

Time-Base Setting Dependence of Pulse Parameters Using High-bandwidth Digital Sampling Oscilloscopes

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Abstract:

Errors in the time-base of digital sampling oscilloscopes (samplers) will cause errors in the reported pulse parameters of the sampler-acquired waveforms and also contribute to the uncertainty estimate for these parameters. We present the results of our investigation on the dependence of these time-base errors on the time-base setting used and the significance of these errors on the uncertainty estimate.

Introduction:

High-speed/high-bandwidth digital sampling oscilloscopes are used to capture the transient response of high-speed electrical signals, such as those found in state-of-the-art digital telecommunication devices and computers. The fidelity of this capture process is important for future improvement in these high-speed systems. Several researchers have recently measured the timing (or time base) errors of these high-speed samplers [1,2]. The typical time base structure consists of a clock and a vernier to interpolate the clock period. Two types of errors can be manifested by the time base and these are deterministic and stochastic (jitter) errors. Jitter will not be considered here because it can be dealt with separately [3,4]. The deterministic errors have notably distinct features. One feature is related to the vernier range and the clock period. A mismatch between the vernier and the clock results in large errors in the time base settings that occur at the clock period. These errors manifest themselves as a step discontinuity in a plot of the actual time versus the sampler-reported time. A second feature is the unequal spacing between sampling instances, and this is typically small over short regions of an epoch. This feature typically occurs throughout the record and may impact the values of temporal pulse parameters (such as transition duration) and their uncertainties. A third feature is that the average sampling interval may not be equal to the instrument-reported interval, ΔT_s .

Experimental:

Three different high-speed samplers were tested from two different manufacturers, M1 and M2. These samplers will be referred to as S1 (20 GHz sampler from M1), S2 (50 GHz sampler from M1), and S3 (50 GHz sampler from M2). The time-base errors are obtained using the technique described in [2]. To summarize this technique, the single-frequency output from a

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synthesized source is input into the sampler and two or more unique waveforms are acquired, where each unique waveform has a different phase relative to the trigger (see fig. 1). The waveforms are then operated on by the method described in [2] to yield the time-base error. The time-base error is the deviation of the actual time from the reported time (sampler-provided time) as a function of the actual time.

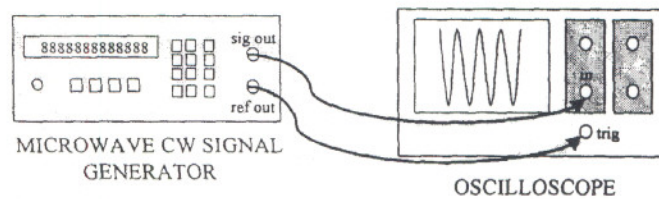


Figure 1. Measurement setup.

Results:

Figure 2 shows the time-base errors for samplers S1 and S3. The rather large localized errors (the time base discontinuity) shown in the figure are the result of the time-base clock and architecture. Essentially, the time-base vernier (or fine control) period and clock period are not matched. As can be seen from fig. 2, the time base discontinuity is repetitive. For M1, the repetition period is approximately 4.0 ns and for M2 it is 2.6 ns. Because the timing errors around the discontinuity can be large and it would be difficult to accurately correct the waveform data around the timing discontinuity, waveforms should be acquired such that the discontinuity does not

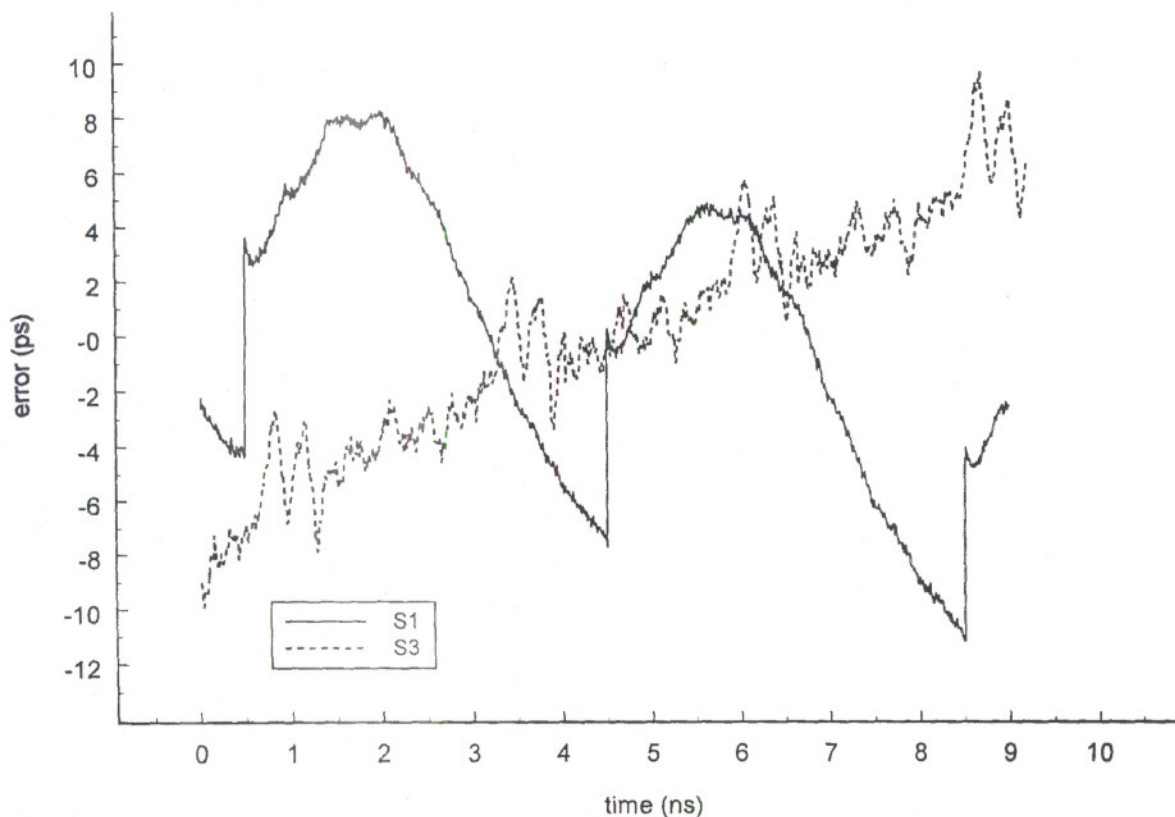


Figure 2. Time base error containing timing discontinuity for sampler S1 and S3.

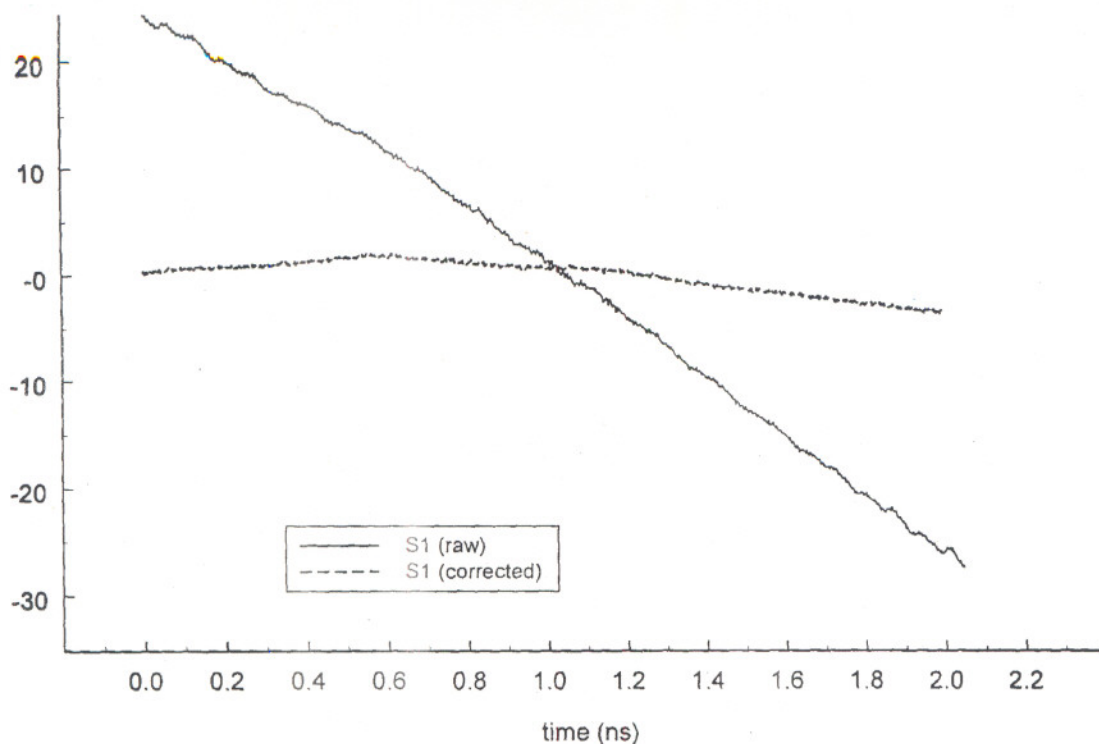


Figure 3. Time base error in region without timing discontinuity for sampler S1.

occur within the waveform epoch. If the discontinuity is not avoidable, then the discontinuity should not be placed in or near waveform features containing important temporal information (such as transition regions).

Figure 3 shows time base errors for S1 for an epoch where the timing discontinuity is not present. The slope of the curve marked “raw” in fig. 3 shows that the average sampling interval in this region differs from the instrument reported value, ΔT_s . This error can also be thought of as a time-base gain (expansion or contraction) error. This slope can be used to determine the average value of the sampling interval, ΔT , for this region, if the calibration frequency source is stable and accurate. Note how using ΔT instead of ΔT_s in computing the time base error significantly reduces the computed time base error (see curve labeled “corrected” in fig. 3). The ΔT_s introduces a time scaling factor to the waveform epoch and temporal features. (Note, some of the errors in fig. 3 may be due to signal noise.) The deviations of the errors from the sloped line are the deterministic time-base errors that we are primarily interested in addressing. These errors reflect non-equispaced sampling instances.

The non-equispaced sampling (nes) errors affect the accuracy of the values reported for temporal waveform parameters, the validity of using Fast Fourier Transforms to look at spectral properties or perform frequency-domain operations (like waveform reconstruction), and the ability to compare the performance of different samplers. The nes errors depend on the duration of the epoch and the number of samples taken in an epoch. The curves in fig. 4 show the sampling errors for S1, S2, and S3 where the time base gain error has been removed by using ΔT to compute the time base errors. From fig. 4 we can see that regions can be found where the error in the time base is small for S1 and S2. For S3, on the other hand, it is difficult to find regions where the time base errors are small (see fig. 4). We have observed that, for short duration epochs using S3, the time

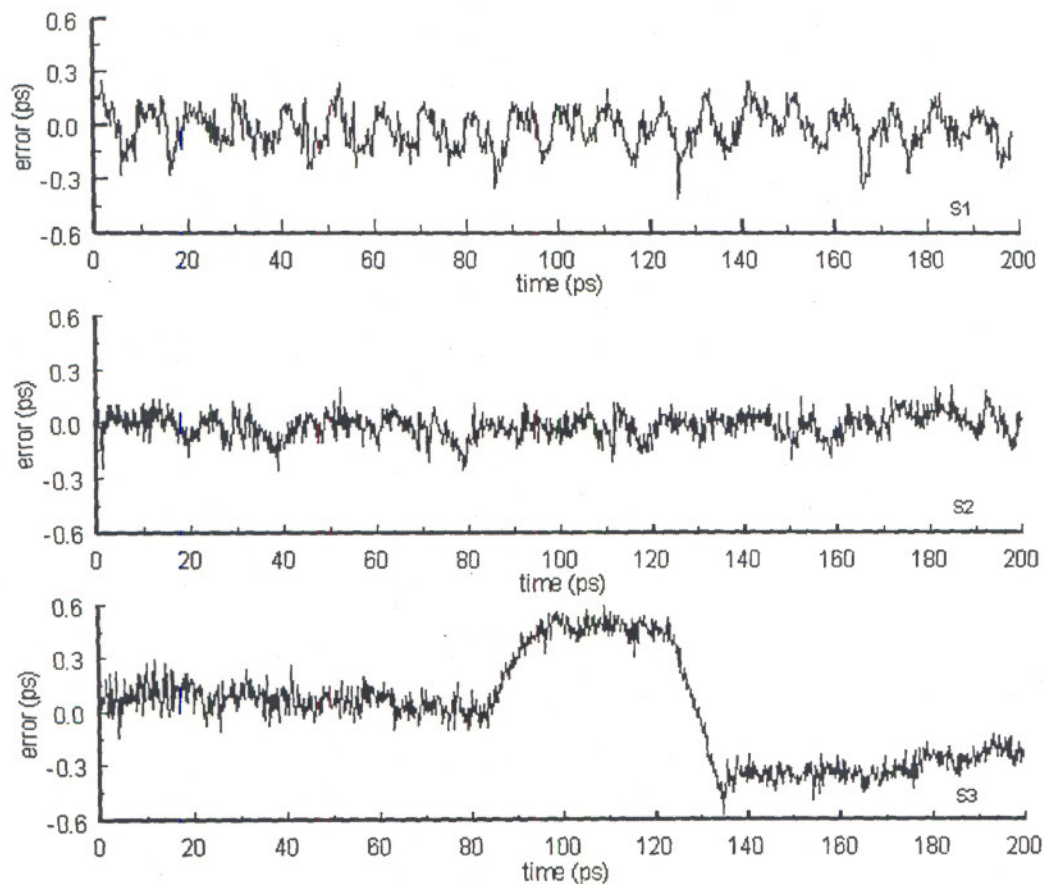


Figure 4. Time base error in region without timing discontinuity and calculated using correct nominal sampling interval for sampler S1, S2, and S3 for a 200 ps epoch.

base errors are not stable. For example, the time base errors appear differently if the sampler is turned off then on, if the internal time base calibration is performed, or if the time delay setting is changed. We did not observe these changes for S1 and S2 (M1 does not provide internal time base calibration).

Whether or not the waveform values should be corrected for time-base errors depends on the magnitude of the reported uncertainties for the given pulse parameters and on the magnitude of the effects the correction process on the waveform values. We have observed that the difference between pulse parameter values of corrected and uncorrected waveforms is within the noise or reproducibility of the measurement. Consequently, waveform time base corrections may provide little value to the customer. To determine if waveform correction is necessary, the time-base errors in the region of a temporal waveform feature (such as the transition duration) must be used. Figure 5 more clearly demonstrates how this can be done for S2 and S3. The epoch duration in fig. 5 is 2 ns. The approximate error in the transition duration can be calculated by multiplying the slope of the error vs time curve and the transition duration. For example, if the transition was placed over a region exhibiting a time base error slope of $0.9 \text{ ps}/200 \text{ ps}$ (which occurs at a delay

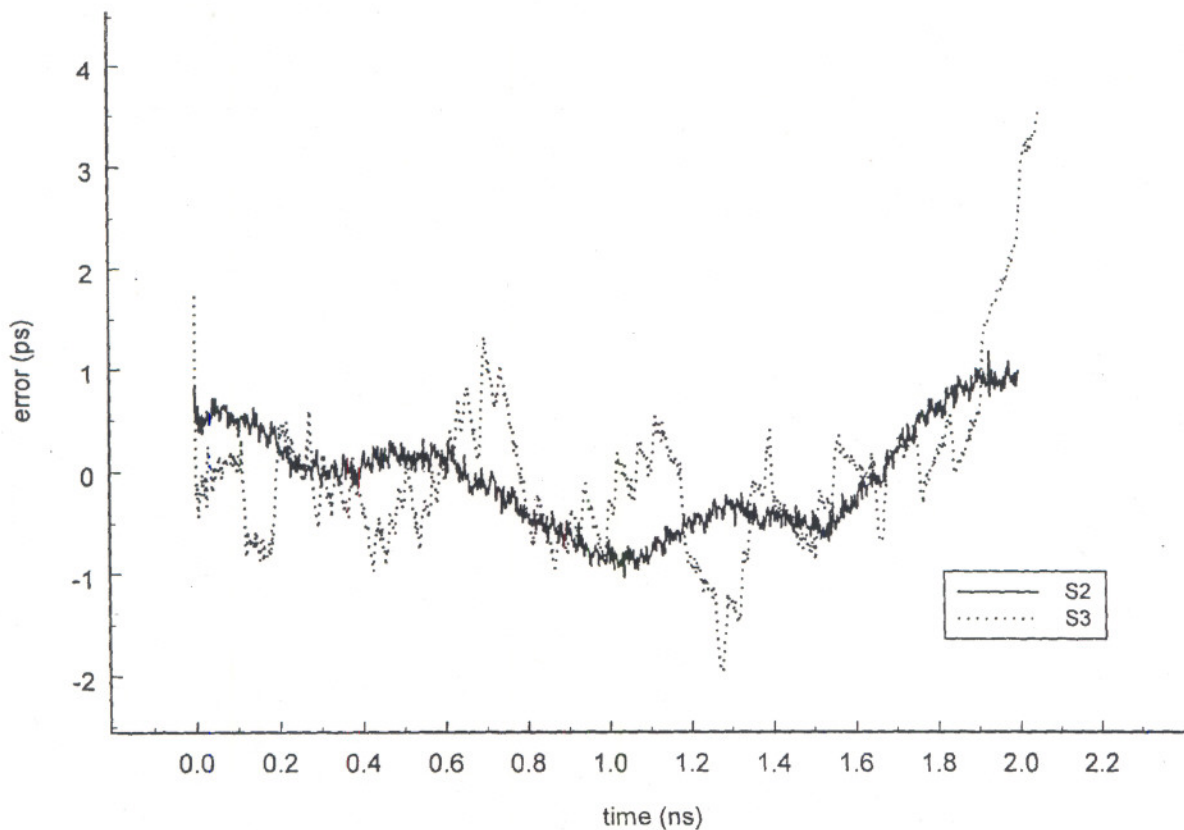


Figure 5. Time base error in region without timing discontinuity and calculated using correct nominal sampling interval for sampler S2 and S3 for a 2 ns epoch.

setting of 1.8 ns for S2 in fig.5), then a 20 ps transition duration may have an error of 90 fs. The time base errors for S3 (see fig. 5), on the other hand, exhibit regions of large slope and if the transition was placed in these regions the error in transition duration would be large.

We suspected that the non-equispaced sampling errors would be related to the quantization of the time base values. That is, the time base error would be smaller if the duration of waveform epoch, T , was chosen such that T was an integer number of instrument-quantized sampling intervals, Δt :

$$T = Nm\Delta t, \quad (1)$$

where Δt is the smallest possible time interval for a particular sampler, N is the number of samples, and m is an integer. For S1, Δt is 244.125 fs, for S1 it is 61.03125 fs, and for S2 it is 10 fs. We did not observe the time base errors to be smaller when T satisfied (1) than when it did not.

Conclusions:

Time-base errors of sampling oscilloscopes can cause errors in the acquired data. The deterministic errors we observed can be broken into three types: the timing discontinuity, the error in the instrument-provided sampling interval value, and the non-equispaced sampling (nes)

intervals. The timing discontinuity causes large errors in waveform data, but this error can and should be avoided by using an appropriate time-base delay setting. The error in the instrument-provided sampling interval value can be determined from a measurement of the time-base error. The nes error will affect pulse parameters and may need to be corrected. The nes errors do not appear to be dependent on time base settings. For S1 and S2, the local nes error can be very small, less than ± 100 fs rms and have a derivative of less than 4 fs/ps. Consequently, correcting a waveform for these small (relative to the reported uncertainty) deterministic errors will have a negligible effect on the waveform values and, therefore, has limited value because 1) the difference between corrected waveform values and uncorrected values is within the noise of the measurement and 2) the reported uncertainties are much greater than the nes errors. For S3, on the other hand, no similar regions of small nes error is routinely observed and, therefore, it may be necessary to perform a time-base correction on the waveform values.

References:

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