Measuring the Response of
High-Speed Pulse Generators and Samplers

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Abstract:
The National Institute of Standards and Technology (NIST) provides a service for measuring parameters associated with the step response of high-speed (transition durations ≥ 7 ps) samplers and the output signals of high-speed pulse generators. These parameters include transition duration (also known as rise time and/or fall time), waveform amplitude, overshoot, and undershoot (also known as preshoot). Accurate measurement of these parameters with tractable uncertainties requires consideration of many measurement variables for which the measurement system and process must be calibrated.

1. Introduction
NIST is one of two national metrology laboratories that currently provide a waveform parameter measurement service [1-3] for high-speed (≥ 7 ps transition duration) electrical pulses; the other national laboratory is the National Physical Laboratory (NPL) in the United Kingdom. NIST and NPL have completed a comparison of the results of their respective waveform parameter measurement services. This comparison (submitted for publication) shows that the waveform parameter measurement results of either national laboratory are within the other’s published uncertainties.

The NIST measurement service, the 65200S (NIST service identification number), “Fast Repetitive Pulse Transition Parameters,” provides traceable measurements of the waveform parameters of waveform amplitude, \(A_p\), transition duration, \(t_o\), and pre-transition and post-transition overshoot, \(OS\), and undershoot, \(US\). See Figures 1 and 2 for a graphical representation of these parameters. All of these terms are defined by the IEEE Standard on Transitions, Pulses, and Related Waveforms, IEEE Std-181-2003 [4]. The algorithms for computing values for these parameters are also defined by IEEE Std-181-2003.

The NIST measurement service presently uses commercially available, high-bandwidth sampling oscilloscopes and pulse generators (3 dB attenuation bandwidths of approximately 50 GHz) to measure the waveform parameters of short-transition-duration (high-speed) pulse generators and the impulse response of high-speed samplers. Higher-bandwidth sampling methods are being

¹ Electricity Division, Electronics and Electrical Engineering Laboratory, Technology Administration, Department of Commerce. Official contribution of the National Institute of Standards and Technology, not subject to copyright in the U.S.A.
explored [5] as well as high-bandwidth pulse generation methods. The use of the 50 GHz samplers instead of the previously used 20 GHz samplers reduces the effect of sampler impulse response uncertainties on the reconstructed waveforms.

Prior to 2001, the published uncertainty for the 65200S for $t_d$ was $(3 \text{ ps} + 0.005 \ t_d)$ and for $A_p$ was $(2 \text{ mV} + 0.005 \ A_p)$; $OS$ and $US$ uncertainties were not published. Because of the recent reduction in transition duration of high-speed pulse generators and samplers, from 30 ps to 15 ps for pulse generators and 15 ps to 7 ps for samplers, NIST started an effort to increase the range of the pulse parameter measurement service and at the same time to reduce the reported uncertainties for these parameters. The range of the measurement was successfully increased by reducing the lower range limit to 7 ps and the uncertainties were reduced (see Table 1) by using newer measurement instruments and developing a new uncertainty analysis [6]. The parameters of overshoot and undershoot were added because of the interest of signal aberrations, especially overshoot and undershoot, in signal integrity. In Table 1, $\Delta A$ is the amplitude discretization interval and is calculated using the full-scale amplitude range setting on the sampler (for example, the full scale amplitude range is 100 mV for an amplitude sensitivity setting of 10 mV/div and a full scale display of 10 vertical divisions) and the effective number of bits of the analog-to-digital converter at the input of the sampler. The effective number of bits is

Figure 1. Positive-going transition waveform showing transition amplitude, reference levels and instants, and time parameters.

Figure 2. Positive-going transition waveform showing state levels, boundaries, aberration regions, overshoot, and undershoot.
Table 1. Uncertainty for Calibration of Fast Repetitive Waveform Transition Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Parameter Range</th>
<th>Typical Expanded Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waveform Amplitude ($A_p$)</td>
<td>$-400 , \text{mV} \leq A_p \leq 400 , \text{mV}$</td>
<td>$1.5 , \text{mV} + 1.4 , \Delta A$</td>
</tr>
<tr>
<td>Transition Duration ($t_d$)</td>
<td>$7 , \text{ps} \leq t_d \leq 100 , \text{ns}$</td>
<td>$1.25 , \text{ps} + 0.1 , \Delta t$</td>
</tr>
<tr>
<td>Pulse Duration ($t_p$)</td>
<td>$10 , \text{ps} \leq t_p \leq 100 , \text{ns}$</td>
<td>$1.77 , \text{ps} + 0.14 , \Delta t$</td>
</tr>
<tr>
<td>(between 50% reference level instants)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overshoot</td>
<td>$\leq 0.5 , A_p$</td>
<td>$0.02 , A_p$</td>
</tr>
<tr>
<td>Undershoot</td>
<td>$\leq 0.5 , A_p$</td>
<td>$0.02 , A_p$</td>
</tr>
</tbody>
</table>

Based on the actual number of bits of the converter and signal averaging if the noise level exceeds the range of the least significant bit of the converter, $\Delta t$ is the sampling interval, that is, the interval between sampling instants used during acquisition of the DUT waveform. For example, a waveform epoch of 1 ns where the waveform contains 1000 elements has a sampling interval of 1 ps.

Although the instrumentation presently used in the 65200S does not have the highest bandwidth available, it and the methods in which it is used are amenable to an exhaustive uncertainty analysis [6]. Although higher bandwidth experimental test arrangements can be assembled, an uncertainty analysis that can be applied to pulse parameters is not easily accomplished. For example, calibration of instruments in the frequency domain is not helpful unless the frequency-domain uncertainties can be mapped into the time domain. If the calibration of the test instrumentation is performed in the time domain, this instrumentation must have an interconnect environment (coaxial, uniplanar, etc.) that is compatible to that of the device under test or have an accurate method of transferring the calibration (reflection and transmission coefficients for the physical discontinuity, for example). Even between coaxial environments having the same impedance, the differences in geometries will cause discontinuities that must be taken into account.

The parameters provided by the 65200S are derived parameters that are based on time and/or voltage values. The time values are traceable to NIST time standards via ovenized crystal oscillators. The voltage values are traceable to NIST Josephson voltage standards via measurement of these standards by the NIST-developed sampling voltage comparator [7,8].

The purpose of this paper is to describe the considerations, in a prescriptive way, necessary for accurate pulse metrology. In Section 2, a brief description of the 65200S measurement system [9,10] and measurement process is described. In Sections 3, 4, 5, and 6, the measurement variables that affect pulse parameter uncertainty are listed and discussed.
Pulse Parameter Measurement System

Figure 3 Diagram of NIST waveform measurement system. The dotted lines indicate insertion of instruments used in time-base calibration.

2. Pulse Parameter Measurement System
This description is generalized and, therefore, can be applied to almost any pulse measurement system.

2.1 Instrumentation
The 65200S presently uses commercially-available instrumentation, the test instrumentation arrangement for which is shown in Figure 3. Not shown in the figure is the equipment used to estimate the step response of the sampler or the output step of the pulse generator. This equipment and its calibration are the most difficult and crucial aspect of accurately measuring high-speed pulse generators and samplers (see Section 4.1). However, there are many other factors that must be considered when trying to provide the most accurate characterization of the high-speed performance of high-speed samplers and pulse generators.

A pulse generator with an accurately measured output is used as the reference source for measurement of the impulse or step response of the sampler. Conversely, a sampler with an accurately measured impulse or step response is used as the reference for the measurement of the output of pulse generators. (The device being characterized is the device under test, or DUT.)
The characteristics of both these reference devices must be known with sufficient accuracy to act as a reference, and this will be the gist of Sections 3 to 6.

The delay and trigger unit (shown in Figure 3) are used to provide a common trigger pulse for both the sampler and pulse generator [11]. If this was not done, the jitter would be much larger than that presently observed (discussed in Section 3.3). The microwave synthesizer has two functions. One of its functions is to provide a nominally spectrally pure sinewave from which the timebase function is calibrated [12]. The other function is to provide a redundant check on the magnitude of the sampler’s transfer function that is obtained from the Fourier transform of a time-domain sampler calibration method [13,14] presently used in the 65200S. (The transfer function is the Fourier transform of the sampler’s impulse response.)

2.2 Analysis Methods

In addition to the instruments used in the 65200S, the methods used to extract the information from the data also affects pulse parameter uncertainty. For example, the 65200S uses a histogram method to determine state levels from which the pulse amplitude is determined [4]. Timing parameters are determined by interpolating between appropriate sample instants [4].

3. Overall System Considerations

3.1 Transition Durations

The reference device, ideally, should have a transition duration that is only a fraction of that of the DUT. The value of that fraction is dependent on the additional uncertainty that can be tolerated if it is assumed that the reference is ideal when it is not. The following is an example of the effects of this assumption for the case when the reference device is the pulse generator and the DUT is the sampler. The uncertainty caused by this assumption can be estimated using the following approximation relating the transition durations of Gaussian pulses:

\[
t_{\text{tsamp}} = \sqrt{t_{\text{meas}}^2 - t_{\text{gen}}^2} = t_{\text{meas}} \sqrt{1 - \alpha^2} = t_{\text{meas}} \left(1 - \frac{\alpha^2}{2} - \frac{\alpha^4}{8} - \ldots \right).
\]

where \(t_s\) is the 10 \% to 90 \% transition durations of either the sampler, the measured waveform, or the pulse generator, and \(\alpha = t_{\text{gen}} / t_{\text{meas}}\). The last line is a Taylor series expansion. For most practical measurements only the first two terms in the parentheses are used. The uncertainty on \(t_{\text{tsamp}}\) from assuming an ideal step (\(t_{\text{gen}} = 0\)) is asymmetric: \(t_{\text{tsamp}}\) will be less than \(t_{\text{meas}}\), but it will not be more than \(t_{\text{meas}}\), that is, \(t_{\text{tsamp}} = t_{\text{meas}} + 0.0 \pm 0.5[\alpha t_{\text{meas}}]^2\). If \(\alpha < 0.1\), the uncertainty caused by this assumption is less then 0.005 \(t_{\text{tsamp}}\), which for typical pulse metrology applications is satisfactory. However, if \(\alpha = 1\), such as the case for measuring high-speed devices with comparable high-speed samplers, the uncertainty in \(t_{\text{tsamp}}\) is 0.5\(t_{\text{tsamp}}\), which is not acceptable. In this case, the effect of the reference on the DUT measurement must be removed by deconvolution (see Section 4.1).
3.2 Temperature
Temperature affects both the parameters of pulse amplitude and transition duration for both pulse generators and samplers [15], as shown in Figures 4 and 5. Figures 4 and 5 show the temperature effects for samplers having 50 GHz and 20 GHz 3 dB attenuation bandwidths from two different manufacturers and for pulse generators from two different manufacturers. These temperature effects must be corrected. This correction is done in the 65200S in three steps. The first step is to obtain data such as that shown in Figures 4 and 5. The second step is to obtain an equation relating the pulse parameter to temperature (the coefficients of which, for the data in Figures 4 and 5, are shown in Table 2). Lastly, the equation is used to alter the value of the pulse parameter [6,16,17].

![Figure 4. The effect of temperature on the amplitude of sampler (given by SH) step responses and signal generator (given by SG) outputs.](chart)

<table>
<thead>
<tr>
<th></th>
<th>SG1</th>
<th>SG2</th>
<th>SH1</th>
<th>SH2</th>
<th>SH3</th>
<th>SH4</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplitude slope (mV/°C)</td>
<td>0.059</td>
<td>0.037</td>
<td>0.007</td>
<td>0.008</td>
<td>-1.478</td>
<td>0.093</td>
</tr>
<tr>
<td>10%-90% transition duration slope (ps/°C)</td>
<td>-0.137</td>
<td>0.020</td>
<td>0.076</td>
<td>0.032</td>
<td>-0.003</td>
<td>0.068</td>
</tr>
<tr>
<td>20%-80% transition duration slope (ps/°C)</td>
<td>-0.071</td>
<td>0.019</td>
<td>0.080</td>
<td>0.016</td>
<td>-0.003</td>
<td>0.041</td>
</tr>
</tbody>
</table>
3.3 System Jitter

A typical triggering method for a pulse measurement system is to have a pulse generator that provides two outputs, one output for the pulse generator and one for the sampler. This method results in three jitter components, the jitter between the two output pulses provided by the common trigger source, the trigger jitter of the pulse generator, and the trigger jitter of the sampler. The trigger system used in the 65200S uses a common pulse from the trigger generator that is split, sending one replica to the pulse generator and the other to the sampler after appropriate delay [11]. This reduces the system jitter to two components, the trigger jitter of the sampler and of the pulse generator. The system jitter of the 65200S is approximated by the following:

$$\sigma_{\text{sys}} = \sqrt{\sigma_{\text{sh}}^2 + \sigma_{\text{sg}}^2},$$  \hspace{1cm} (2)$$

where $\sigma$ is the rms jitter value in the appropriate time units. Using the system described in [11], $\sigma_{\text{sys}} \leq 1$ ps.

The jitter also affects the bandwidth of the measurement system. This effect can be modeled as a low-pass filter [18]. The discrete spectrum, $J$, of the jitter is given by:

$$J[k\Delta f] = e^{-2\pi k\Delta f/\sigma},$$ \hspace{1cm} (3)$$

where $k$ is the frequency counter, $k = 0,1,...,N/2-1$, $N$ is the number of samples in the waveform, and $\Delta f$ is the frequency interval. This jitter, although small for the 65200S, is deconvolved from...
the DUT waveform as part of the waveform reconstruction process (see Section 4.1). The jitter waveform is not deconvolved in a separate deconvolution step but is first convolved with the waveform from the reference device prior to deconvolving the reference device waveform from the measured DUT waveform.

3.4 Averaging
Averaging is necessary to reduce the effect of noise in the measurement system on the data. This is the well known reduction in the observed noise by $1/M^{1/2}$, where $M$ is the number of averages taken. However, an additional uncertainty in the temporal characteristics of the waveform will exist if the pulses have been drifting in time during the period it takes to acquire $M$ averaged waveforms. Therefore, it is either necessary to perform jitter measurements for an interval identical to that used for acquiring the DUT waveforms or to determine that drift does not occur over the DUT measurement interval. Our observations have been that drift does not occur during the time required to perform a measurement [19].

3.5 Duration of Waveform Epoch
The consideration of the duration of the waveform epoch is important for two reasons. First, the epoch should be short enough for the given $N$ so that aliasing of the spectrum is minimized. This requirement is typically satisfied if there are at least three or four samples on the transition of the pulse. If this requirement is not met, an aliasing error in the spectrum of the DUT will occur. This aliasing error is given by [20,21]:

$$
\epsilon[k \Delta f] = 4Bk \Delta f \Delta t^2,
$$

where $B$ is the 3 dB attenuation bandwidth of the spectrum of the measured impulse and $\Delta t$ is the interval between waveform samples.

The other requirement for the waveform epoch is that it needs to be long enough to capture the steady state regions on either side of the transition. This is important because a histogram method is used in the 65200S to determine the level of $s_1$ and $s_2$ (see Figure 1) of the waveform (see Section 6.1). If these levels are not correctly determined, all the pulse parameters reported in the 65200S will be in error.

4. Pulse Generator
In addition to the transition duration of the output pulse (Section 4.1), there are several other parameters that must be known to accurately measure the step or impulse response of the pulse generator. These parameters include:

- step or impulse output (the time-varying signal)
- change in $A_p$ and time characteristics of the step or impulse with temperature (see Section 3.2)
- noise
- jitter (see Section 3.3)
4.1 Output Pulse
The pulse generator output must be accurately measured. Therefore, the instruments used to measure the output pulse characteristics must possess much better performance than the pulse generator or, if this is not the case, a reconstruction process is necessary. This is because pulse characteristics such as aberrations, including overshoot, undershoot, and settling, will affect the estimated sampler step response. The 65200S presently relies on waveform reconstruction to remove the effects of the pulse generator on the DUT (sampler). To determine the effect of variations in the characteristics of the reference waveform on the reconstructed DUT waveform, a set of reconstructs is simulated and this gives an empirical formula relating the effect of variations in the parameters of the reference waveform to those of the reconstructed DUT waveform.

The pulse used for calibration of the samplers is an impulse-like pulse that is generated, or “kicked-out,” by samplers having certain architectures. The kick-out pulse occurs when the sampler is triggered and its offset voltage is not set to zero [13,14]. This kick-out pulse resulted in the “nose-to-nose” (ntn) sampler calibration method [13,14]. The basic premise behind this calibration method is that the kick-out pulse is identical to the sampling function. Our measurements have shown that this assertion is not entirely accurate [19,22,23], but that the uncertainty in $t_d$ of the step output is less than 0.5 ps. The effect of this uncertainty on that of the transition duration of the reconstructed sampler step response is less than 0.3 ps. This reduction in uncertainty is possible because the empirical equations, derived from the waveforms [6], show that for the given transition duration values used, large changes in the transition duration of the output step cause small changes in the transition duration of the sampler step response.

Pulse settling is determined using the NIST-developed sampling comparator system [7,8], a sampling device that has a nominal -3 dB bandwidth of approximately 2.5 GHz and the settling of which has accurately been determined from direct measurements of the comparator step response and static response. Settling is important in helping to determine if the waveform epoch is of sufficient duration to capture accurate values for the state levels (see Figures 1 and 2).

4.2 Noise
Noise is typically assumed to be zero-mean, normally-distributed white noise. Our observations have shown that the noise in most of the sampling systems we have examined exhibit this type of noise or very close to it.

5. Sampler
To accurately measure the pulse generator output, the following must be known of the sampler:
- step or impulse response (analogous to discussion in Section 4.1)
- change in $A_p$ and time characteristics of the step response with temperature (see Section 3.2)
- gain errors (linear and nonlinear) in the impulse or step response
- noise (analogous to discussion in Section 4.2)
- amplitude discretization effects
- timebase gain (expansion or contraction)
- timebase nonlinearities
- jitter (see Section 3.3)
- time discretization effects (see Section 3.5)
5.1 Gain Errors
The gain of the sampler can exhibit both linear and nonlinear errors. Our observations have shown that for the small signal measurements performed in the 65200S, the primary gain error is a linear gain error. However, because of the frequency dependent response of typical commercial samplers, it is not advisable to use dc levels to calibrate the pulse-signal gain of the sampler. This information is typically not contained within the impulse response estimate of the sampler because of the difficulties mentioned previously (Section 4.1). The sampler pulse-signal gain must be calibrated with an accurately characterized pulse (see Section 4.1). In this characterization process, the output of a pulse generator is measured using the 65200S sampler and using the NIST-comparator [7,8]. These two measurements are compared to yield a pulse amplitude gain term [6]. This gain term is then used to correct the amplitude values of the measured waveform. To date, this is the largest contributor to the uncertainty contributions to the parameter of waveform amplitude in the 65200S.

5.2 Amplitude Discretization Effects
Amplitude discretization occurs from both the digitization of the input signal and the discretization of the histogram. Although Table 1 includes the effect of this amplitude discretization, it is typically much less than the amplitude of the signals being measured and much less than the other uncertainty contributors. Histogram effects are described in Section 6.1.

5.3 Timebase Gain
Timebase gain describes the expansion or contraction of the timebase relative to what is expected. For example, if there are \( N \) sampled elements for an epoch of duration \( T \), then the sampling interval, \( \Delta t \), is:

\[
\Delta t = \frac{T}{N}.
\]

However, measurements of the timebase error [12] may show that the average value of \( \Delta t \) is not equal to that shown in (5). This error is easily remedied by multiplying the time values by the ratio of the expected and measured values of \( \Delta t \). The waveform does not need to be corrected for this error. Nevertheless, uncertainties in the measurement of the average value of \( \Delta t \) must be included in the calculation of the uncertainties of the values of the time parameters.

5.4 Timebase Nonlinearities
Timebase nonlinearities are measured using the same process as timebase gain. These nonlinearities describe local variations in the timebase error that exist after removal of that caused by timebase gain (Sec. 5.3). In this case, however, the local variations cannot be as easily dealt with as timebase gain. One way to correct for timebase nonlinearities is to correct the waveform amplitude values using interpolation and then add the uncertainties due to the interpolation process. However, it is really only necessary to correct waveform amplitude values in those waveform regions containing waveform parameters affected by timebase nonlinearities, such as transition duration, overshoot, and undershoot. Therefore, only waveform values in the pre-transition aberration region, the transition region, and the post-transition aberration need to be corrected. Another option is to include the standard deviation of the timebase nonlinearity in the computed uncertainty values for these parameters. This is what is done in the 65200S.
because the standard deviation of the timebase nonlinearity is less than 0.005 $\Delta t$ [24]. Waveform values are not corrected because other contributions to parameter uncertainty dominate.

6. Computational Parameters
The methods used to compute the pulse parameters also affect pulse parameter uncertainty. Uncertainties from the following have been included in the 65200S uncertainty analysis:

- histogram effects
- position of transition within epoch
- number of bins
- interpolation to find reference instants
- reconstruction process
- Fourier transforms
- computation precision
- value of stopping criterion parameter.

6.1 Histogram Effects
The first step in the calculations of the pulse parameters is to compute the histogram of the waveform [1,4,6]. From the histogram, the topline ($V_{s2}$) and bottomline ($V_{s1}$) values are obtained. Then using $V_{s2}$ and $V_{s1}$, all the waveform parameters reported are computed.

6.1.1 Position of Transition within Epoch
The position of the transition within the waveform epoch is important because the regions of the waveform on either side of the transition must be long enough for the state levels ($s_i$ and $s_j$) of the waveform to settle to some nominal value. It is from these state levels that the waveform amplitude and, consequently, all other reported waveform parameters are computed. To determine how well those states are settled to their nominal value requires calibration of these state levels using an accurate and fast settling measurement instrument (see Section 4.1).

6.1.2 Number of Histogram Bins
In addition to this discretization of the amplitude (see Section 5.2), we also consider the discretization caused by the histogram binning operation [6]. The histogram discretization is a result of the number of histogram bins or, equivalently, the bin size not being adequate to provide sufficient resolution for accurately determining the state levels of the waveform [25]. There are several ways to generate the histogram and each is subject to failure when exposed to certain types of data, such as level switching around $s_i$ and/or $s_j$ [26]. However, for typical waveforms expected in pulse metrology, these types of problematic cases are not observed. The upper limit to the number of histogram bins is set by the number of effective bits of the analog-to-digital convertor (ADC) of the sampler. Finer discretization than that of the ADC is not useful. The lower limit on the number of bins is dependent on the amplitude resolution required by the measurement.
6.2 Interpolation to Find Reference Instants
Waveform values typically do not coincide with the crossing of predetermined reference levels, such as the 10% reference level (a level equal to the level of $s_1$ plus 0.1$A_p$) that is used to compute the 10% to 90% transition duration. Interpolation is used to determine the instants when such crossings occur. Errors in the interpolation can be exacerbated by a poor selection of the histogram bin size (see Section 6.1.2). Interpolation errors introduce uncertainties into the values of the temporal waveform parameters. However, if the criteria discussed in Section 3.5 are satisfied, namely to prevent aliasing of the spectrum, then the uncertainties caused by the interpolation errors will be small compared to the reported parameter uncertainty. Reference 6 provides details on the effect of interpolation on the uncertainty of transition duration, which in turn affects the uncertainty of overshoot and undershoot.

6.3 Reconstruction Process
The reconstruction [27-29] consists of dividing the spectrum of the measured waveform by the spectrum of the estimate of the reference (either the pulse generator or the sampler) and then filtering this quotient in an iterative fashion. In the iteration process, a parameter for the filter is changed every iteration and some characteristic of the resultant filtered spectrum or waveform is examined. When this characteristic, call it $g$, exhibits the desired properties, the iteration process is stopped and the reconstruction process is deemed complete. The value of the filter parameter, $\gamma$, at which the filtered spectrum exhibits the desired property is the optimal $\gamma$, $\gamma_{opt}$. Uncertainties from the reconstruction process can arise from the computational processes, the selection of $\gamma_{opt}$, and the filter.

6.3.1 Computation Processes
The computation process in the reconstruction includes Fourier transforms and arithmetic operations. Using numerically generated waveforms, the noise generated by a Fourier transform, division of spectra, and inverse Fourier transform is very small, typically less than $10^{-8}A_p$. Consequently, these operations do not contribute significantly to the uncertainty in the reported pulse parameters.

6.3.2 Optimal Filter Parameter Value
The filter parameter values are varied over several orders of magnitude in the iteration process. At each step in the iteration, $g$ is measured and stored to yield a curve, $g(\gamma)$. The $g$ is typically selected so that $g(\gamma)$ exhibits an extremum at $\gamma_{opt}$. Studies were done to examine the effect on the waveform parameter values for reconstructions using values of $\gamma$ that were different from $\gamma_{opt}$. This study (not published) was directed primarily at looking at how fine the increment in $\gamma$, $\Delta\gamma$, had to be to accurately reconstruct simulated waveforms. The study showed that the reconstructed waveform is not sensitive to the size of $\Delta\gamma$ when $\gamma$ is in the vicinity of $\gamma_{opt}$; a variation in $\Delta\gamma$ of 100 did not cause an observable difference in the pulse parameter values extracted from the reconstructed waveforms. It was observed that the value of $\gamma$ used in the reconstruction could be a few $\Delta\gamma$ from $\gamma_{opt}$ and still yield waveforms with parameter values almost identical to those found when using $\gamma_{opt}$. However, waveforms reconstructed using $\gamma$ values far from $\gamma_{opt}$ were sensitive to shifts of a few $\Delta\gamma$. 
6.3.3 Filtering Process
The 65200S deconvolution filter is a regularizing filter, which means for this particular application that the filter is based on the estimate of the reference waveform itself. This filtering process introduces a bias on the waveform parameters of transition duration, overshoot, and undershoot (results not yet published). To determine the magnitude of this bias and consequently the uncertainty in the reported waveform parameters, the waveform reconstruction process was simulated numerically. To do this, several “time-domain” waveforms were generated numerically and then convolved in the “time-domain” to simulate measurement. This provided a set of simulated measured waveforms, a set of simulated reference waveforms (that represented either the step response of the sampler or the output of a step generator), and a set of input signals. These waveforms were then operated on using the 65200S waveform reconstruction software and the resultant reconstructed waveforms compared to the simulated input signals. The following was observed for a set of 30 reconstructions: 0.066 ps bias (±0.37 ps) in transition duration for transition duration values between about 22 ps and 28 ps, 0.00063Ap bias (±0.0036Ap) in overshoot for overshoot values between about 0.035Ap and 0.10Ap', -0.00035Ap bias (±0.001Ap) in undershoot for undershoot values between about 0.002Ap and 0.012Ap'.

7. Summary
Accurate measurement of the response of high-speed samplers and the output of high-speed pulse generators requires consideration of many effects that can affect the measured waveform, which represents either the sampler step response or pulse generator output. Each of these effects on the value of each of the waveform parameters must be measured and, if necessary, the waveform or waveform parameter values adjusted. For each waveform parameter, the total uncertainty must reflect the exact method of measurement, the parameter extraction algorithm, the parameter adjustment algorithm, and any calibration artifact uncertainties.

References:


Conference Theme:

The Spectrum of Metrology: From the State-of-the-Art to the Everyday

As Metrologists, Scientists, and Engineers, we can lose sight of where metrology often takes place. When many of us hear the word metrology, we think of the lab-coat-adormed scientist working in a state-of-the-art laboratory, performing what we sometimes call "black art" and attempting to measure what has never been measured. While this is metrology, we must remember that "the science of measurement" takes place at many levels and takes many forms. For example, a technician calibrating a scale in a warehouse, a specially designed in-process gage used to control a machining line, or the analysis of wastewater to ensure that we are not impacting the environment all of these involve the science of measurement. The spectrum of metrology is very broad and encompasses a range of sciences, techniques, tools and levels of accuracy. One does not need to measure micoinches or at the parts-per-million level to perform metrology. In many instances, metrology that touches our everyday lives is the metrology that makes the final decision as to whether the product meets our requirements. At the end of the day, metrology covers a continuum of measurements performed from the highest-level laboratories to the gasoline pump, and each level presents unique challenges and rewards.

The 2003 Conference is intended to provide a forum for those involved across the entire spectrum of metrology and will provide a unique opportunity to network with other measurement professionals.

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