by input amplifier saturation and some are caused by the scope's Sin(x)/x reconstruction filter digitally processing clipped data points. But it doesn't matter where the distortion comes from or the degree of error; any distortion is too much when attempting to improve measurement accuracy.

The specified dynamic range of the 54855A oscilloscope is +/– 4.0 divisions. However, Agilent does not specify the overdrive recovery/settling time if the dynamic range of the oscilloscope is violated. The 54855A oscilloscope has been optimized for the most accurate measurements with the signal always scaled on-screen. Agilent recommends that the signal under test never be scaled such that the input signal overdrives the scope's input amplifiers, regardless of which vendor's scope you may be using. So, how should these types of measurements be performed on both the Tektronix and Agilent scopes to achieve the most accurate and reliable measurement results when measuring small signal perturbations on high-speed digital signals... without overdriving the input amplifiers?

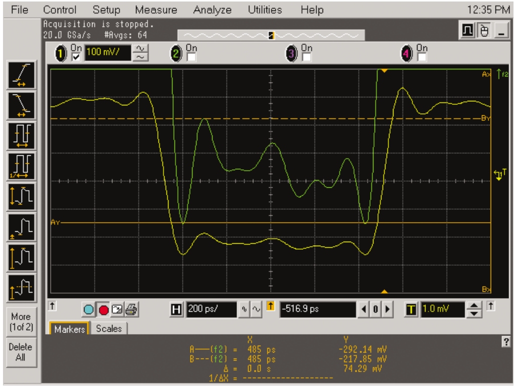


```
              X                Y
A——(1) =  485 ps         -285.30 mV
B---(1) =  485 ps         -219.0 mV
      Δ =  0.0 s           66.30 mV
   1/ΔX = ------------------
```

Figure 4. Ripple captured at 20 mV/div on an Agilent 54855A scope with improved resolution and similar signal distortion.

Increasing Signal Resolution and Accuracy Using Waveform Averaging and Math Functions

Figure 5 shows the proper measurement method using the Agilent 54855A oscilloscope. This same measurement technique can also be used on scopes from both Tektronix and LeCroy Corp. Using waveform averaging, measurement resolution on small signal perturbations can be increased significantly (11 to 12 bits relative to full-screen). Unfortunately, display resolution on most DSOs is limited to approximately 8 to 9 bits.



```
Acquisition is stopped.
20.0 GSa/s   #Avgs: 64
```

```
                    X                  Y
A——(f2) =  485 ps            -292.14 mV
B---(f2) =  485 ps            -217.85 mV
       Δ =  0.0 s              74.29 mV
    1/ΔX = ------------------
```

Figure 5. Ripple measurement on an Agilent 54855A scope using waveform averaging and math functions to increase resolution and accuracy.

In order to see and more accurately measure these small perturbations after averaging, you should use the scope's waveform math functions to digitally magnify the waveform around the signal portions of interest. With the input signal scaled to be within the scope's dynamic range (yellow/bottom trace), digital magnification performs a software expansion of the captured and averaged waveform (green/top trace) to reveal additional vertical resolution beyond the 8-bit resolution of the scope's A/D converter.

This technique does not overdrive the input amplifiers and will not induce any signal distortions due to oscilloscope amplifier saturation. The net result is a higher resolution and more accurate measurement of small perturbations on larger signals. With digital magnification set to 20 mV/div (5X expansion), we now measure approximately 74.3 mV of peak-to-peak ripple. This should be a more accurate measurement than our original 74 mV measurement.

If repetitive averaging is not possible due to a single-shot or transient input signal, then your measurements will be limited to the 8-bit vertical resolution of the scope's A/D converter with the signal scaled to be fully on-screen. You should not attempt to expand the waveform and drive portions of the signal beyond the scope's specified dynamic range. This technique may induce signal distortions resulting in less accurate measurements.

Conclusion

There is a familiar American joke where a patient says to his doctor, "Doctor, it hurts when I bang my head against the wall." The doctor then responds, "Well then, don't bang your head against the wall." The same could be said about the problems associated with overdriving a scope's input amplifier. If you don't want to make inaccurate measurements, then don't overdrive the amplifier! Use waveform averaging and digital magnification to make the most accurate measurements on signal perturbations, whether you are using a Tektronix, LeCroy, or Agilent high-speed oscilloscope.

Related Literature

Publication Title	Publication Type	Publication Number
Digital and Mixed Signal Oscilloscopes	Selection Guide	5988-8460EN
Infiniium 54850 Series Oscilloscopes and InfiniiMax 1130 Series Probes	Data Sheet	5988-7976EN

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