

Siglent SDS2000X Plus Bandwidth Discussion

V 1.03

Introduction

The Siglent SDS2000X Plus series models come as 100, 200 and 350 MHz bandwidth versions. The 4-channel 350 MHz model can be upgraded with a two-channel 500 MHz option on top of that, which changes the model name to SDS2504X Plus. As with most modern DSOs, the sample rate is not much higher than dictated by the Nyquist criterion. This raises the question how we can benefit from higher bandwidths and what drawbacks we'll have to face.

This article is intended to give some assistance by answering the following questions:

1. What are the benefits of the higher bandwidth?
 2. Can the SDS2000X Plus models handle 500 MHz bandwidth in half channel mode?
 3. Can the SDS2000X Plus models handle 350 MHz bandwidth in full channel mode?
- **Half Channel Mode** (aka **interleaved mode**) is defined as only half of the input channels are active, i.e. only one channel in each channel group.
 - **Full Channel Mode** is defined as all input channels are active, i.e. both channels in a channel group.
 - **Channel Group** is defined as all the input channels that are using the same ADC (which has up to four conversion channels). Any input channel of the DSO can use one or more conversion channels of the ADC. It is two input channels per ADC in the SDS2000X Plus.

For all the demonstrations shown here, a Siglent SDS2354X Plus with the 500 MHz option installed (SDS2504X Plus) has been used. A 2 GHz SDS6204 oscilloscope is used as a reference instrument to characterize the test signals.

Why we need Bandwidth

This question is much harder to answer nowadays, when even entry level scopes like the Siglent SDS1000X-E series start at no lower than 100MHz. The 100MHz bandwidth covers many areas, including audio, RF up to the low VHF band, all sorts of slow standard logic and 8/16-bit microcontrollers, as well as most peripherals even for the high speed 32-bit MCUs. Who really needs more?

Well, the ones who really do will of course know. For signal integrity tests, the bandwidth of the DSO should ideally cover the entire signal spectrum. In practical applications about five to ten times the fundamental signal frequency should be sufficient though. The more important question is, what are the benefits of 350 MHz over 100 or 200 MHz? And what can we gain with the 500 MHz option?

First, the nominal bandwidth specifications do not describe what we actually get. The lower bandwidth versions of any DSO series are usually derived from higher bandwidth versions by adding a filter in the analog frontend. Since pulse fidelity is paramount in any serious oscilloscope, we need a minimal phase system with as constant a group delay as possible. This requirement rules out any filter with a steep transition from passband to stopband. Consequently, a simple first order RC-lowpass at the output of the PGA (Programmable Gain Amplifier) in the frontend is the preferred solution, and because PGAs are integrated circuits nowadays, the filter is part of this. Since we cannot get accurate resistors within a monolithic integrated circuit, we need to accept high tolerances of up to 40 % for the corner frequency. Consequently, manufacturers need to allow for that and choose an appropriate higher corner frequency in order to get enough safety margin for meeting the specs under all circumstances.

Furthermore, high bandwidth frontends do not have a purely gaussian frequency response, because there is no dominant pole in the multistage amplifier design and/or the frequency response might have been trimmed to flatten the passband response on purpose. Of course, this will introduce some pulse distortion as explained earlier, so that a certain amount of overshoot needs to be specified. Likewise, users expect a passband where the frequency response does not continuously go down until the -3 dB amplitude drop is reached only a few percent above the specified bandwidth, but rather want a decent flatness on the lower bandwidth models as well. This is one more reason to use a higher cutoff frequency for the artificial bandwidth limit. Finally, at least hobby users always are excited when they find out that their instrument exceeds the bandwidth specification. By contrast, user switchable bandwidth limits are mostly set as specified, but because of the high tolerances might still be off quite a bit.

Bandwidth of the SDS2504X Plus Frontend

I don't know about the 100 and 200 MHz models. There are claims that the 100 MHz SDS2104X Plus is 3 dB down only at 180 MHz. Of course, we cannot rely on such figures because of the before mentioned tolerances of the bandwidth limiter. What we can rely on, is the genuine bandwidth of the frontend, which will have low tolerances – but we're only going to see it in half channel mode, when the 500 MHz bandwidth option is active.

The measurement on my sample of the SDS2504X Plus shows the full bandwidth in half channel mode as some 570 MHz, so this again is quite a bit more than specified. The frequency response graph is shown in Figure 1. Detailed frequency responses of various bandwidth limits can be found later in this document when aliasing is discussed.



Figure 1. SDS2504X Plus_FR_B500M_1GSa_1GHz

The graph confirms what has been stated before and there is only 1.3 dB amplitude drop at the specified upper bandwidth limit of 500 MHz.

Various signal spectra

While we obviously need more bandwidth when dealing with higher frequencies, we might also want it even with low frequency signals if they happen to include high frequency content (e.g. fast transitions) and we're interested in a faithful rendition of the original waveform. A spectrum analyzer can be used in order to learn about the bandwidth needed to get a high-fidelity representation of the signal on the screen.

The spectrum of a 2 MHz square wave with 13 ns transition times from a 60 MHz AWG is shown in Figure 2 as an example. When looking at this spectrum, we know at first glance that 70MHz bandwidth would be plenty to give us a perfect representation of the real signal:

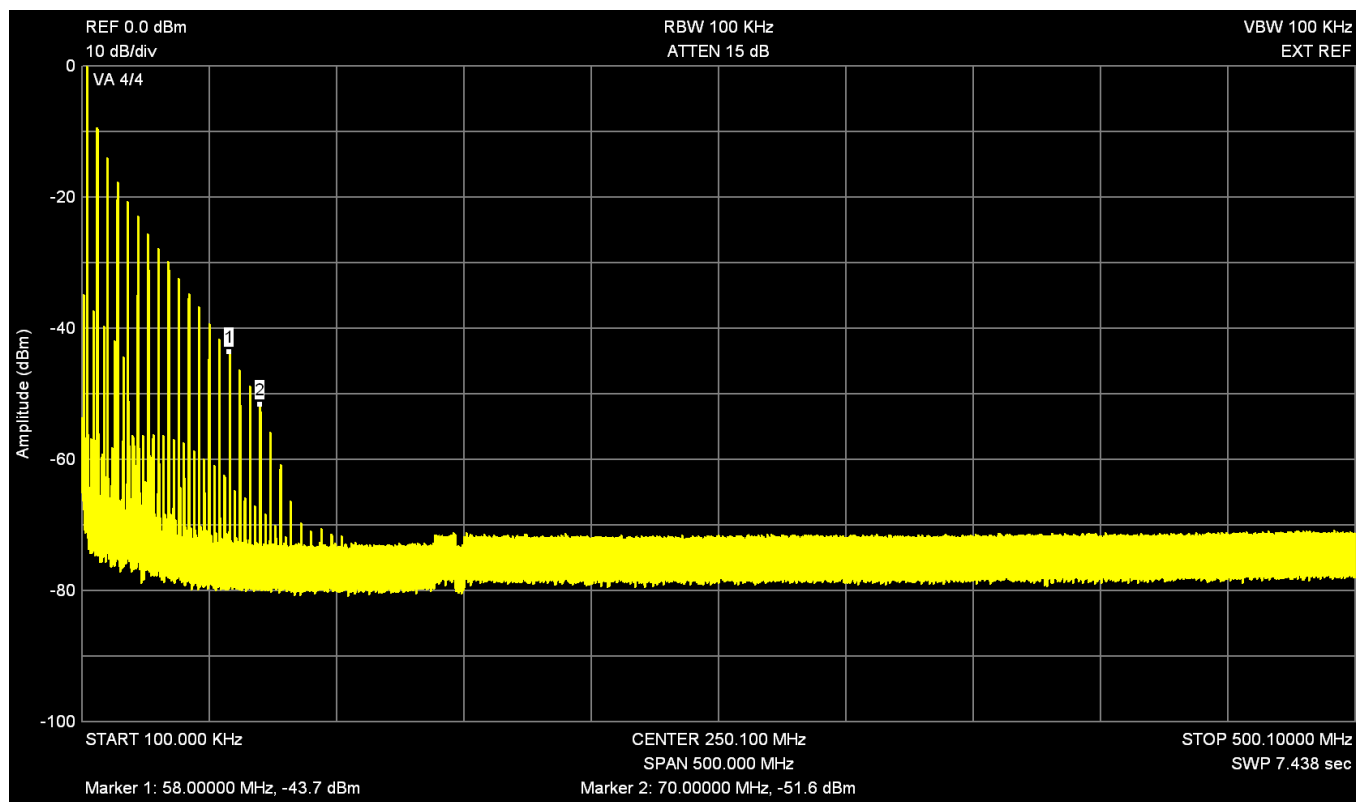


Figure 2. UTG2062A_Square_2MHz_Spectrum

It is a little different for a 2MHz signal from an ancient 100MHz pulse generator with about 3.5 ns rise time, which has some serious VHF-power transistors in its output stage (Figure 3). Here we'd probably need 200MHz bandwidth to keep the total error below 1%.

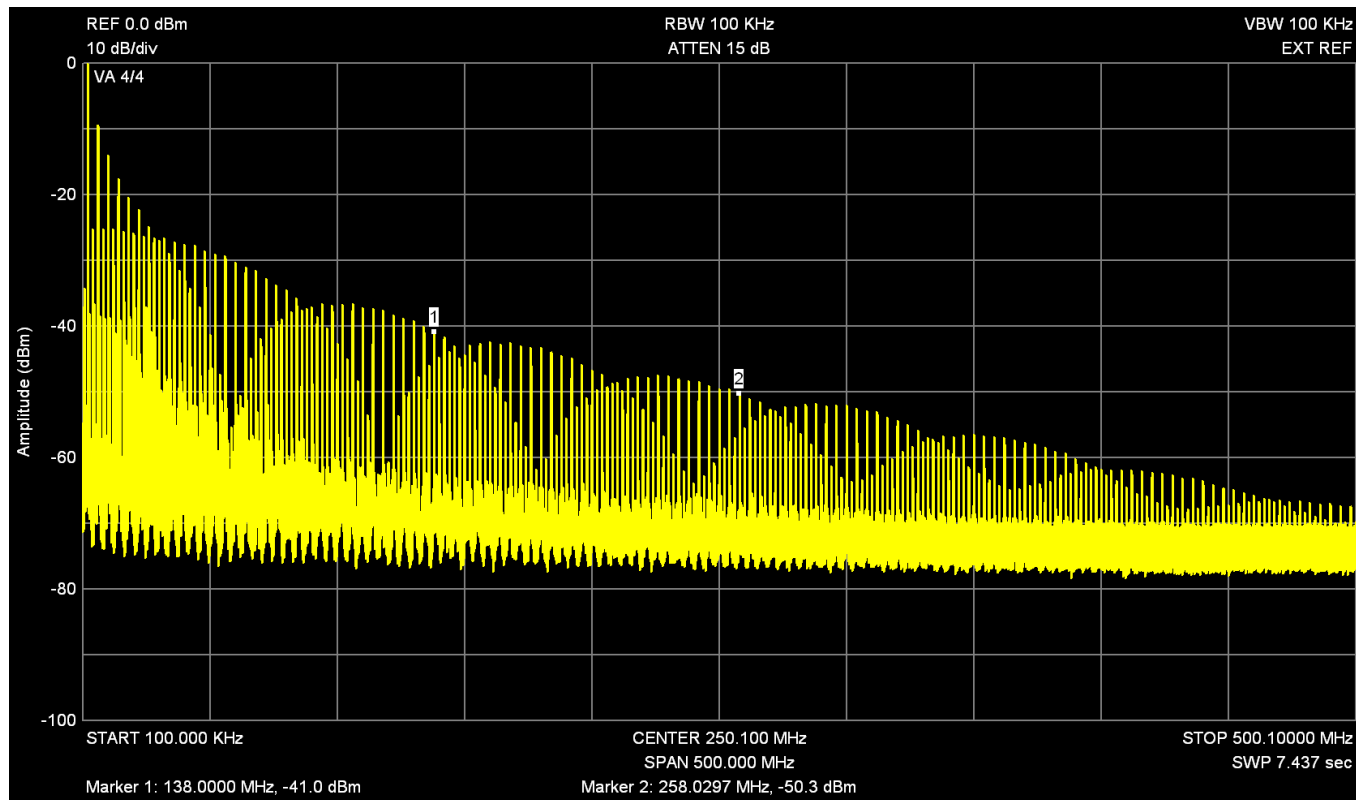


Figure 3. PM5771_Square_2MHz_Spectrum

Even faster signals will be used for the SDS2504X Plus tests in this application note and they will be introduced later in the "Pulse & Square Wave Test" section.

How much bandwidth do we need?

It appears to be the same old story again: the more the merrier. As a first rule of thumb, the rise time of the DSO should be faster than the signal – at the very least it should not be slower. Of course, this is less of an issue if someone uses the DSO as a simple signal indicator and is only interested in the signal frequency and the position of the zero crossings but doesn't care for transition times and wave shapes.

For meaningful signal integrity checks, the previously introduced spectrum analysis can be helpful to determine the required bandwidth. Figure 4 shows the spectrum of an exemplary 30 MHz square wave with 200 ps rise time.

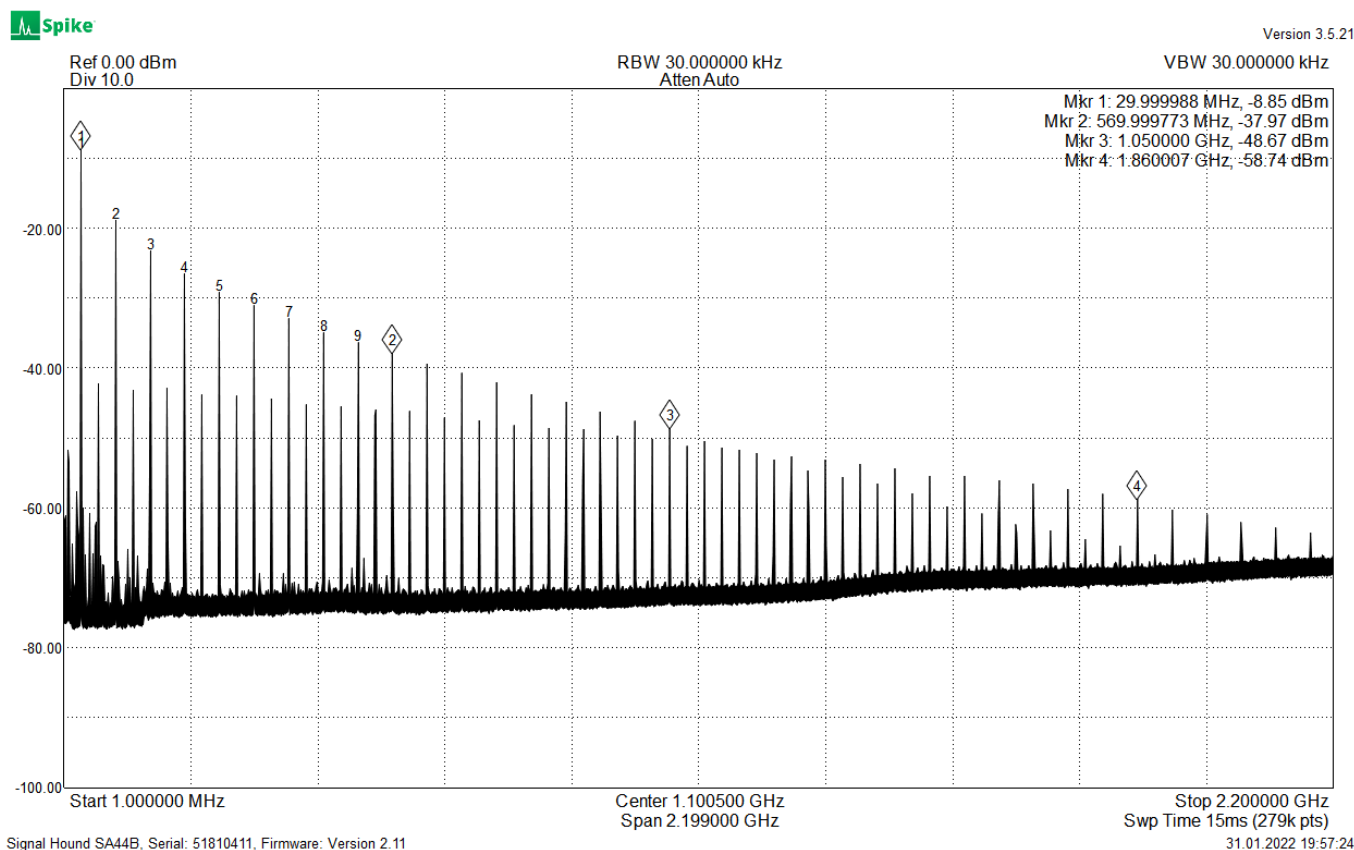


Figure 4. Spectrum_30MHz_170mVpp_Duty50_T200ps

As can be seen, the required bandwidths for not missing harmonics above a certain level are 570 MHz for -30 dBc, 1.05 GHz for -40 dBc and 1.86 GHz for -50 dBc. Including all harmonics down to -50 dBc is supposed to be sufficient for a high-fidelity reproduction of the original signal. Now let's have a look at various bandwidths.

Caution: The bandwidth limits shown here come from digital brick wall filters and are not comparable with the bandwidth limits of oscilloscope frontends!

Figure 5 shows the difference between the original bandwidth limit of the DSO frontend (which is -3 dB at about 2.2 GHz) and a brick wall lowpass with 2.2 GHz corner frequency.

As can be seen, both signal traces are pretty much identical.

Figure 6 illustrates the degradation of signal fidelity when the bandwidth is limited to 1.2 GHz (brick wall).

There is already a visible difference, but it is predominantly the Gibbs phenomenon and would be much less of a problem with a genuine 1 GHz frontend.

The green trace shows the original input signal, whereas the orange math trace represents the filtered signal.



Figure 5. SDS6204_PR_30MHz_170mV_200ps_BW2.2GHz

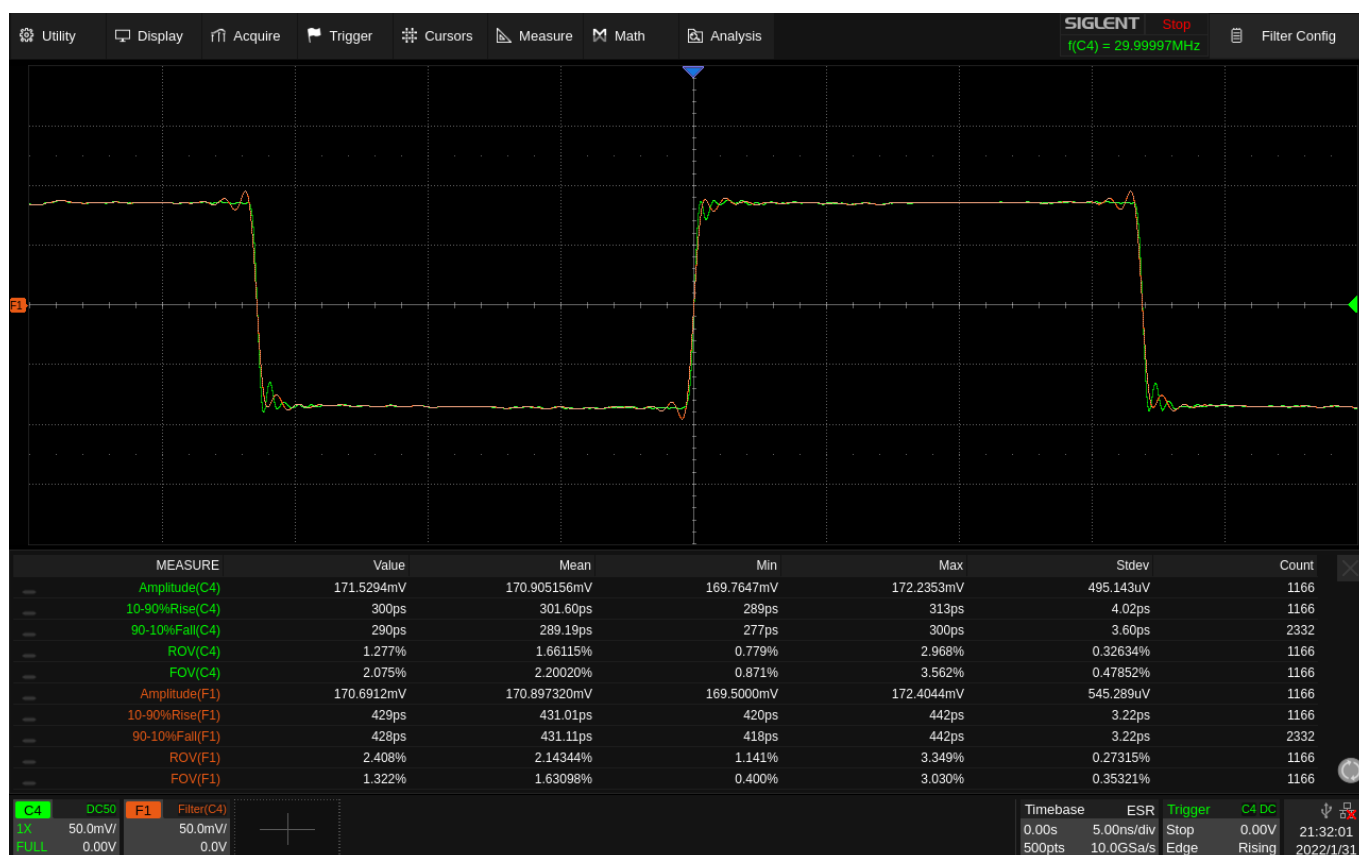


Figure 6. SDS6204_PR_30MHz_170mV_200ps_BW1.2GHz

Figure 7 shows the degradation of signal fidelity when the bandwidth is limited to 580 MHz (brick wall).

There is a significant difference, which includes the Gibbs phenomenon, and this would be much less of a problem with a genuine 580 MHz frontend. The slow-down of the transition time also gets obvious by now.

Figure 8 illustrates the degradation of signal fidelity when the bandwidth is further limited to 400 MHz (brick-wall).

Even though the difference of 400 to 580 doesn't sound to be that much, it does make a significant difference. Apart from the Gibbs phenomenon, the transition times now exceed 1 ns.

The green trace shows the original input signal, whereas the orange math trace represents the filtered signal.

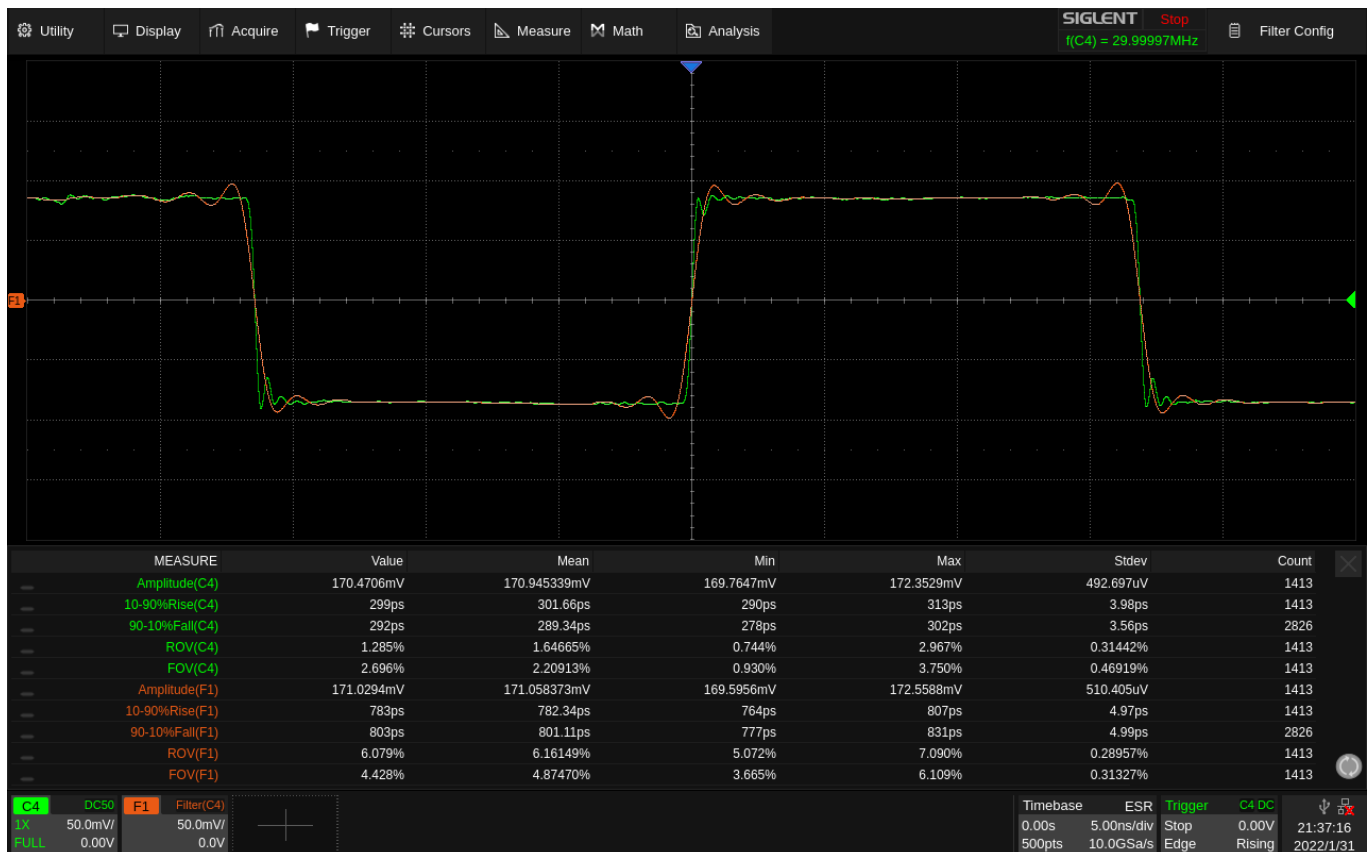


Figure 7. SDS6204_PR_30MHz_170mV_200ps_BW580MHz

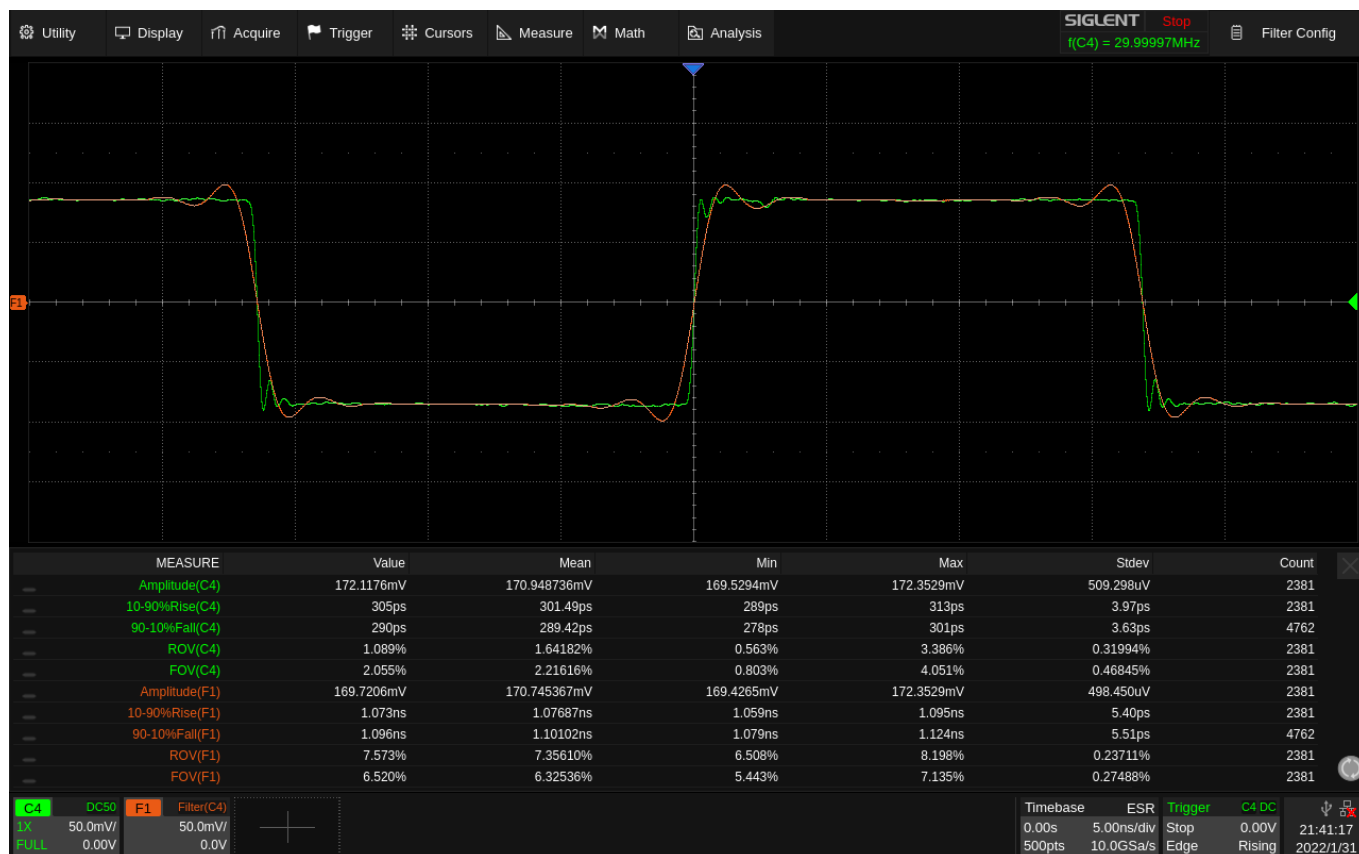


Figure 8. SDS6204_PR_30MHz_170mV_200ps_BW400MHz

Two more bandwidth limits are examined here just for completeness:

Figure 9 shows the degradation of signal fidelity when the bandwidth is further limited to 240 MHz (brick wall).

Figure 10 illustrates the degradation of signal fidelity when the bandwidth is finally limited to just 100 MHz (brick-wall).

The green trace shows the original input signal, whereas the orange math trace represents the filtered signal.

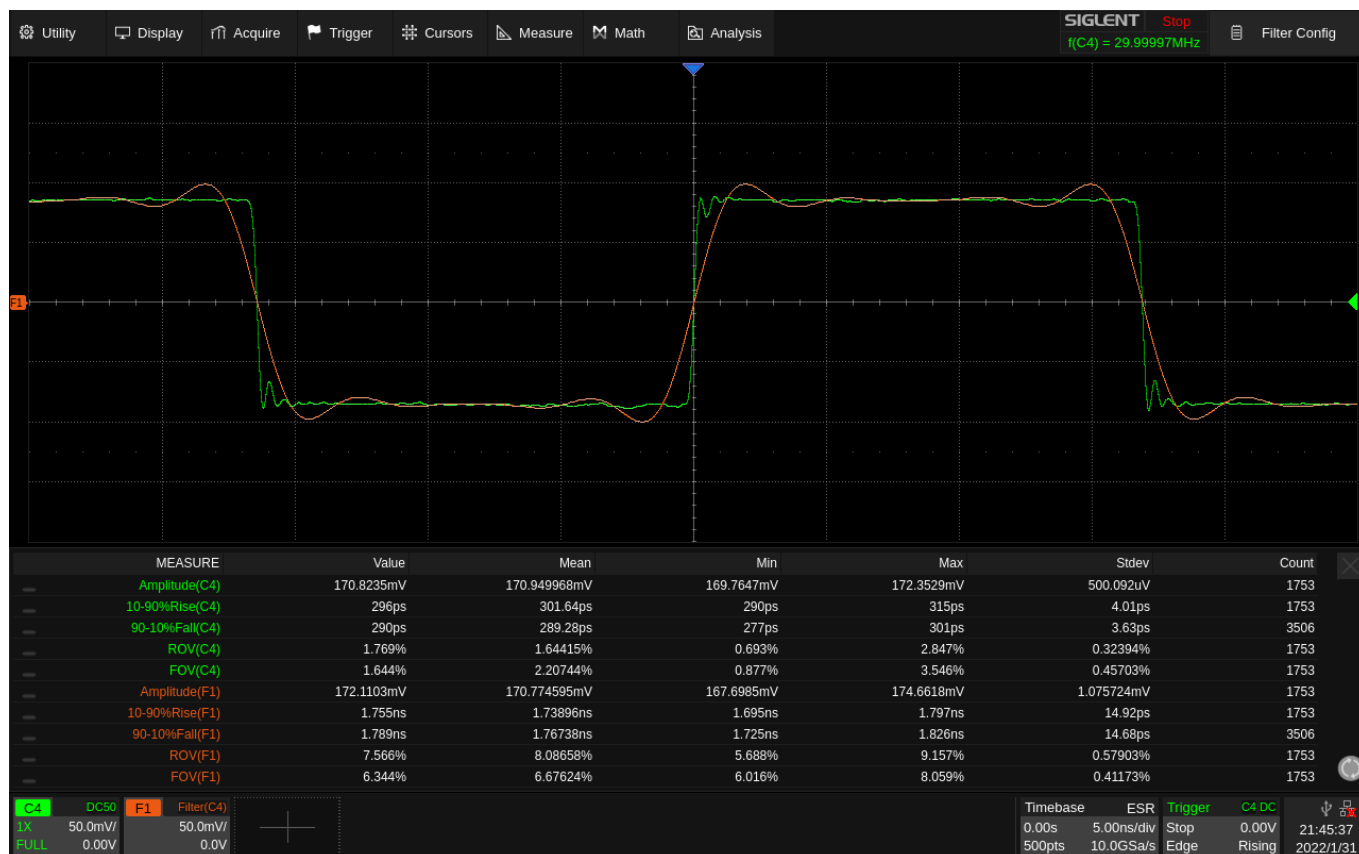


Figure 9. SDS6204_PR_30MHz_170mV_200ps_BW240MHz

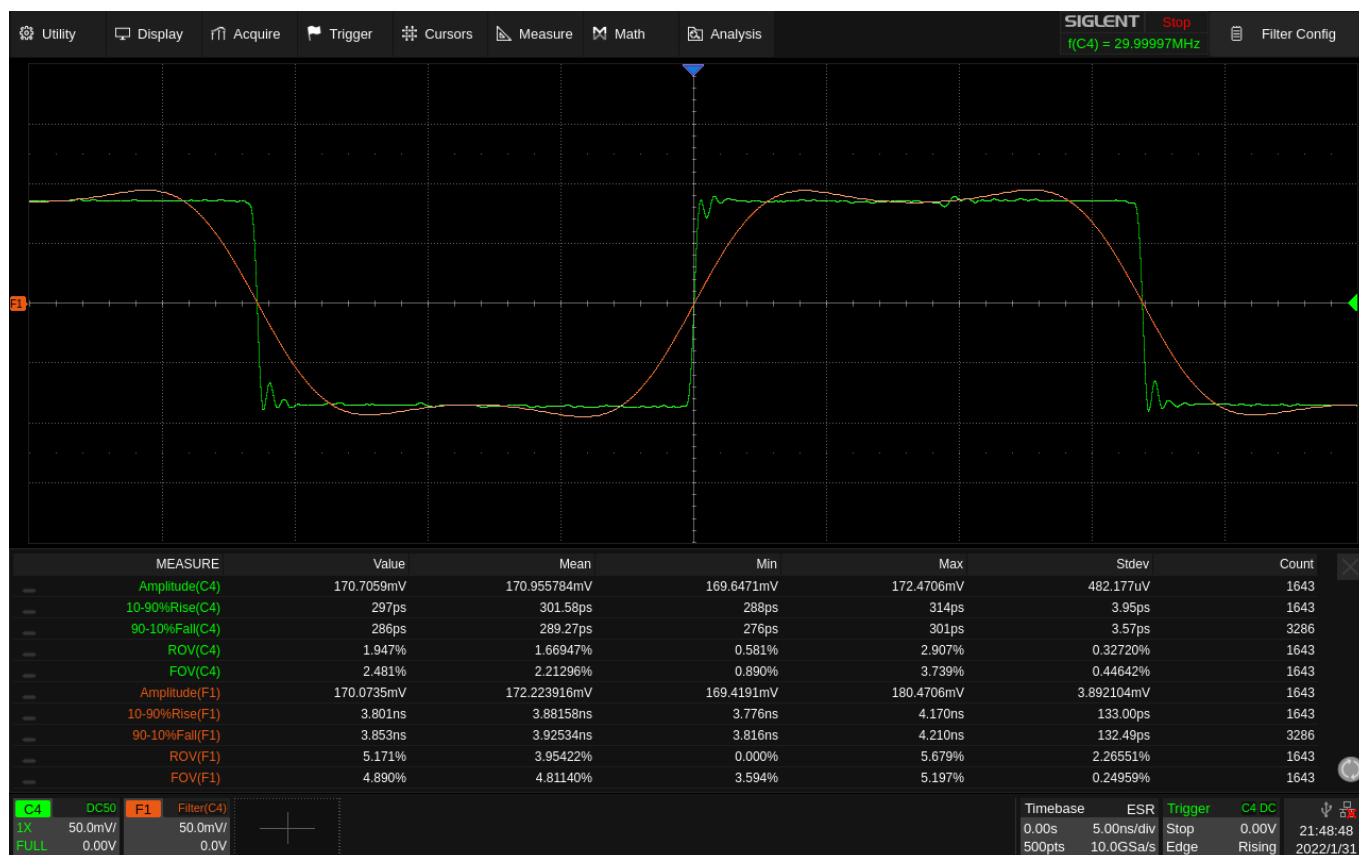


Figure 10. SDS6204_PR_30MHz_170mV_200ps_BW100MHz

Finally a warning: high bandwidth can also have its drawbacks. We need better probes alongside with better probing techniques, better cables and connectors – which all sums up in additional cost and effort. This deserves more and more attention at increasingly higher frequencies. Plus, there might be other pitfalls, see next chapter...

Why we need Sample Speed

High bandwidth is great, but without sufficient sample speed it could create more headaches than benefits. At all times, there have been digital scopes with a bandwidth higher than the maximum sample speed. In the past, these scopes made use of equivalent time sampling to digitize stably triggered, strictly periodic signals up to the full input bandwidth. Today, this technique is mostly limited to multi-GHz digitizers and hardly found in modern general-purpose scopes anymore. These are true real time scopes now, which appears to be great from a user's perspective, as there's no need to worry about the limits of the real-time bandwidth. But even today there are real-time scopes whose sample rates are too low to support the full bandwidth with all channels active – and at least now we might start worrying about aliasing...

Everyone should know the sample theorem. In short, we can faithfully reconstruct a strictly bandwidth limited signal as long as it is sampled at a rate higher than twice the highest input frequency. In other words, the highest input frequency must not touch or exceed half the sample rate, which is also known as the Nyquist frequency. Does that mean we only need 1 GSa/s sample rate in a 500 MHz scope?

Of course not. The sample theorem is just theory assuming a strictly bandwidth limited signal, digitized by a perfectly linear ADC with infinite resolution (in fact, the sample theorem only deals with quantization of time, but not magnitude) and finally the reconstruction with a perfect brick-wall filter.

It should be clear that none of these conditions can be met in any practical device. We can get a reasonably bandwidth limited signal out of a low distortion sine wave generator, but any other signal source might well produce significant harmonics and other spurious signals above the Nyquist frequency. We'd need an input filter with ideal brick-wall characteristic to remove that unwanted signal content, this is also known as anti-aliasing filter, short: AA-filter. Yet I very much doubt that many real DSOs have one – and if so, it can only be a rather ineffective low order filter that still forces some compromises regarding pulse distortion and overshoot. The bandwidth limit of a scope traditionally is supposed to have some sort of Gaussian response and it's ultimately the natural roll-off of the input amplifier that defines the maximum input bandwidth. No one wants a brick-wall filter at the scope input for various reasons and if manufacturers fit some filter (in high end scopes), then this is for equalization of phase response and group delay, which is quite the opposite from what a brick-wall filter does. In fact, about the only way to fulfill this very first requirement of keeping signals above Nyquist out, is oversampling to an extent that the smooth natural roll-off of the input amplifiers (or the first order bandwidth limiter) yields sufficient attenuation at and above the Nyquist frequency. However, at just 6 dB/octave in an 8-bit system we might need about 256 times oversampling to be totally safe against aliasing, so this is not very practical anyway.

The next problem is the quantizing of the signal magnitude. The fact that we only have 256 discrete steps in an 8-bit ADC does not invalidate the sample theorem, but every ADC has some nonlinearity, thus producing harmonics and unwanted mixer products, some of them above the Nyquist frequency – and these signal components cannot be filtered out. But then, a good ADC with < 1 LSB INL shouldn't cause any visible problems.

Finally, we need reconstruction. After all, we want to create a contiguous signal out of the discrete samples again. Linear interpolation was an early method, still offered by most scopes today. It requires little processing power, but does a lousy job, as it cannot be called a reconstruction filter at all. Consequently, signal rendition will only be reasonable as long as the sample rate is at least ten times the signal bandwidth. $\text{Sin}(x)/x$ aka Sinc is a true reconstruction function that would act as a brick-wall filter – if it could process an infinite number of data points. Quite obviously this is not going to happen in any scope, let alone at fast timebase settings (where reconstruction is needed the most), where the visible record consists just of a handful of samples. Yet the results can be surprisingly good, and a $\text{Sin}(x)/x$ filter usually manages to reasonably reconstruct a signal at 40 % of the sample rate, which is equivalent to 80 % of the Nyquist frequency, even under these adverse conditions.

As a result, it is perfectly possible to reconstruct a 400 MHz signal that has been sampled at only 1 GSa/s. But any higher than that might lead to distortion and modulation effects. Furthermore, a 400 MHz frontend will not magically stop frequencies above 500 MHz (the Nyquist frequency at 1 GSa/s) from entering the ADC, thus causing aliasing artifacts.

Now let's check how all these requirements are met in the SDS2304X Plus, especially when both channels in a group are enabled and the sample rate is limited to 1 GSa/s.

Aliasing in the SDS2304X Plus

After the explanations given earlier in this article, we cannot expect any wonders. At least my sample of this 350MHz scope has an actual 3dB bandwidth of some 460 MHz and the passband is fairly flat with about -1.8 dB amplitude drop at 350 MHz. We can safely state that there is barely any attenuation (~3.4 dB) at the 500 MHz Nyquist frequency for 1 GSa/s. See the plot in Figure 11, which shows the frequency response for the nominal 350 MHz full channel bandwidth up to the Nyquist frequency (orange) and then the aliased response (running from right to left) in the so-called 2nd Nyquist zone up to 1 GHz (yellow).



Figure 11. SDS2504X Plus_FR_B350M_1GSa_1GHz

It should be clear that signals whose spectra exceed the 500 MHz Nyquist frequency can cause heavy aliasing, as shall be demonstrated later.

We can still use the 200 MHz bandwidth limit to reduce aliasing, as shown in Figure 12 – but this cripples our DSO to a lower bandwidth instrument, increasingly unsuitable for looking at fast signals. Quite obviously we cannot have it all at the same time. Actual -3 dB corner frequency is only 185 MHz, attenuation at 500 MHz is little more than 10 dB, so the AA-effect is limited anyway. Please note that this would probably not be a suitable emulation for the genuine 200 MHz model, where the bandwidth exceeds 200 MHz for sure. In some Siglent DSOs an additional digital filter with 18 dB/octave is implemented in order to get a uniform bandwidth limit, but this doesn't seem to be the case for the SDS2000X Plus series.

Finally, there is the 10-bit HiRes mode, which is bandwidth limited to 100 MHz implicitly. With the additional 200 MHz bandwidth limiter, the attenuation at 100 MHz is increased by almost one decibel and the resulting 3.26 dB amplitude drop even violates the specification. This should be bearable for most applications. Apart from the slow roll-off 200 MHz bandwidth limit, this is a digital filter that does not reduce the bandwidth before the ADC. Some might think it cannot be expected to be effective in suppressing aliasing artifacts, yet it still helps a lot, because the stopband is effective in the 2nd Nyquist zone as well, hence there should be an additional minimum attenuation of about 18 dB up to 780 MHz. The genuine 100 MHz model might have a similar characteristic even in 8-bit mode. The corresponding frequency response plot can be found in Figure 13.

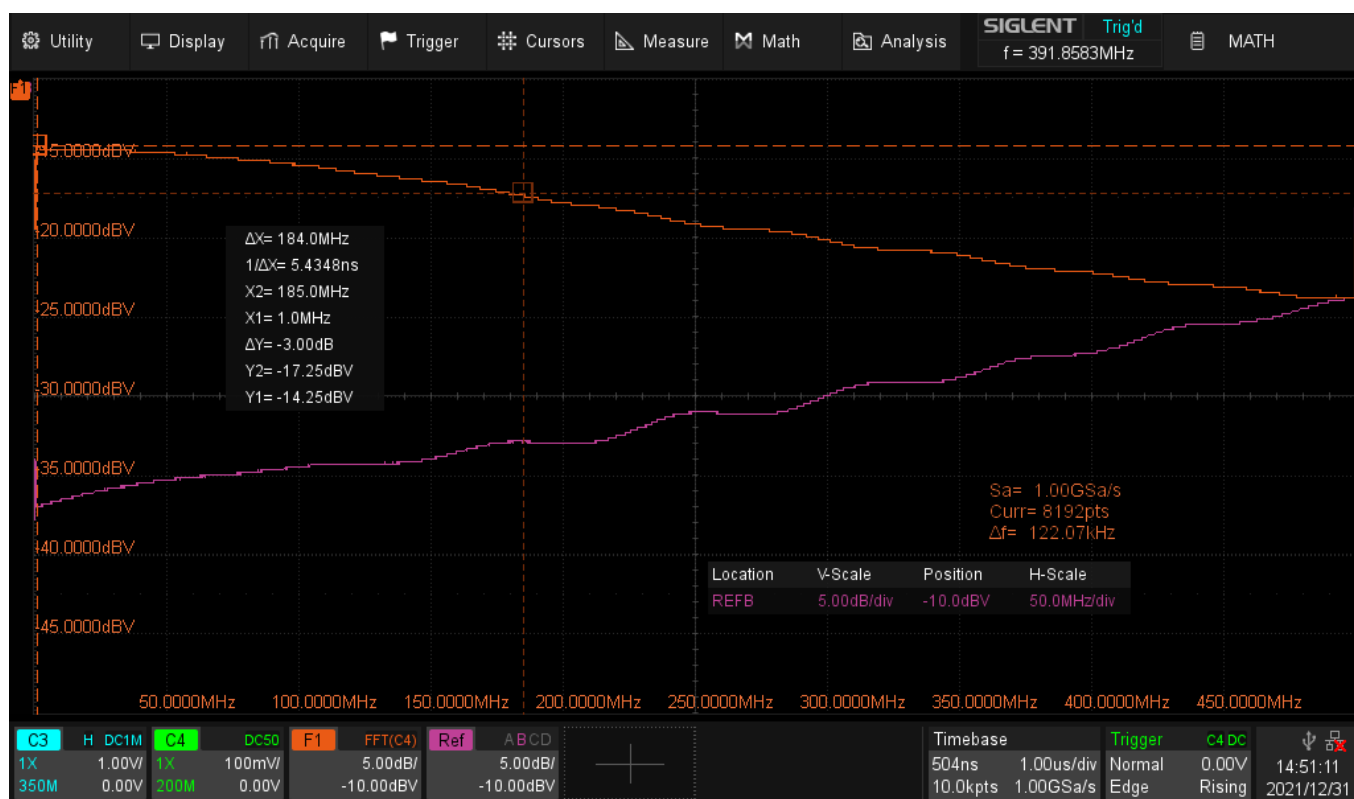


Figure 12. SDS2504X Plus_FR_B200M_1GSa_1GHz

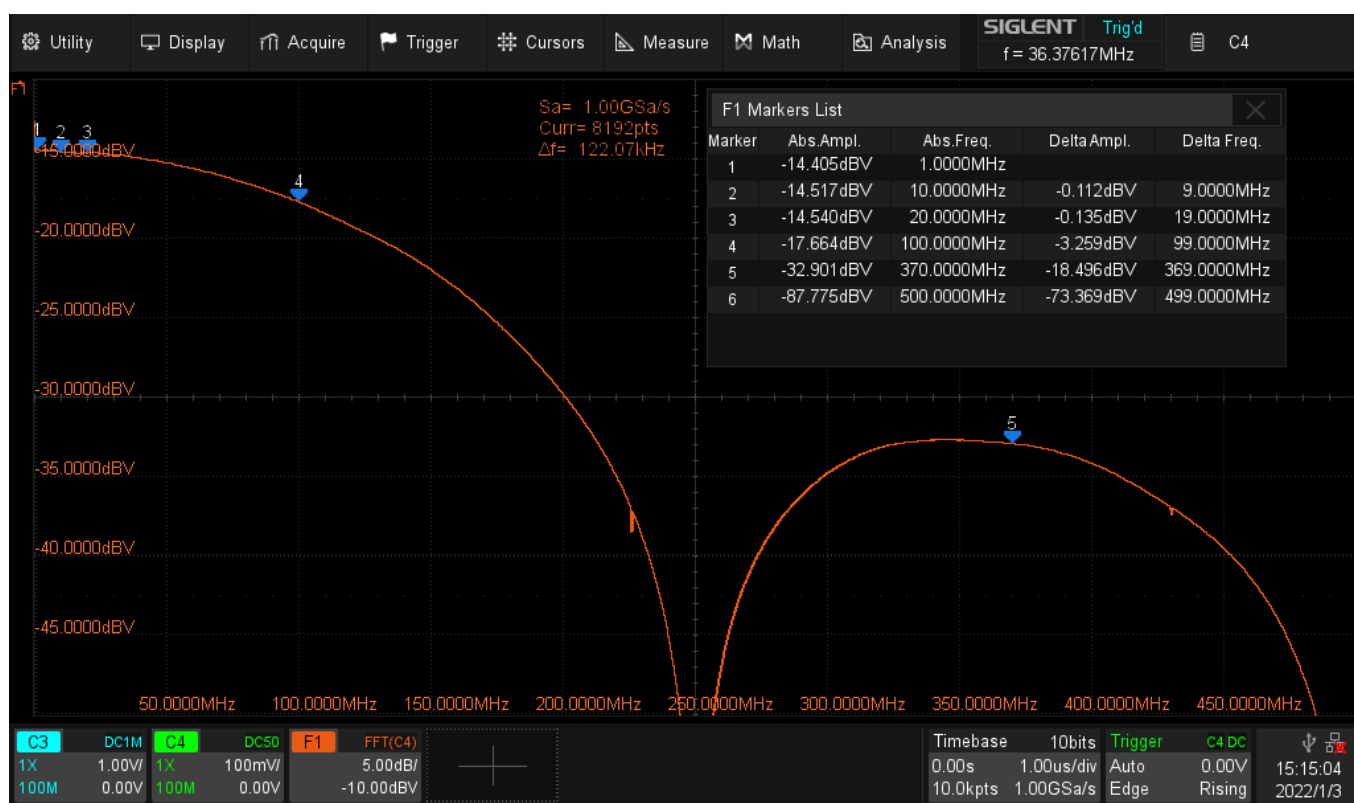


Figure 13. SDS2504X Plus_FR_B100M_1GSa_500MHz_10bit

Of course, aliasing should be much less of a problem with only one channel per channel group enabled (half channel mode), because we have 2 GSa/s sample speed then and Nyquist frequency appears sufficiently high at 1 GHz. But with the 500 MHz option installed, the upper bandwidth limit is now higher as well, at about 570 MHz. As we can see from the frequency response plot earlier in this document (Figure 1), there is more than 15 dB attenuation at 1 GHz. The big question remains: is this sufficient? We'll examine this later.

How to identify aliasing artifacts?

As we will see later in the “Pulse & Square Wave Test” section, there are several indicators for signal distortion caused by aliasing:

- High standard deviation in the measurement statistics
- Signs of jitter and fuzzy rendering in vector display mode
- Unnatural and implausible signal shapes in dots mode (in those severe cases, where even the trigger signal path is affected)

Reconstruction in the SDS2304X Plus

This scope did not shine in the (anti) aliasing section, as there is absolutely no attenuation worth mentioning at the Nyquist frequency in full channel mode. As expected, the frontend has a slow roll-off and the -3 dB corner frequency is much higher than the specified 350 MHz. Consequently, even at 1 GHz a significant portion of the signal will pass through. Now let's see if at least the reconstruction filter makes the best out of the few data points at high frequencies.

Let's ignore the nominal bandwidth limit and immediately jump up to 40 % of the sample rate, i.e. 400 MHz at 1 GSa/s, as with all channels enabled. First screenshot (Figure 14) is with $\sin(x)/x$ reconstruction, 2nd one (Figure 15) with linear interpolation. What a difference!



Figure 14. SDS2504X Plus_Sine_400MHz_BW350MHz_1GSa_SinX



Figure 15. SDS2504X Plus_Sine_400MHz_BW350MHz_1GSa_X

$\sin(x)/x$ reconstruction is perfectly fine, whereas linear interpolation results in useless artwork. But we can always get an artifact-free rendition by using dots display mode (Figure 16). Well, at frequencies that high (and only 10 samples per screen width), we don't get a fully contiguous trace anymore, but that's really a very minor problem.

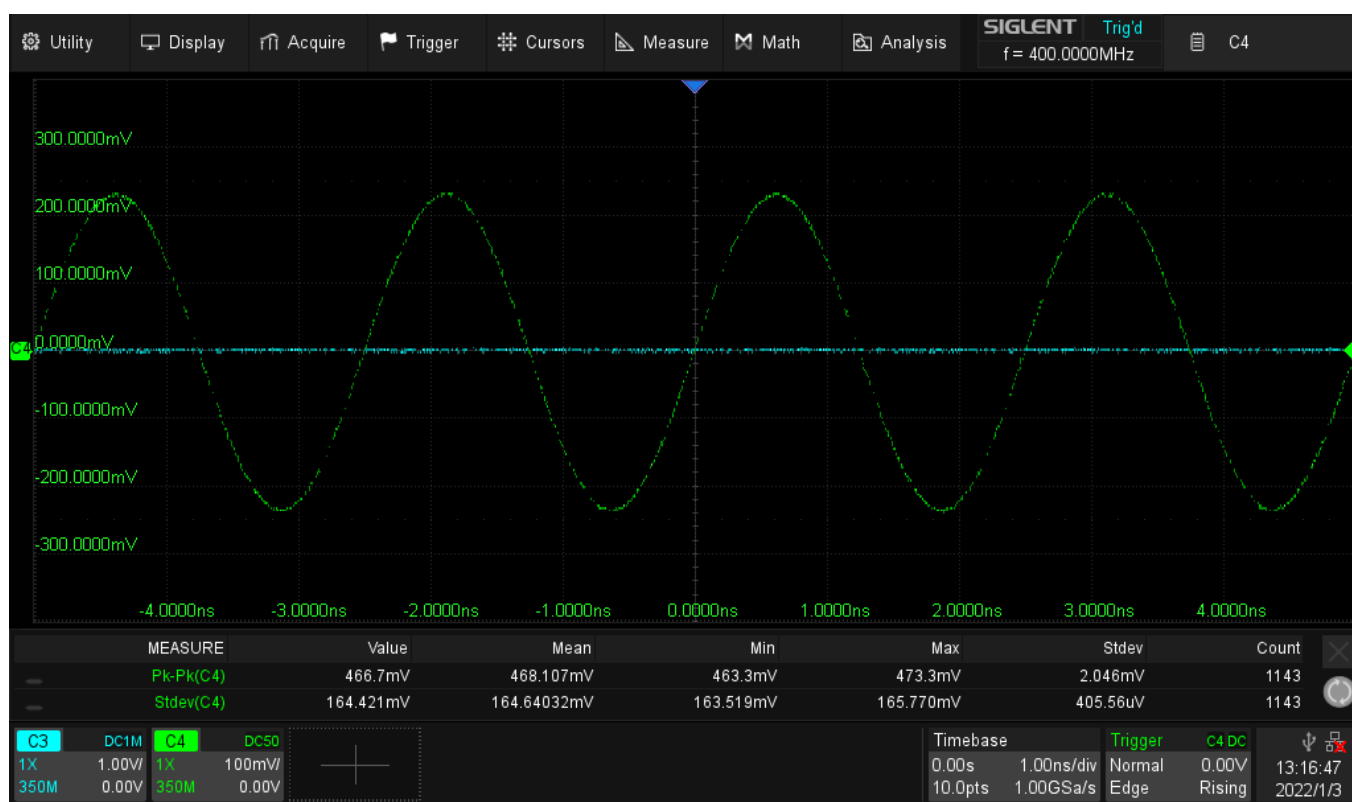


Figure 16. SDS2504X Plus_Sine_400MHz_BW350MHz_1GSa_Dots

As we could see, dots mode as well as $\sin(x)/x$ reconstruction yielded flawless renditions at a signal frequency 80% of Nyquist. Now we want to see what it looks like if we go even higher.



Figure 17. SDS2504X Plus_Sine_440MHz_BW350MHz_1GSa_SinX



Figure 18. SDS2504X Plus_Sine_450MHz_BW350MHz_1GSa_SinX



Figure 19. SDS2504X Plus_Sine_460MHz_BW350MHz_1GSa_SinX



Figure 20. SDS2504X Plus_Sine_500MHz_BW350MHz_1GSa_SinX

The screenshots speak for themselves. With only 10 samples for the entire record, $\sin(x)/x$ on the SDS2304X Plus manages to reconstruct signals up to 440 MHz, thus even higher than the usual 40 % of the sample rate. But it still inevitably fails at frequencies any higher than 88% of Nyquist.

Pulse & Square Wave Test

Now let's use some test signals to evaluate the practical implications of our findings so far.

1 ns transition time Pulse

The signal spectrum shown in Figure 21 already requires the full 570 MHz bandwidth of the SDS2504X Plus in half channel mode to show a reasonable realistic representation of the real signal.

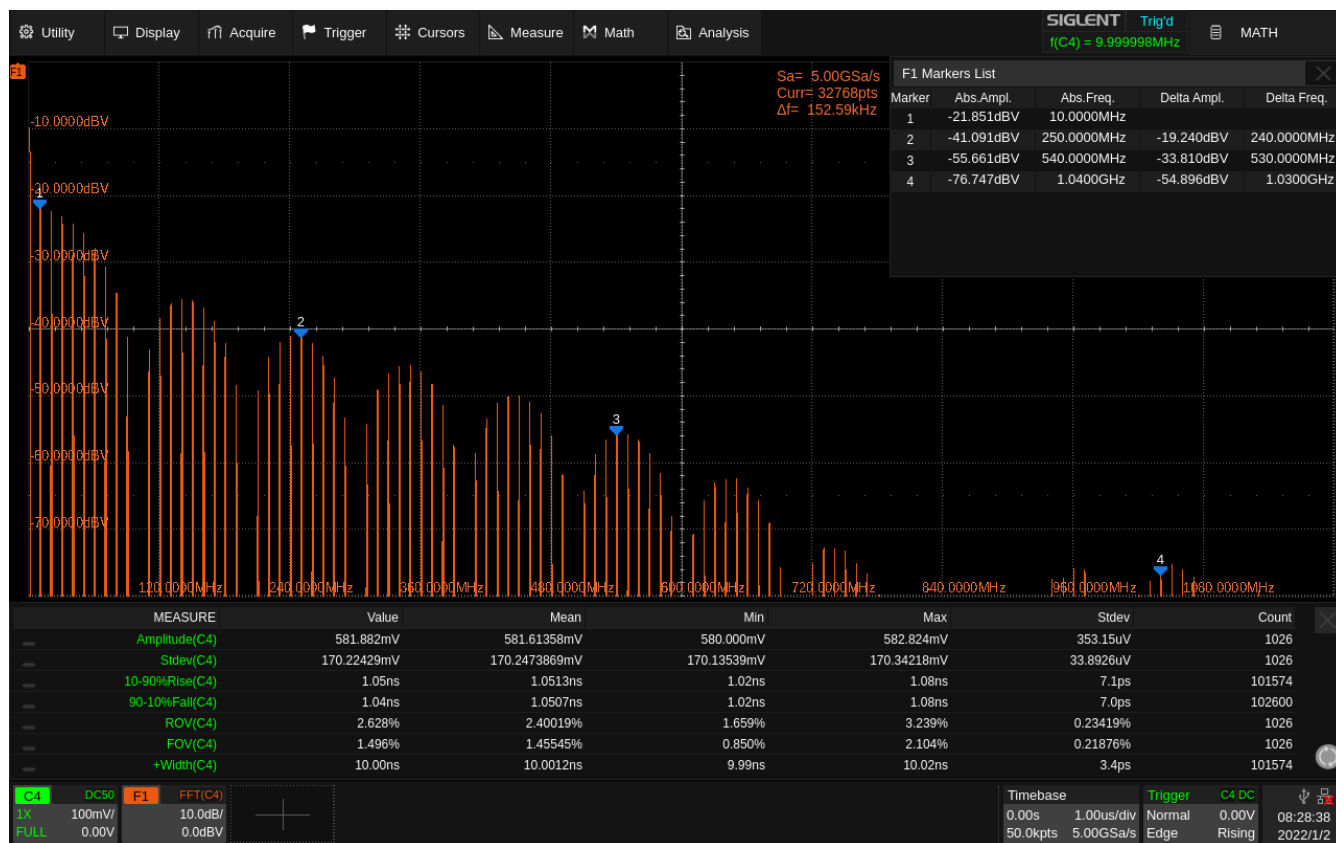


Figure 21. SDS6204_FFT_B1200M_5GSa_10MHz_W10ns_T1ns

Here is what the waveform looks like on a 2 GHz SDS6204 DSO (Figure 22). It is a nice and clean 10 ns wide pulse with very little overshoot.

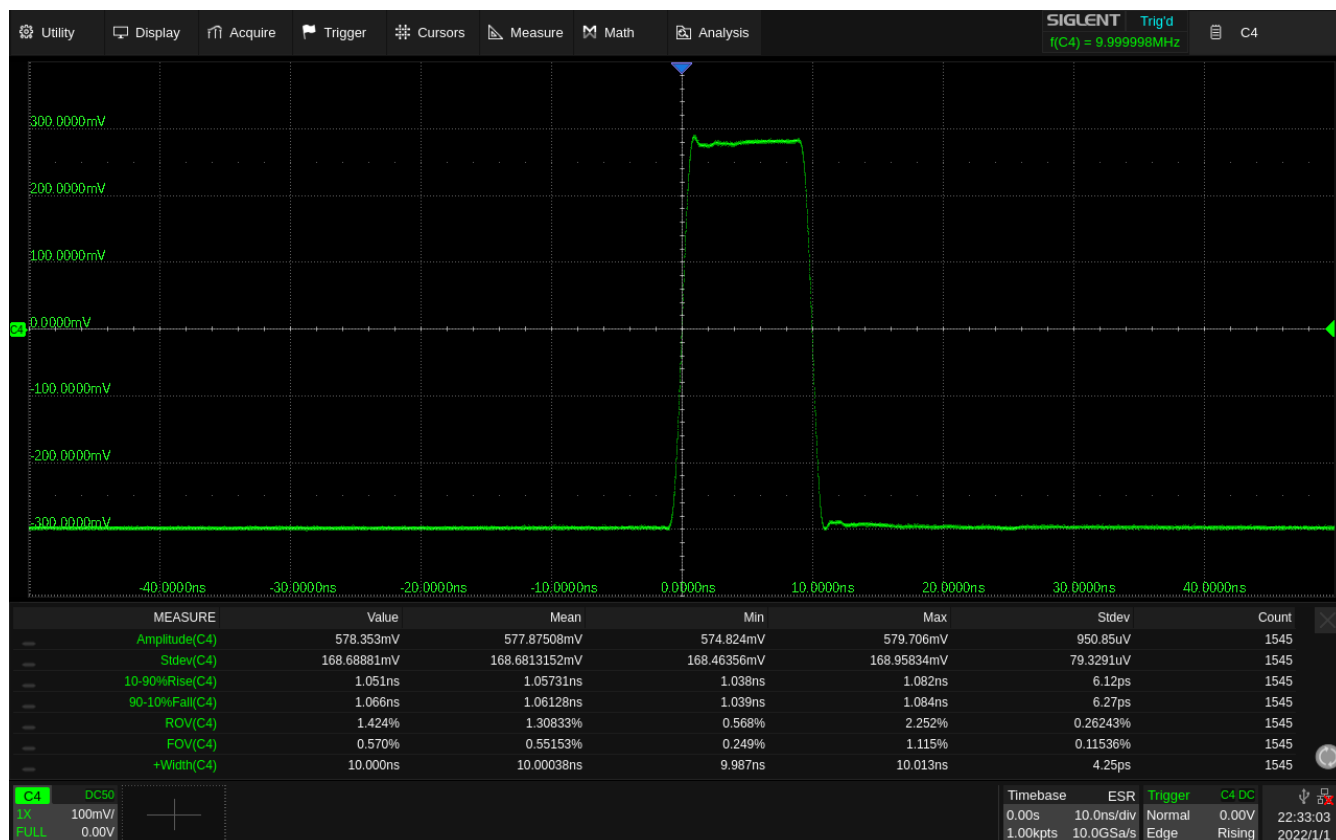


Figure 22. SDS6204_PR_B2G_5GSa_10MHz_W10ns_T1ns

Let's keep these measurement results in mind and compare them with the subsequent screenshots. Now the SDS2304X Plus in half channel mode with 570 MHz input bandwidth and 2 GSa/s (Figure 23):



Figure 23. SDS2504X Plus_PR_B500M_2GSa_10MHz_W10ns_T1ns

570 MHz vs. 2 GHz – with this relatively benign signal it's not a big difference. Overshoot is a little worse on the SDS2304X Plus and rise time measurements are not as accurate (no wonder, since we are so close to the scope's own rise time), yet we get a very good idea what the real signal looks like.

Now let's try the full channel mode with only 1 GSa/s (Figure 24):



Figure 24. SDS2504X Plus_PR_B350M_1GSa_10MHz_W10ns_T1ns_V

First signs of imperfection start creeping in, even though aliasing is not yet an issue. The pulse width and amplitude measurements are pretty much correct, hence also the zero crossings; just the transition time measurements go up and the pulse shape gets distorted, showing Gibbs phenomenon.

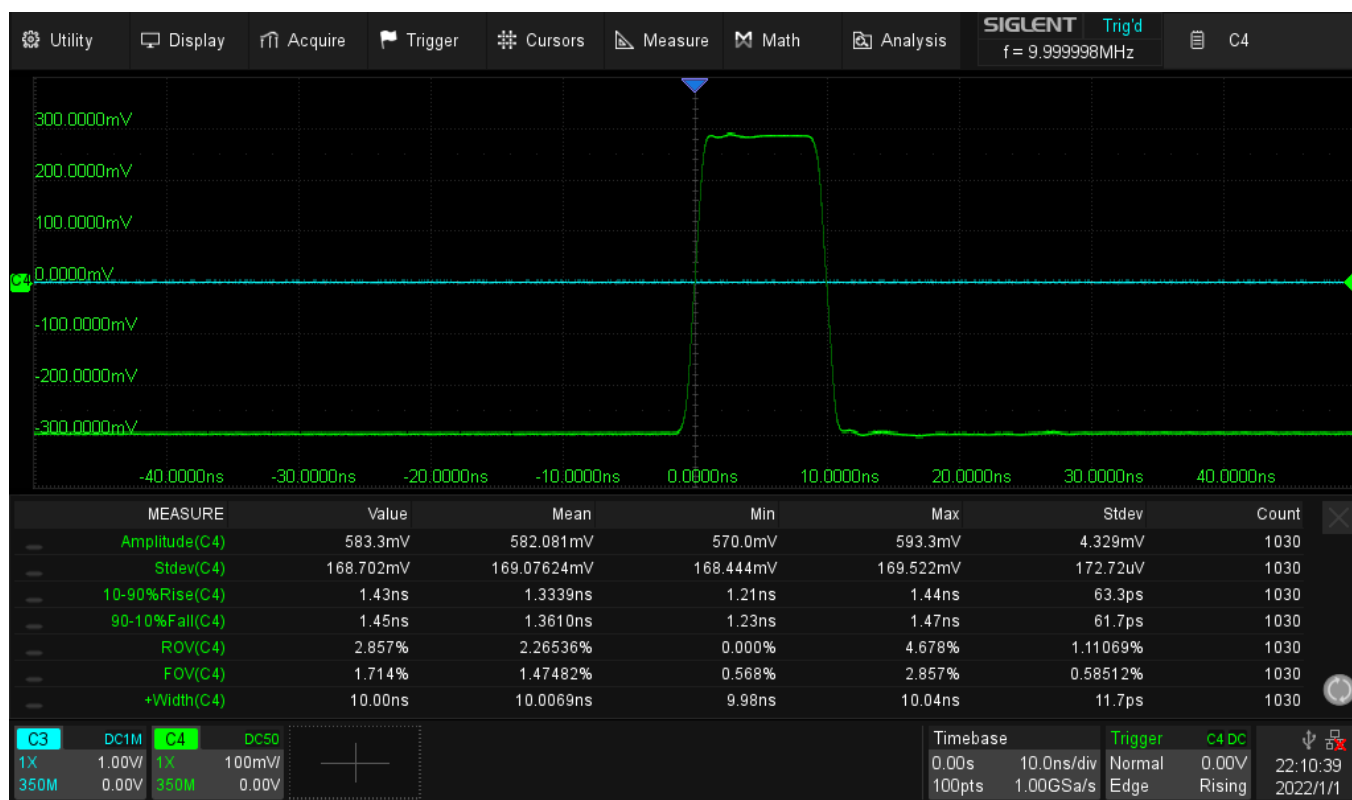


Figure 25. SDS2504X Plus_PR_B350M_1GSa_10MHz_W10ns_T1ns

To get a nicer graphical representation of the waveform, we can resort to dots display mode (Figure 25), where the reconstruction errors are limited to the trigger signal path – and as can be seen from the screenshot in Figure 24, this is not yet an issue here at the zero crossings.

Most of the signal detail is gone now and the trace looks rather clean. This test confirms that even 460 vs. 570 MHz can make a visible difference in some situations.

We could also use the 200 MHz bandwidth limiter as an attempt to get rid of the high frequency signal portions that cause Gibbs phenomenon (Figure 26). Unsurprisingly, we see the typical response of a first order analog filter together with the total loss of any detail. Again, pulse amplitude and width measurements are not affected, just the transition times and overshoot are.

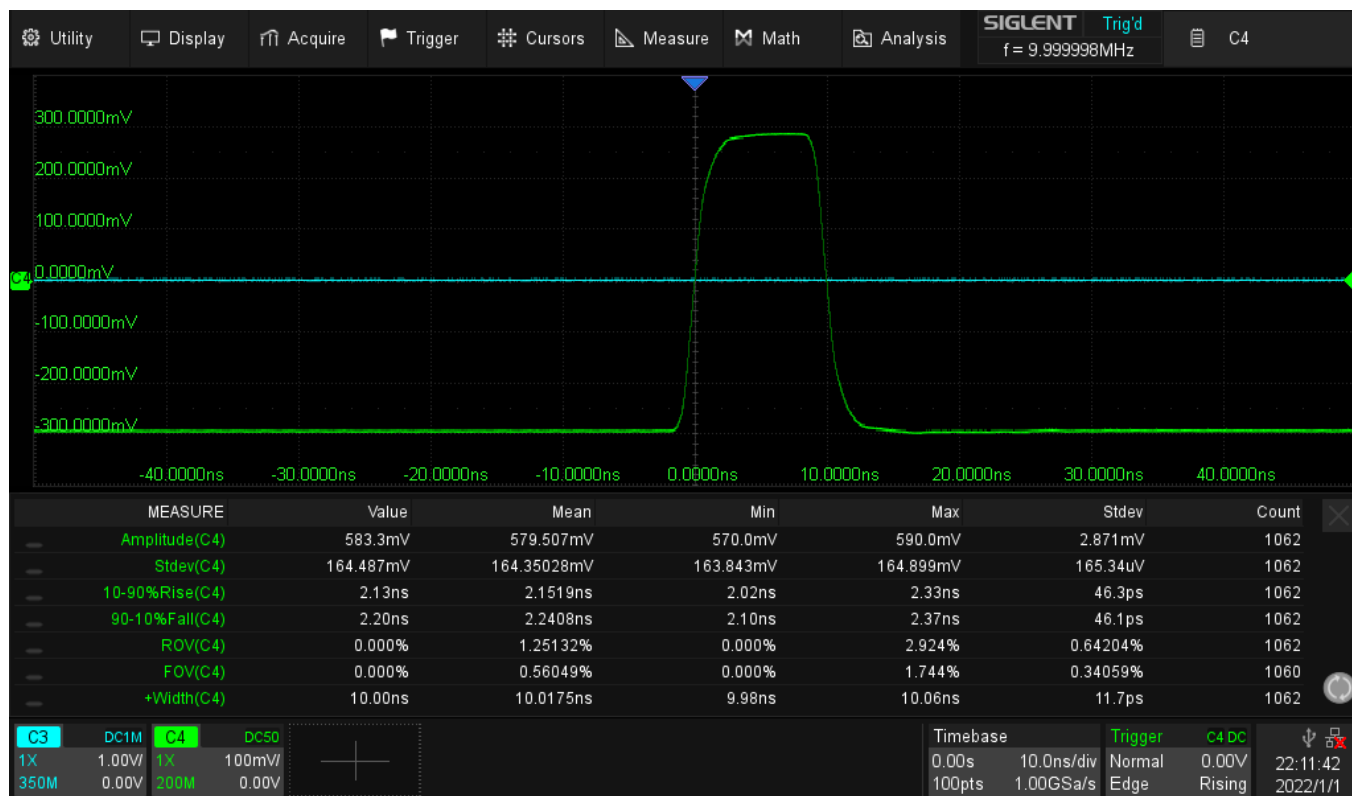


Figure 26. SDS2504X Plus_PR_B200M_1GSa_10MHz_W10ns_T1ns

We have one more option: using the 10-bit mode (limited to 100 MHz bandwidth) together with the 200 MHz bandwidth limit (Figure 27). We can see the huge difference between analog and digital filtering, as the pulse now appears much more symmetric. Even though filtering is primarily digital, it still helps reducing the aliasing artifacts, but this is not required with this signal yet.



Figure 27. SDS2504X Plus_PR_B100M_1GSa_10MHz_W10ns_T1ns_10bit

500 ps transition time Pulse

Our second signal has faster 500 ps edges that produce some overshoot but is identical otherwise. The signal spectrum shown in Figure 28 requires at least 1 GHz bandwidth to show a reasonable realistic representation of the real signal.

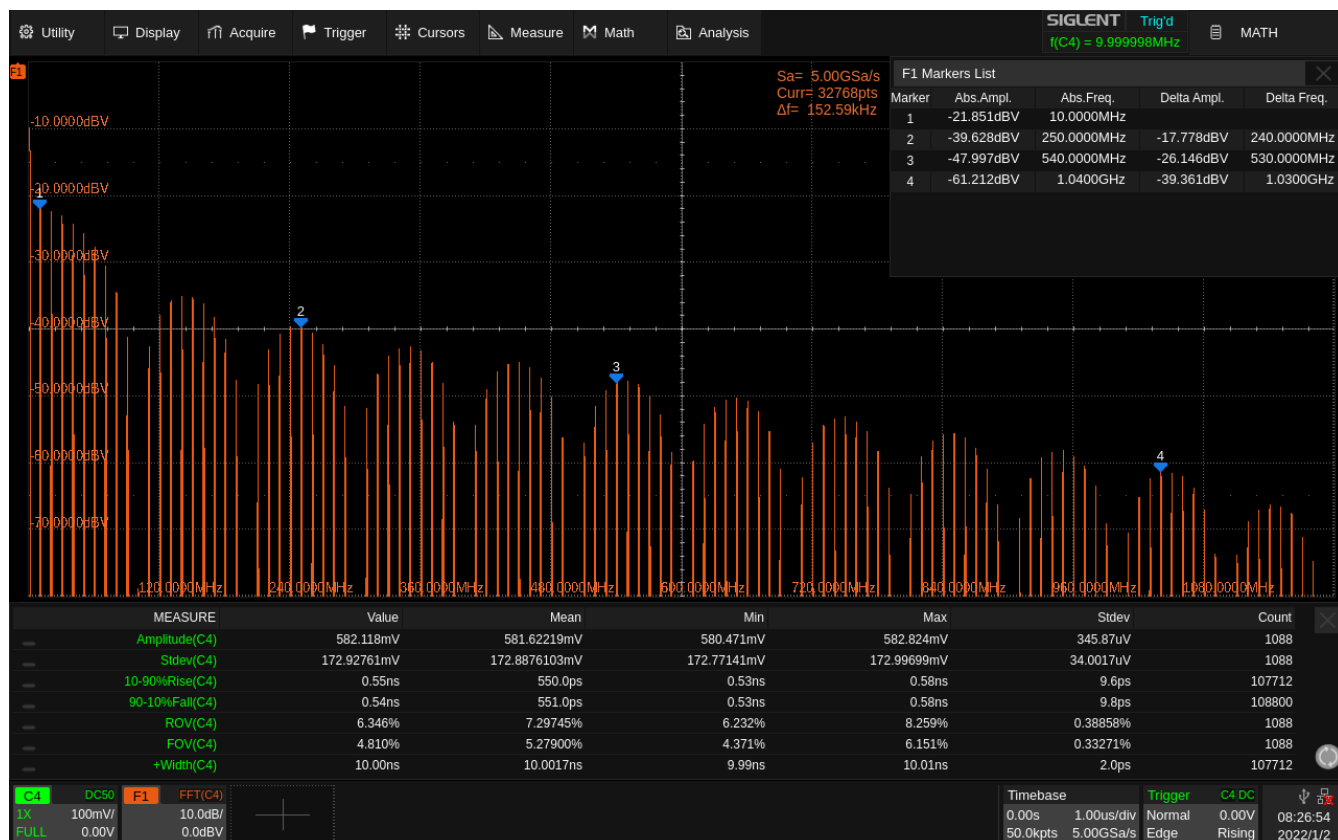


Figure 28. SDS6204_FFT_B1200M_5GSa_10MHz_W10ns_T500ps

Here is what the waveform looks like on a 2 GHz SDS6204 DSO (Figure 29). It is a fast 10 ns wide pulse with some substantial overshoot.



Figure 29. SDS6204_PR_B2G_5GSa_10MHz_W10ns_T500ps

Let's keep these measurement results in mind and compare them with the subsequent screenshots. Now the SDS2304X Plus in half channel mode with 570 MHz input bandwidth and 2 GSa/s (Figure 30):



Figure 30. SDS2504X Plus_PR_B500M_2GSa_10MHz_W10ns_T500ps

The fine high frequency signal details are gone now, yet the difference is not huge and amplitude measurements read very similar. Overshoot is worse again on the SDS2304X Plus and transition time measurements approach the scope's own rise time, yet we still get a coarse idea what the signal actually looks like.



Figure 31. SDS2504X Plus_PR_B350M_1GSa_10MHz_W10ns_T500ps_V

The full channel mode with only 1 GSa/s is shown in Figure 31. In vector display mode, Gibbs phenomenon together with a tiny bit of aliasing become an obvious problem. We get to see a jittery representation of the pulse shape. This confirms that without massive oversampling, we should avoid signals that have a faster rise time than the scope itself. Yet the pulse width and amplitude measurements are pretty much correct, hence also the zero crossings, just the transition time measurements are far off, and the overshoot is reduced – ironically the measurements are now even closer to the truth.

Once again, we can deal with situations like this – just by getting rid of the reconstruction and using dots mode instead (Figure 32). While the automatic measurements are unaffected – as one would expect, as they still use $\sin(x)/x$ reconstruction at fast timebase settings like this, the waveform rendering is much closer to the truth now. We don't see the massive overshoot anymore, but this would have more to do with the lack of high frequency detail because of the limited bandwidth.



Figure 32. SDS2504X Plus_PR_B350M_1GSa_10MHz_W10ns_T500ps

We can try the 200 MHz bandwidth limiter again but cannot expect much different results than with the previous 1 ns edge pulse (Figure 33). Unsurprisingly, we see the typical response of a first order analog filter together with the total loss of any detail. Again, pulse amplitude and width measurements are not affected, just the transition times and overshoot are.



Figure 33. SDS2504X Plus_PR_B200M_1GSa_10MHz_W10ns_T500ps

Also, in 100 MHz 10-bit mode, together with the 200 MHz bandwidth limit, we get pretty much the same result as we got with the 1 ns edge pulse (Figure 34).



Figure 34. SDS2504X Plus_PR_B100M_1GSa_10MHz_W10ns_T500ps_10bit

200 ps transition time Square

Finally, the spectrum in Figure 35 shows the third test signal, a 200 MHz square wave with less than 200 ps transition times. The spectrum is shown up to 2.5 GHz and it is quite obvious that even a 2 GHz DSO like the SDS6204 struggles to show all the high frequency details of such a signal. The highest odd harmonic in this range is only about 30 dB down at 2.2 GHz, so a remaining error of more than 3 percent is to be expected.

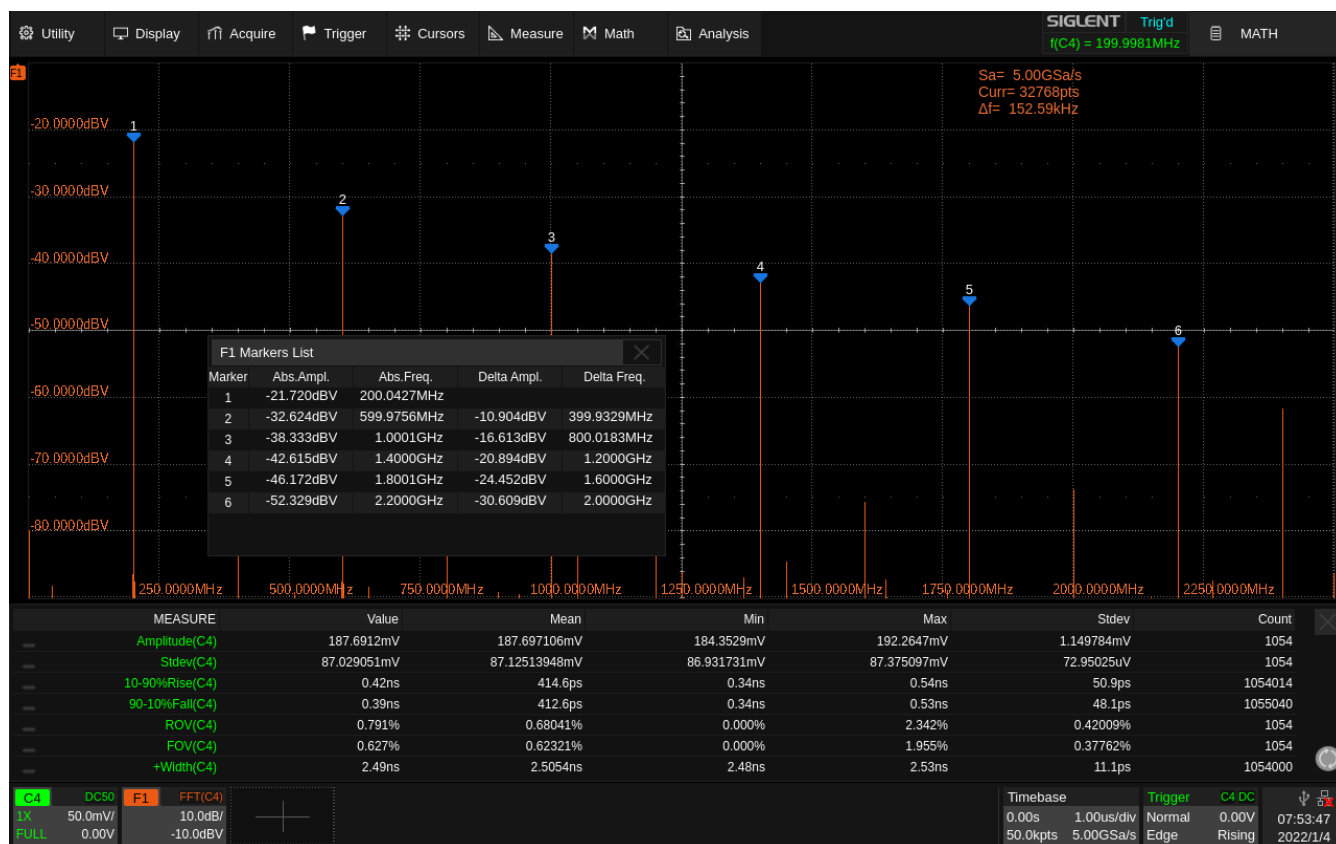


Figure 35. SDS6204_FFT_B2G_5GSa_200MHz_Duty50_T200ps

Here is what the waveform looks like on a 2 GHz SDS6204 DSO (Figure 36). It is a reasonable shaped 200 MHz square wave with negligible overshoot and its edges are slightly faster than the oscilloscope's own rise time of 230 ps.

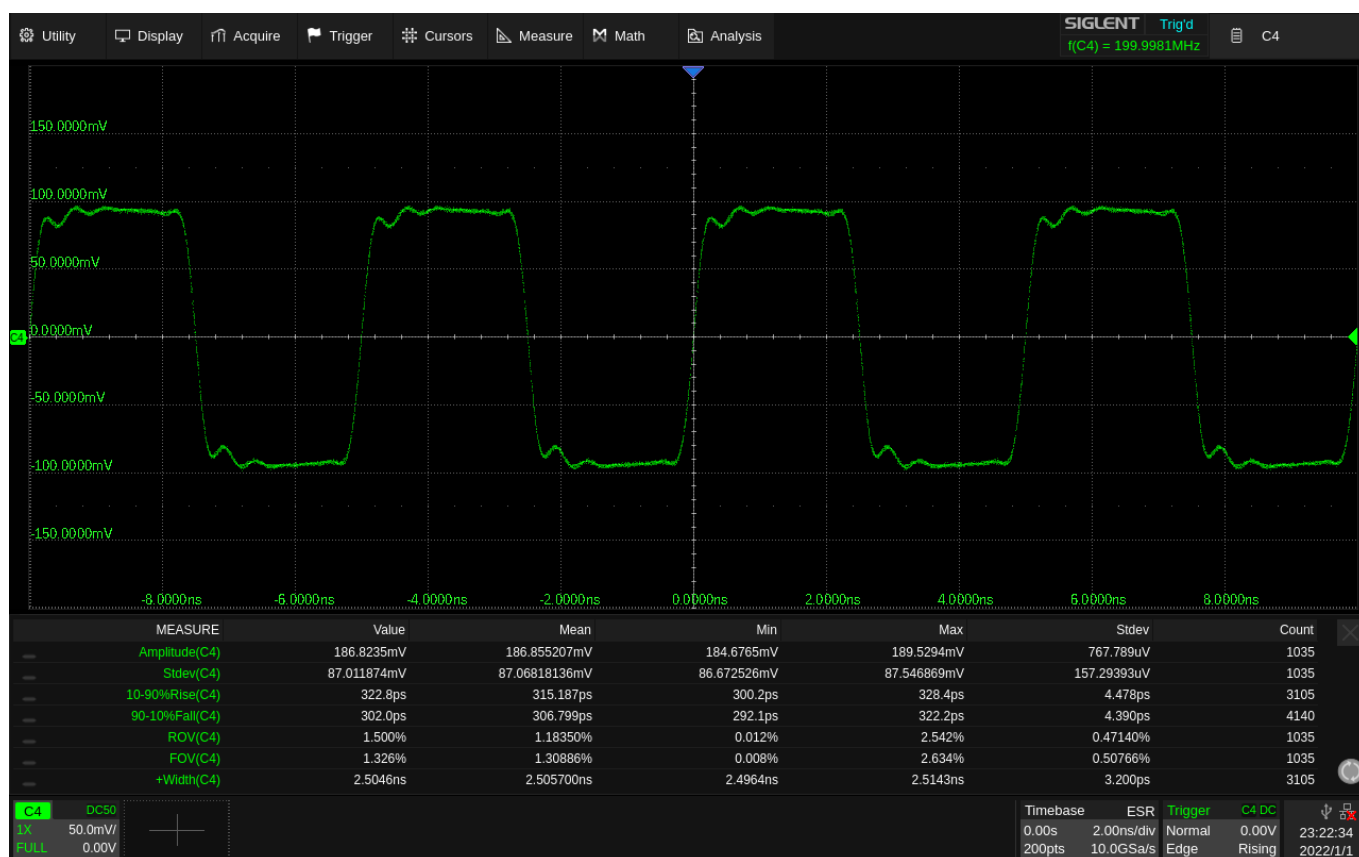


Figure 36. SDS6204_PR_B2G_5GSa_200MHz_Duty50_T200ps

Let's keep these measurement results in mind and compare them with the subsequent screenshots. Now the SDS2304X Plus in half channel mode with 570 MHz input bandwidth and 2 GSa/s (Figure 37):



Figure 37. SDS2504X Plus_PR_B500M_2GSa_200MHz_Duty50_T200ps

The difference in the wave shape is quite striking, yet there is no aliasing. Overshoot readings are off because of the slanted pulse flats and rise time measurements read far too high as expected. Amplitude and pulse width measurements are still very usable though. Now the full channel mode with only 1 GSa/s (Figure 38):



Figure 38. SDS2504X Plus_PR_B350M_1GSa_200MHz_Duty50_T200ps_V

The signal shape has turned into a jittery sine wave now. Not a big surprise since the lowest odd order harmonic at 600 MHz is far outside the bandwidth. Aliasing is all too obvious and none of the measurements yields useful results anymore – even the pulse width measurement is a little bit off by now.

In dots display mode we see an ugly waveform that we would never experience in any real-world circuit, which immediately hints on the heavy aliasing that is affecting even the internal trigger signal path (Figure 39). And in Figure 38 we can see the heavy jitter also at the zero crossings, which happens to be the trigger level.



Figure 39. SDS2504X Plus_PR_B350M_1GSa_200MHz_Duty50_T200ps

After these demonstrations it should be obvious that an upper entry level oscilloscope like the SDS2000X Plus cannot be the right tool for analyzing signals as fast as this one – not even the highest model in the series (SDS2354X Plus) with the 500 MHz option in half channel mode. Yet it can at least serve as a good signal detector in half channel mode without problems, whereas the full channel mode doesn't work at all.

There's no point in trying to measure a fast 200 MHz square wave with 200 MHz bandwidth limit or 100 MHz HiRes mode.

Safe Signals

We have seen three different signals with different speed, i.e. transition times of 1 ns, 500 ps and <200 ps. We had to accept that there is Gibbs phenomenon and visible aliasing in some situations, especially in full bandwidth four channel mode, where the actual bandwidth vastly exceeds the specifications and there's almost no attenuation at the Nyquist frequency.

This raises the question, what the ultimate speed limits for "safe" signals are, that can be unscrupulously used in conjunction with the different modes of this oscilloscope.

Half Channel Mode (2 GSa/s)

This will be the nominal 500 MHz bandwidth in the fully optioned top model, measured as some 570 MHz. Lower models will have lower bandwidth, hence would be less suitable for looking at fast signals, but inherently safer against aliasing.

As we already know, 500 ps rise time is handled just fine in this mode, whereas 200 ps cannot be properly analyzed anymore but still doesn't cause any aliasing problems. I have not tested any faster signals, yet I'm pretty confident that these would hardly cause any troubles. Here's a screenshot for the <200 ps rise time square wave again, in revealing vector display mode (Figure 40) – and there are absolutely no signs of aliasing yet.



Figure 40. SDS2504X Plus_PR_B500M_2GSa_200MHz_Duty50_T200ps_V

Full Channel Mode (1 GSa/s)

This will be the nominal 350 MHz bandwidth in the top model, actually measured as some 460 MHz in my sample. Lower models will have lower bandwidth, hence would be less suitable for looking at fast signals, but inherently safer against aliasing.

Full bandwidth

As we already know, the true 460 MHz bandwidth is not helpful to avoid aliasing when the Nyquist frequency is only 500 MHz. Even a relatively benign pulse with 1 ns rise time showed some imperfections in the shape of Gibbs phenomenon. I found the absolute limit of artifact-free operation with some 1.6 ns rise time, as can be demonstrated by a screenshot in vector display mode (Figure 41):



Figure 41. SDS2504X Plus_PR_B350M_1GSa_10MHz_W10ns_T1.6ns_V

200 MHz bandwidth limiter

200 MHz (which is actually 185 MHz in my sample) sounds like a lot of safety margin regarding the Nyquist frequency of 500 MHz, but because of the slow roll-off it's still barely 10 dB attenuation at that frequency. Keep in mind that the 200 MHz variant of this scope will have a higher bandwidth limit – but no manually switchable 200 MHz bandwidth limit anymore.

The absolute limit of artifact-free operation is reached at some 1.2 ns rise time, as can be demonstrated by a screenshot in vector display mode (Figure 42):



Figure 42. SDS2504X Plus_PR_B200M_1GSa_10MHz_W10ns_T1.2ns_V

Conclusions

As could be demonstrated, the SDS2304X Plus with 500 MHz option works without any artifacts in half channel mode at 570 MHz bandwidth even with fast signals like the <200 ps rise time square wave.

Special caution is required when using more than two channels, because then the sample rate drops to just 1 GSa/s and even the input bandwidth limit is rather ineffective for various reasons. Consequently, for happy tinkering and probing around without further considerations, 4-channel operation should be limited to signals slower than 1.6 ns rise time if pulse fidelity is of any importance.

On the other hand, pulse integrity checks which require a reasonable accurate waveform display usually need not be performed on all channels all the time, so the half channel mode can be used for this exclusively. After these tests have been completed with a positive result, even the digital logic channels are good enough for many tasks, all the more so the analog channels in full channel mode.

For the timing analysis, the true waveform is not important – we often use the digital channels for this anyway – and in contrast to the logic channels we can still see a coarse approximation of the signal shape in dots display mode even when visual signs of aliasing start creeping in – and we still get fairly accurate amplitude and time measurements.

As has been demonstrated, dots display mode eliminates the reconstruction error and works well even close to the Nyquist frequency, so this can save your day in certain borderline situations, where aliasing artifacts are limited to overshoot and ringing on the pulse flats, hence not affecting the trigger signal path.

At the end of the day, the SDS2504X Plus can handle all kinds of TTL and CMOS logic up to GTL. With some precautions even LVDS is not completely out of the question, even though a higher bandwidth midrange scope with active probe support like the SDS6000 would be much better suited and the obvious choice for this.