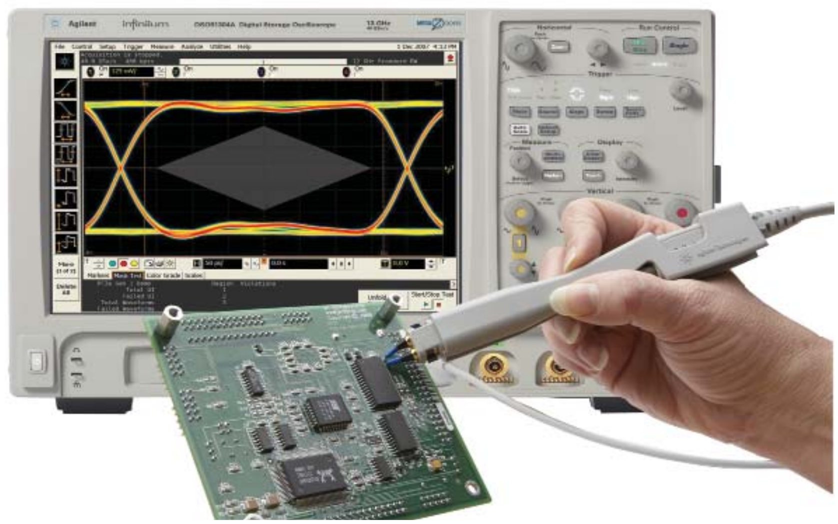
How Offset, Dynamic Range and Compression Affect Measurements

Application Note

Introduction

If you work with Agilent InfiniiMax probes, you probably understand how offset is applied when you use them in single-ended or differential modes, but you may not have a clear picture of the effects of using offsets. Offsets are applied differently depending on the type of probe head you use and the nature of the signal. You will find information on probe offset modes in Application Note 1451, Understanding and Using Offset in InfiniiMax Active Probes, but it does not cover how signal offsets affect probe amplifier dynamic range.

In this application note, we will explain how signal offsets and oscilloscope/probe amplifier offsets interact with respect to the dynamic range of the probe amplifiers.



The Problem: Different Settings Yield Different Results

The screen shot in Figure 1 shows the same single-ended signal, double probed. Channel 4 (pink/red) is probed with a differential head set to "single-ended," and Channel 2 (green) is probed with the same differential head, but with it set to "differential."

Which one of these measurements is correct?

Channel 4 shows the correct measurement. The input is a single-ended signal, 3.3-V p-p amplitude (nominal), riding on a 1.5-V offset.

Why do these settings result in different answers, and why is the data for Channel 4 correct?

Offset on the signal can eat up the probe's dynamic range. When you set the **Signal being probed** dialog box to *single-ended*, the probe applies offset to the probe amplifier itself and preserves dynamic range. When you set **Signal being probed** to *differential*, any offset is applied at the oscilloscope front end and the signal offset eats up the probe amplifier's dynamic range. When the signal exceeds a probe amplifier's dynamic range, the probe is said to "be in compression." This usually results in the signal amplitude being less than it should be or harmonic distortion. Compression is more properly called "gain compression," but is also called "overdrive," "clipping," and "non linear operation."

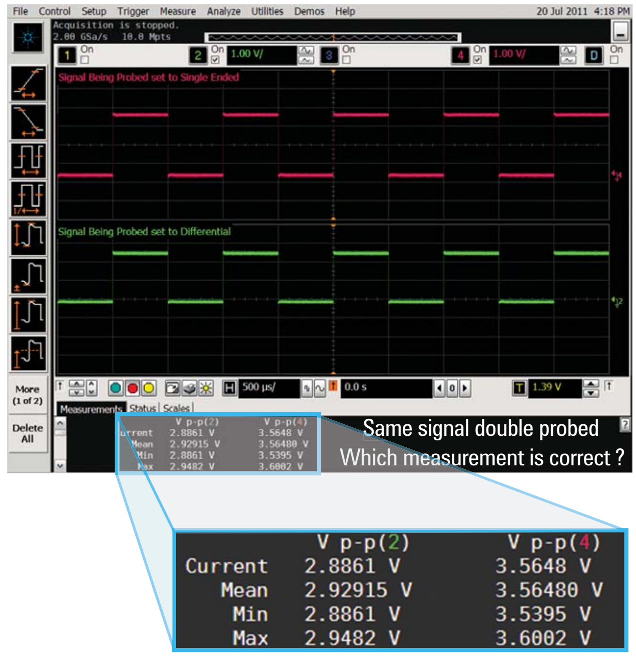


Figure 1. In the screen above, the same single-ended signal is probed twice using different settings, and different results are obtained.

The Inside Story on Offsets

Let's start by understanding how offset is applied with InfiniiMax active probe amplifiers. You can read Application Note 1451, **Understanding and Using Offset in InfiniiMax Active Probes** (http://cp.literature.agilent.com/litweb/pdf/5988-9264EN.pdf) or just review the summary below.
To summarize Application Note 1451:

1. If you are probing a single-ended signal with a single ended head and you set **Signal being probed** to single-ended, the offset is applied at the probe amplifier.
2. If you are probing a single ended signal with a differential head, and you set **Signal Being Probed** to single ended, the offset is applied at the probe amplifier.
3. If you are probing a differential signal with a differential head and you set **Signal being probed** to differential, the offset is applied at the scope.

In any case, using the smaller vertical knobs on the oscilloscope (the offset control knobs), changes the offset physically applied in the signal chain; it does not just move the signal up or down on the screen. Selecting different values for **Signal being probed** changes where the offset is applied.

When you choose the differential setting for **Signal being probed,** the offset is applied by the oscilloscope. In this case, the offset is applied at the oscilloscope front end. The probe amplifier, since it is a differential amplifier, rejects any common mode offset (up to some limit, of course). The amplifier can then use all of its dynamic range on the signal of interest, not on the offset.

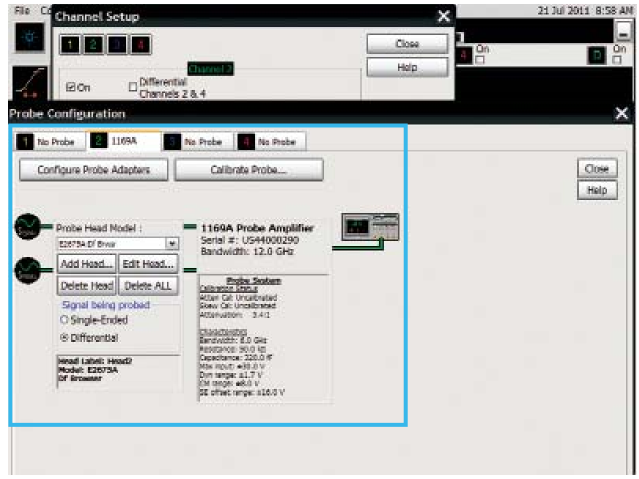
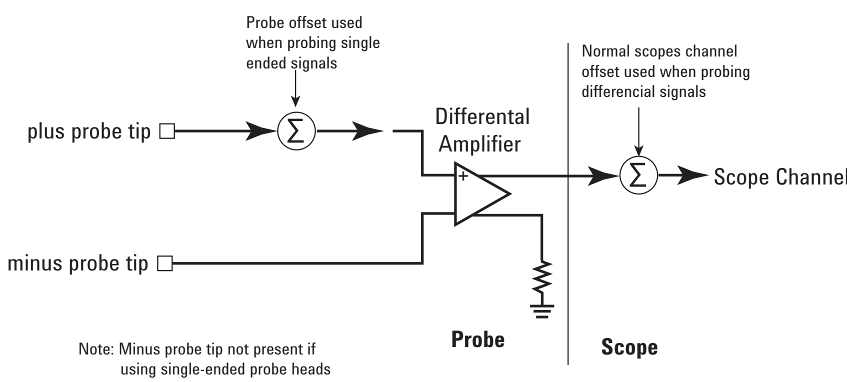


Figure 2. In the Probe Setup menu, use the radio buttons to indicate the type of signal you are probing.



Figrure 3, The schematic clearly illustrates how offset is applied in the two different modes.

The Inside Story on Offsets (cont.)

When you set **Signal being probed** to single-ended, the offset is applied by the amplifier. It is added (or subtracted depending on which way you turn the knob) to the positive leg of the amplifier. This is done to bring a signal within the amplifier's dynamic range. You would use this approach for smaller Vp-p signals with large DC offsets. Let's illustrate with an example: Let's say you have a 50-mVp-p signal riding on a 3-V offset. (See Figure 4 and 5: Scenario 1 below.) To get good resolution on the signal, you set the oscilloscope to 10 mV/div. Here the offset available at the oscilloscope is generally very small. So without applying offset at the probe amplifier itself, there is no way to get it within range of the oscilloscope.

On the other hand, if you have a large offset on a single-ended signal with a large Vp-p signal and you don't remove the offset at the probe amplifier, the signal offset eats up the probe amplifier's dynamic range and the probe amplifier goes into compression. Applying offset at the probe amplifier itself brings the signal within the amplifier's dynamic range.

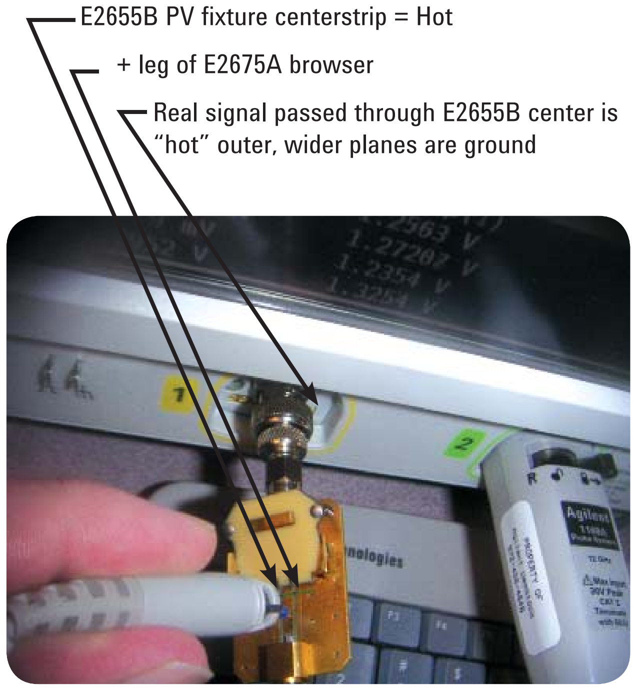


Figure 4. Setup for probing with the E2675A differential browser head for InfiniiMax I and II probe amplifiers. This probe head can also be used for single-ended signals by putting the negative leg to ground.

Figure 4 is a photo of the basic setup used for the rest of this application note.

The signal source is a function generator such as an Agilent 33521A (all voltages for function generator are nominal).

- Channel 1 (yellow) is "real signal."
- Channel 2 (green) is probed signal, 1169A probe amplifier and E2675A differential browser probe head.

"Real signal" is sent through the E2655B probe deskew and performance verification fixture, which is 50 Ohms characteristic impedance. This setup allows for the real signal being routed to the oscilloscope and probing access.

In the following figures, we should compare the signal amplitudes. Peak-to-peak voltage measurements are shown for all signals. The presumption is that the amplitude of the "real signal" is the correct measurement. The Vp-p measurements are always indicated in a blue box.

Single ended operation on a single-ended signal

Scenario 1.

"Correct" generic use model for **Signal being probed** set to single ended.

The function generator is set to slow square wave, 50 mVp-p, 2.5 V offset.

Here we cannot use the raw oscilloscope channel to get both good resolution and large offset. The probe can do this, however, by applying an offset at the probe amplifier that cancels the signal offset, and therefore brings the signal back into the probe amplifier's dynamic range, but it adds noise. All active probes add noise, and non-1:1 probes also add noise. Using average or high resolution acquisition modes will clean up this noise nicely.

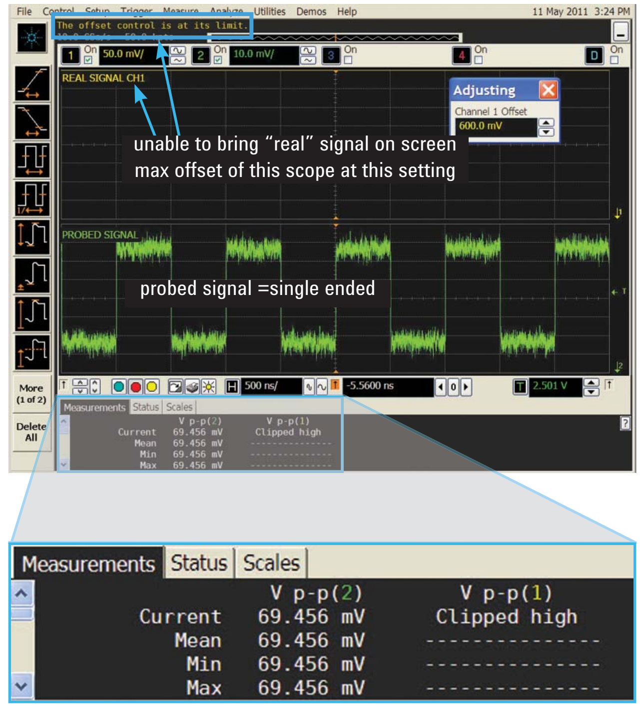


Figure 5. ***Scenario 1,*** ***"Correct" generic use model for Signal being probed set to single ended.***

Scenario 2.

Function generator is set to slow square wave, 3.0 Vp-p, 0 V.

Signal being probed is set to single ended.

Offset applied to probe is zero.

The indicated amplitude measurements are very close, but the probe amplifier is very likely just at the edge of going into compression.

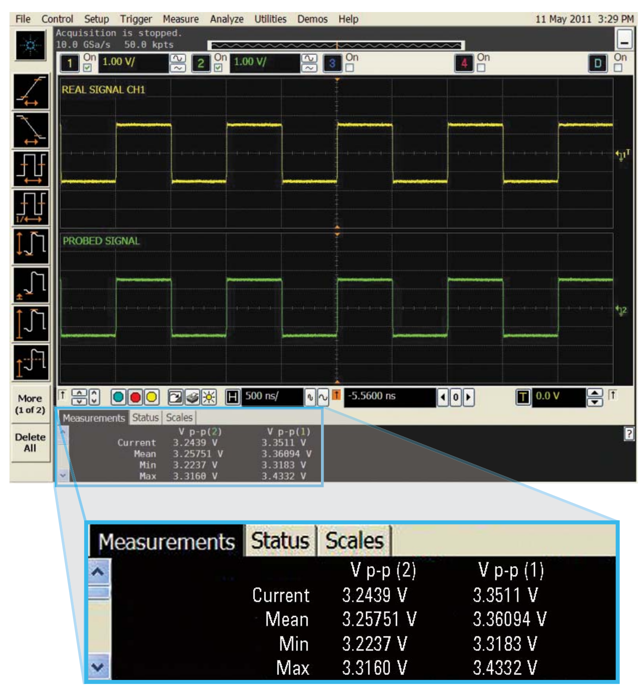


Figure 6. ***Scenario 2,*** ***Function generator is set to slow square wave, 3.0 Vp-p, 0 V.***

Single ended operation on a single ended signal

Scenario 3.

The function generator is set to slow square wave 3.0 Vp-p, 1.5-V offset.

Signal being probed is set to single ended.

Offset applied to probe is zero.

By looking at the measurement results of the peak to peak amplitudes, indicated in the red box, you can see that the probed signal has a smaller amplitude than the unprobed signal. The probe is in compression. This measurement is incorrect

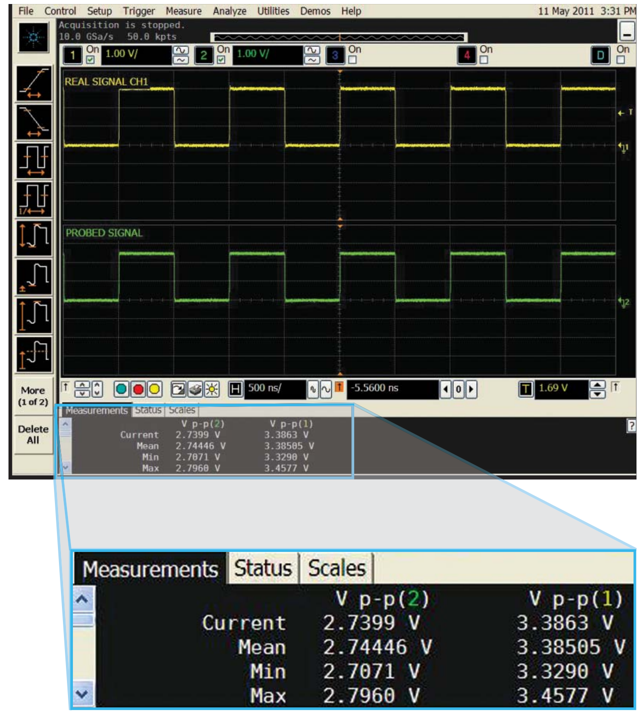


Figure 7. Scenario 3, The function generator is set to slow square wave 3.0 Vp-p, 1.5-V offset.

Scenario 4.

Function generator is set to slow square wave 3.0 Vp-p, 1.5-V offset.

Signal being probed is set to single ended

Offset applied to probe is 1.5 V.

Again, by looking at the indicated measurement results for amplitude, we see that the signals are very close in amplitude. This the same signal as in Figure 6, Scenario 3, but offset has been applied at the probe amplifier. By applying offset at the probe amplifier head, we have brought it back into normal operating range.

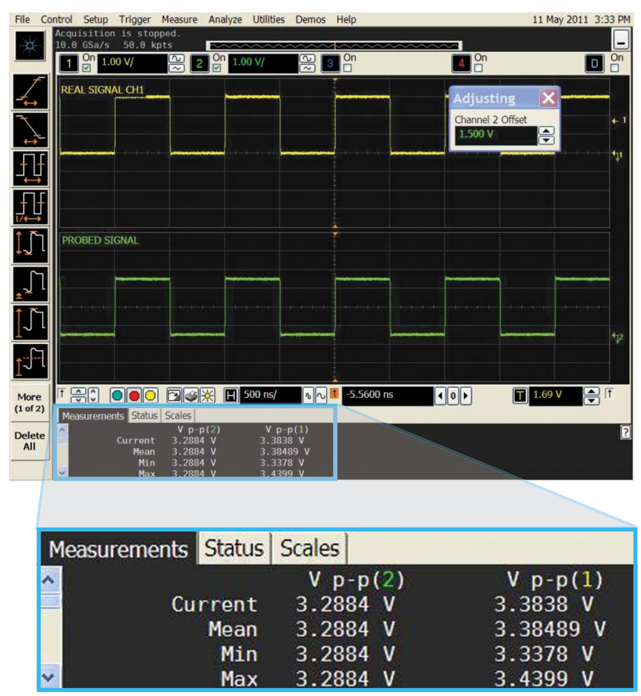


Figure 8. Scenario 4, Function generator is set to slow square wave 3.0 Vp-p, 1.5-V offset.

Single ended operation on a single ended signal

Scenario 5.

The function generator is set to slow square wave, 3.3 Vp-p, 1.5-V offset.

Signal being probed is set to single ended

Offset applied to probe is 4.25 V.

Here, too much offset has been applied to the signal. We can easily tell this by the reduced amplitude of the signal, highlighted by the blue box. The intent is to move the displayed signal vertically down on the display. Since the signal being probed is set to single ended, however, the offset is applied at the probe amplifier, the signal moves outside of the probe amplifier's dynamic range, and is again in compression, returning an incorrect result.

Now let's examine differential operation on a single-ended signal.

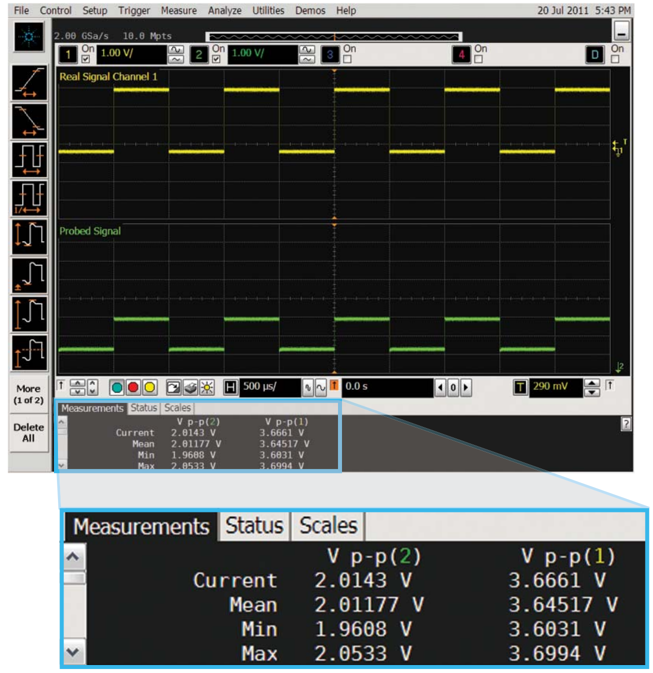


Figure 9. ***Scenario 5, The function generator is set to slow square wave, 3.3 Vp-p, 1.5-V offset.***

Differential operation on a single ended signal

Scenario 6.

Function generator is set to slow square wave, 3.0 Vp-p, 0-V offset.

Signal being probed is set to differential.

Offset applied to scope is zero.

Again inspecting the amplitudes, both measurements are effectively identical. Everything looks great.

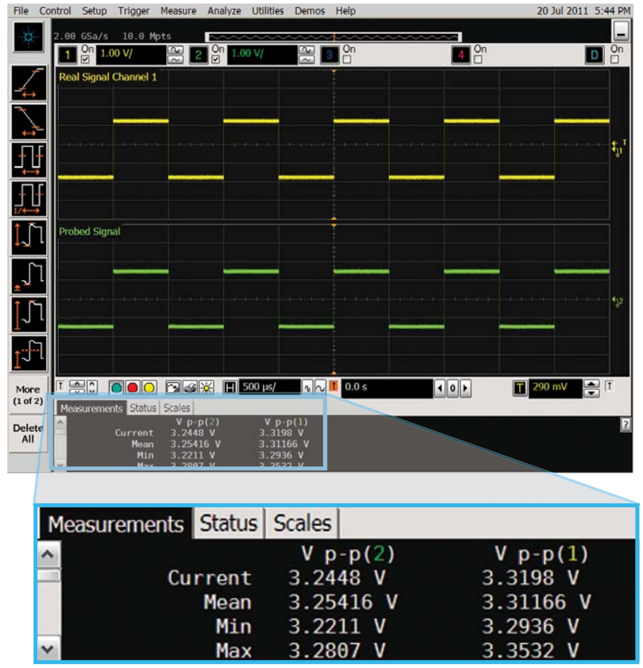


Figure 10.* *Scenario 6,* *Function generator is set to slow square wave, 3.0 Vp-p, 0-V offset.

Scenario 7.

Function generator is set to slow square wave, 3.0 Vp-p, 1.5-V offset.

Signal being probed is set to differential.
Offset applied to scope is zero.

By looking at the amplitudes of the signals, we can tell that the amplifier has gone into compression. Compare this scenario with Figure 7: Scenario 3, which is essentially the same, then with Figure 8: Scenario 4 where the compression is corrected.

The amplifier goes into compression because there is 1.5-V offset, plus 3 V on top of that. The dynamic range of the probe is 3.3 V, and we have exceeded that. The probe does not reject the offset because it has been applied to only one leg of the amplifier. You cannot bring it out of compression by applying an offset at the oscilloscope.

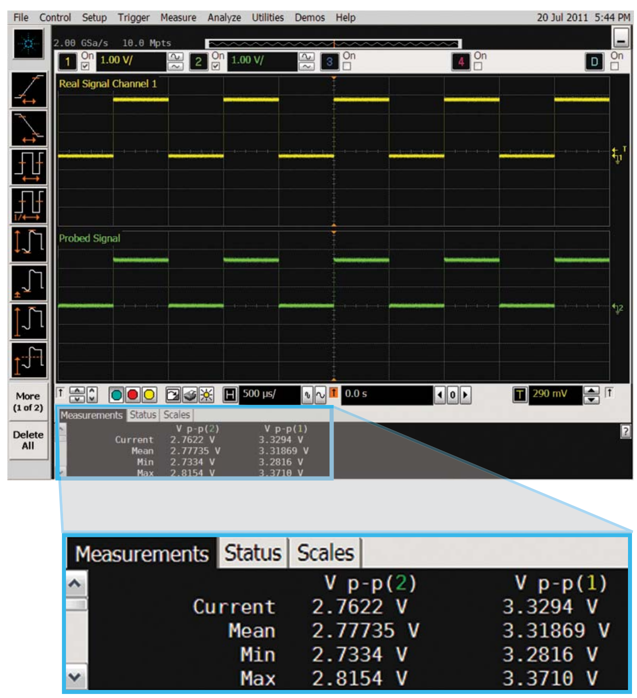


Figure 11.* *Scenario 7,

Differential operation on a single ended signal

Scenario 8.

Function generator is set to slow square wave, 3.0 Vp-p, 1.5 V offset.

Signal being probed is set to differential.

Offset applied to scope is 1.5 V.

You cannot get the amplifier out of compression in this case because the probe is still seeing the 3-V signal on top of the 1.5-V offset, which is outside of its dynamic range. Applying offset at the scope does not alleviate the problem.

Now let's examine differential operation on a differential signal.

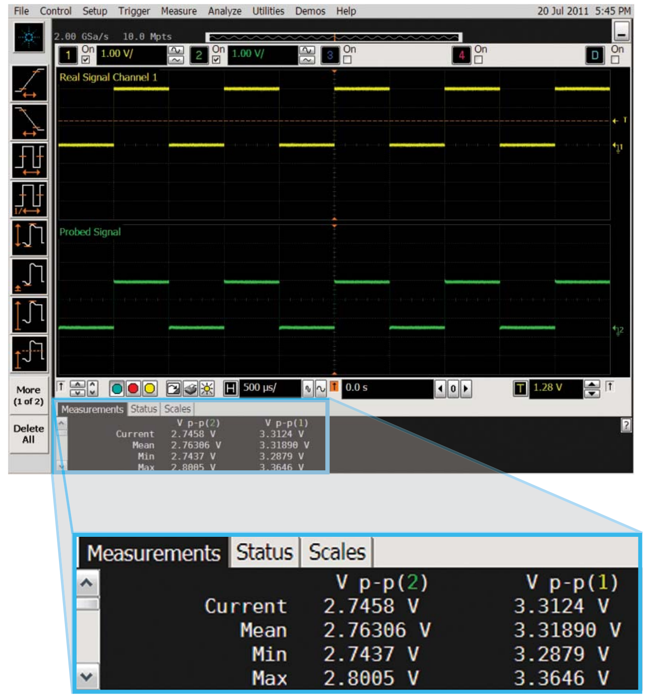


***Figure 12.** Scenario 8,*

To explore differential operation on a differential signal, we need to use a slightly different physical setup. Here, as shown in figure 13, we use a differential function generator and a differential pair trace to feed the raw oscilloscope channel on 1 and 3, subtract them (f4, in pink), and compare them with the probed signal.

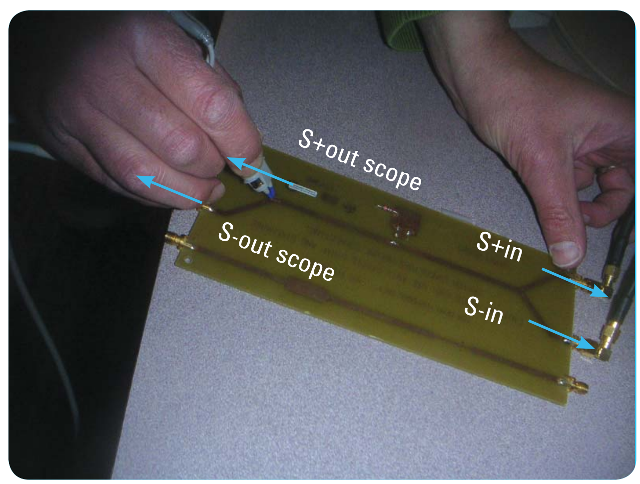


Figure 13. Setup for using differential operation to test differential signals

Differential operation on a differential signal

Scenario 9.

Function generator is set to slow square wave, 3.3 Vp-p, 0-V offset (for example, a voltage differential swing of 3.3 V,(or single ended voltages of 1.65 Vp-p)

Signal being probed is set to differential.

Offset applied to scope is 0 V.

Here (Figure 14), we want to compare f4 (pink trace), which equals Channel 1 minus Channel 3, with Channel 2. The differential p-p amplitudes of f4 and Channel 2 match. Notice that both Channel 2 and f4 are centered around ground.

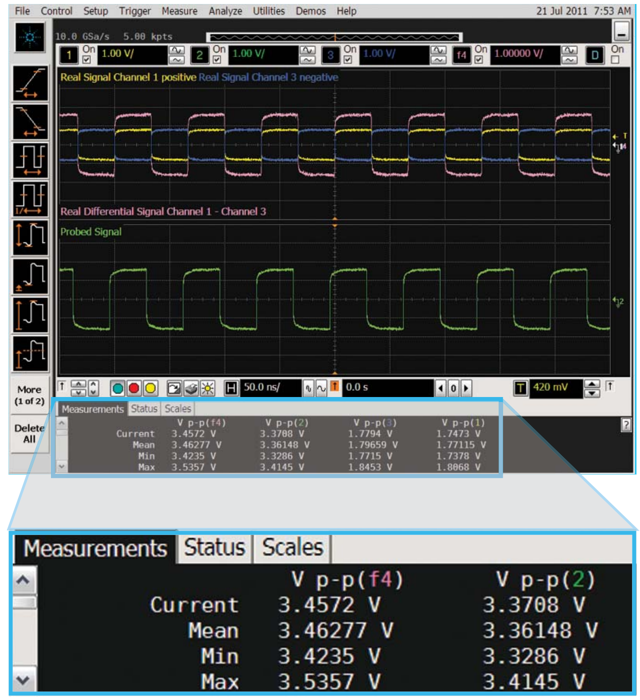


Figure 14. ***Scenario 9,*** ***Function generator is set to slow square wave, 3.3 Vp-p, 0-V offset.***

Scenario 10.

Function generator is set to slow square wave, 3.3 Vp-p, 1 V offset (for example, voltage differential swing is 3.3 V

Signal being probed is set to differential.

Offset applied to scope is 0 V.

Again, everything looks great in Figure 15. Channel 2 and f4 match nicely. Both the differential probe amplifier and the math function "reject" the common offset. Notice, however, that the offset is evident on channels 1 and 3; compare with Figure 12: Scenario 8.

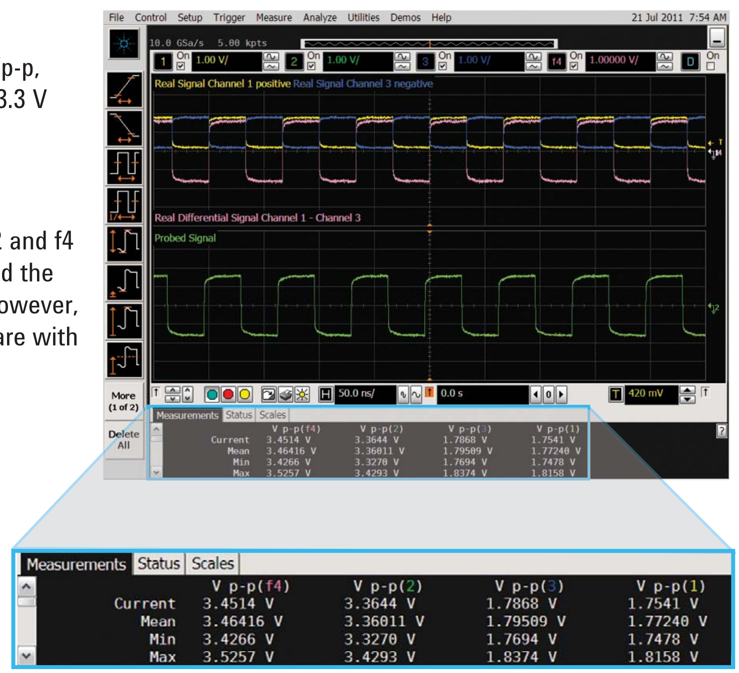


Figure 15. ***Scenario 10,*** ***Function generator is set to slow square wave, 3.3 Vp-p, 1 V offset.***

Differential operation on a differential signal

Scenario 11.

Function generator is set to slow square wave 3.3 Vp-p, 1 V offset

Signal being probed is set to differential.

Offset applied to scope is 9 V; scale on Channel 2 was changed to allow this much offset at oscilloscope.

Here in Figure 16: Scenario 11, this is really no different from Figure 13: Scenario 9, except that we have rescaled Channel 2 and moved the trace towards the top of the screen by applying offset at the oscilloscope. The p-p amplitude on CH2 is a bit larger than it should be, but this is because there is more noise at less sensitive scales.

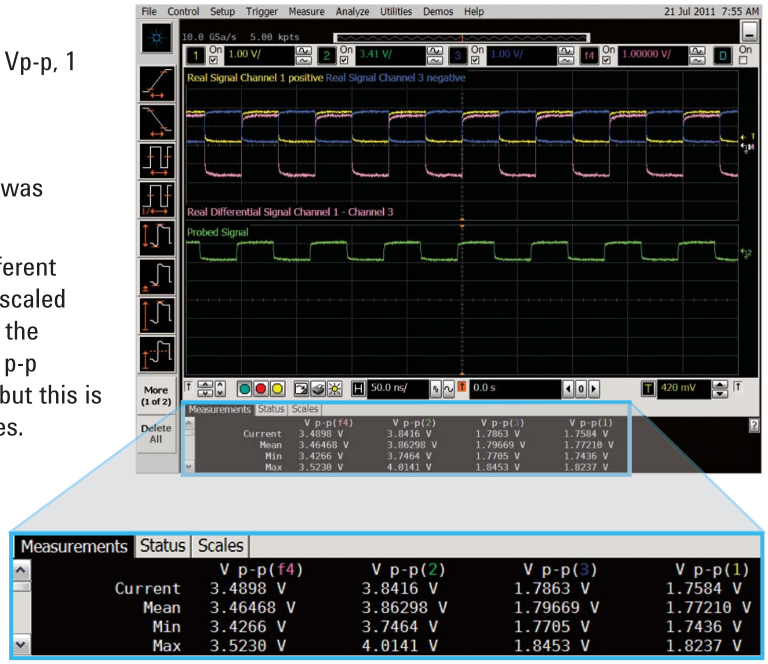


Figure 16. Scenario 11, Function generator is set to slow square wave 3.3 Vp-p, 1 V offset.

Suggested workarounds for overcoming dynamic range limitations

There are a few things you can do in situations like those illustrated in scenarios 3 or 7, where the probe amplifiers are in compression and giving incorrect results.

1. Use a different probe with more dynamic range and offset (or switch to single-ended operation and apply offset at the amplifier in Scenario 7).
2. Use inline attenuators and DC blocks with the InfiniiMax amplifiers

   N2880A offers matched pairs of 6-, 12- and 20-dB attenuators http://www.agilent.com/find/N2880A

   N2881A is a matched pair of DC blocks good to 30 VDC http://www.agilent.com/find/N2881A

These attenuators and DC blocks can be used together. Please see the Agilent 1168A/1169A InfiniiMax Differential and Single-Ended Probes User's Guide for details:

Please note that these attenuators and /DC blocks are not appropriate for use with the E2695A or N5380A SMA probe heads.

Do not stack attenuators.

These attenuators and /DC blocks do not work with the InfiniiMax III probes.

Figure 17. Inline attenuatros used with an InfiniiMax I or II probe head.

3. For single-ended operation, if you need to apply offset to bring the amplifier out of compression, but want to move the signal around on screen, use the "Magnify" math function. On the Agilent Infiniium 9000, 90000A, and 90000 X-Series oscilloscopes, you can do it easily by mapping the channel knobs on the front panel to the math functions.

   To do so, right click on the Chx icon, and select fx, and then set up the magnify math function. You can now use the channel knob to control the magnify math function and move the signal onscreen without changing the offset that is actually applied.

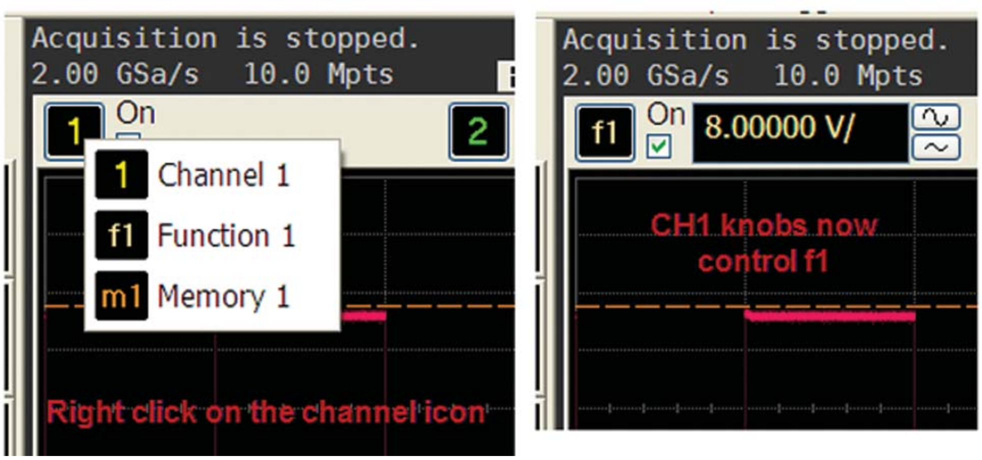


Figure 18. You can easily map front-panel knobs to math functions.

How to tell if your probe amplifier is in compression

There are a few different ways you can tell if your probe amplifier is in compression, some of which may not be appropriate for a given physical setup.

If possible, use the E2655B probe calibration/performance verification fixture, or something similar, to see the real signal on the oscilloscope and the probed signal at the same time, and compare the two. If you think you know what the signal is supposed to look like, you can also try to simulate it with a signal generator.

Of course, it makes sense to understand the dynamic range and limitation of your probe amp before you go make measurements.

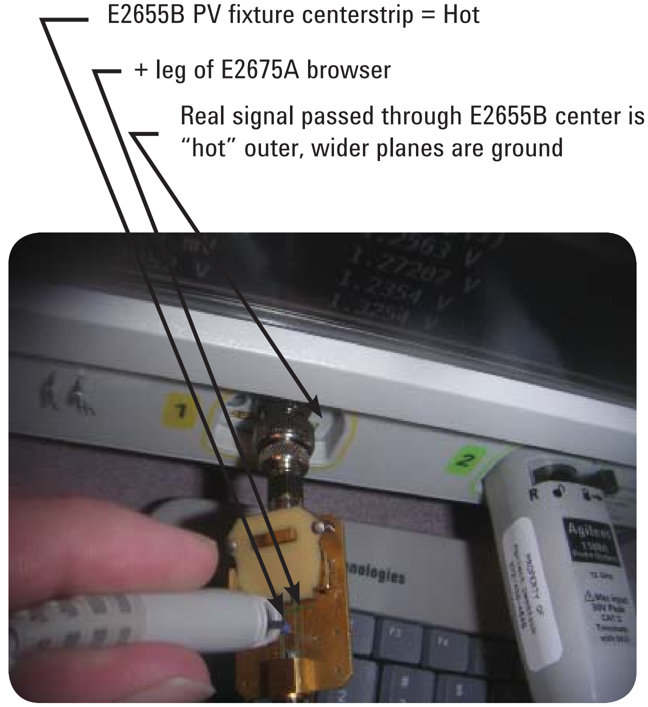


Figure 19. Figure 18. Setup for verify probe amplifier compression.

For sine waves, overdriving the amplifier usually distorts the sine wave, as shown in Figure 20. When you overdrive the amplifier, it will show up in the time domain waveform, as well as in the FFT, as spurious harmonics caused by intermodal distortion.

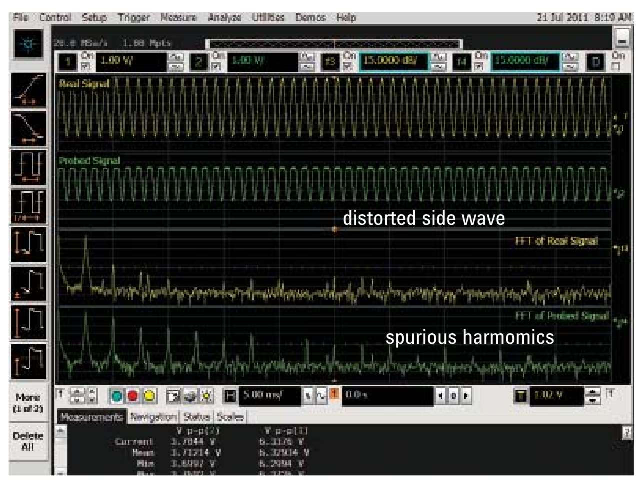


Figure 20. Distorted sine waves caused by overdriving the amplifier

How to tell if the probe amp is in compression (cont.)

For square waves, though, this doesn't show up as much in the FFT, though there are sometimes smaller spurious peaks between the main peaks, as shown in Figure 21. Usually you need to look at the amplitudes, and sometimes you can tell by the time domain waveform, as shown in Figure 21 though there are sometimes smaller spurious peaks between the main peaks, as shown in Figure 22.

Figure 21. Examining the spectra of a square wave to determine is a probe amplifier is in compression.

Figure 22. Comparison of a probed square wave. The one on the left is in compression. The rounded corner is the only telltale sign.

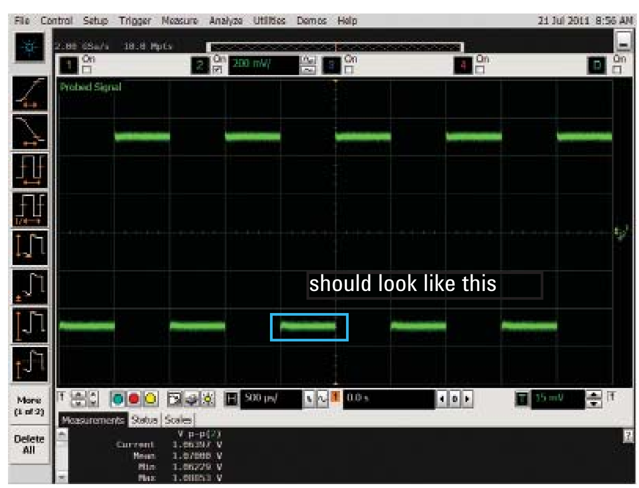


Figure 23. Change after fix

Conclusion

Agilent InfiniiMax active probes provide excellent offset and dynamic range when used correctly, particularly when combined with the DC block and attenuator accessories. Further, they offer minimal probe loading and maximum signal fidelity for high speed signals. If these probes do not meet your measurement needs, Agilent Technologies offers comprehensive line of passive, high voltage passive, single ended active, differential active, and current probes.

Appendix 1: Summary of InfiniiMax I, II, and III specifications

InfiniiMax I probe specifications

Model Number	Range	Input Impedance
1130A, 1131A, 1132A, 1134A	• Dynamic range: +/- 2.5V • DC offset range: +/- 12V when probing single-ended • Maximum (non-destruct) input voltage: 30V peak • Input common mode range: ±6.75 V DC – 100 Hz; ± 1.25V >100 Hz	• Differential input R: 50 kOhm • Differential input C: 0.27-0.34 pF • Single ended input R: 25 kOhm • Single ended input C: 0.44-0.67 pF
113xA Recommended Probe Head Configurations http://cp.literature.agilent.com/litweb/pdf/01134-92002.pdf		
note InfiniiMax I & II probe heads are compatible across InfiniiMax I & II probe amps		

InfiniiMax II specs

Model Number	Range	Input Impedance
1168A, 1169A	• Dynamic range: 3.3 V peak-to-peak • DC offset range: +/- 16V • Maximum (non-destruct) Voltage: +/- 30V • Input common mode range: ±6.75 V DC – 100 Hz; ± 1.25V > 100 Hz	• Differential input R: 50 kOhm • Differential input C: 0.21 pF • Single ended input R: 25 kOhm • Single ended input C: 0.35 pF
1168A 1169A Recommended Probe Head Configurations http://cp.literature.agilent.com/litweb/pdf/01168-92003.pdf		
note InfiniiMax I & II probe heads are compatible across InfiniiMax I & II probe amps		

InfiniiMax III specs

Model Number	Range	Input Impedance
N2800A, N2801A, N2802A, N2803A	• DC attenuation ratio : 6:1 (3:1 with 200 Ω ZIF tip) • Input voltage range : 1.6 Vpp (0.8 Vpp with 200 Ω ZIF tip) • Input common mode range : ±12 V at DC to 250 Hz, ±2.5 V at >250 Hz (±6 V at DC to 250 Hz, ±1.25 V at >250 Hz with 200 Ω ZIF tip) • Offset range : ±16 V when probing a single-ended signal	• DC input resistance : R diff = 100 kΩ ±2%, R se = 50 kΩ ±2% • Input resistance @ >10 kHz : R diff = 1 kΩ, R se = 500 Ω • Input capacitance : C diff = 32 fP, C se = 48 fP (with ZIF probe head
InfiniiMax III Recommended Probe Head Configurations Card http://www.home.agilent.com/upload/cmc_upload/All/5185-9069_man.pdf		
note InfiniiMax I & II probe heads are compatible across InfiniiMax I & II probe amps		

Additional Resources

Publication Name (Application Note)	Publication Number
Understanding and Using Offset in InfiniiMax Active Probes http://cp.literature.agilent.com/litweb/pdf/5988-9264EN.pdf	5988-9264EN
Restoring Confidence in Your High-Bandwidth Probe Measurements http://cp.literature.agilent.com/litweb/pdf/5988-7951EN.pdf	5988-7951EN
Improving Usability and Performance in High-Bandwidth Active Oscilloscope Probes http://cp.literature.agilent.com/litweb/pdf/5988-8005EN.pdf	5988-8005EN
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Publication Name (Selection guides, Specs and user's guides)	Publication Number
Large Probe Selection Guide http://cp.literature.agilent.com/litweb/pdf/5968-7141EN.pdf	5968-7141EN
Agilent Oscilloscope Probes and Accessories Selection Guide http://cp.literature.agilent.com/litweb/pdf/5989-6162EN.pdf	5989-6162EN
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Miscellaneous resources
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