IEEE Instrumentation and Measurement
Technology Conference
Anchorage, AK, USA 21-23 May 2002

NIST's High-Speed Pulse Parameter Measurement Service

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Abstract

The National Institute of Standards and Technology (NIST) provides a measurement service, number 65200S, "Fast Repetitive Pulse Transition Parameters," for measuring the impulse response of high-speed (transition durations > 7 ps) samplers and the output signals of high-speed pulse generators. The 65200S provides traceable measurements of the waveform parameters of waveform amplitude and transition duration (also known as rise time or fall time). This measurement service has recently been improved using new measurement instruments and procedures, more accurate estimates for the behavioral characteristics of the test instruments, and an improved uncertainty analysis. The improvements to the 65200S include reduced transition duration uncertainties (about 1.5 ps) and the introduction of the parameters of overshoot and undershoot.

I. Introduction

The National Institute of Standards and Technology (NIST) provides a measurement service that is used by the military and aerospace, telecommunications, test equipment, and computer industries to satisfy traceability requirements for the waveform parameters of transition duration (also known as rise time and/or fall time) and waveform amplitude. These industries and their customers also use this service to ensure products are performing to manufacturer specifications and for product comparisons. This NIST measurement service is the 65200S, "Fast Repetitive Pulse Transition Parameters," which provides measurements of the impulse response of high-speed (transition durations > 7 ps) samplers and the output signals of high-speed pulse generators[1].

NIST is one of two national metrology laboratories that currently provide a high-speed waveform parameter measurement service; the other national laboratory is the National Physical Laboratory (NPL) in the United Kingdom. NIST and NPL have recently completed a comparison of their waveform parameter measurement methods, which included measured data, corrected data (where applicable), and reconstructed data. This intercomparison (manuscript describing the results in preparation) shows that the waveform parameter measurement results of either national laboratory are within the other's published uncertainties.

The 65200S provides traceable measurements of the waveform parameters of waveform amplitude, A_p, and transition duration, t_d. Previously, the published uncertainties for transition duration were $\pm$ (3 ps + 0.005 t_d) and for waveform amplitude were $\pm$ (2 mV + 0.005 A_p). Over the last few years, higher-speed pulse generators have been developed that produce pulses with shorter transition durations, decreasing from about 30 ps to about 15 ps. Similarly the transition duration of impulse response samplers has decreased from about 15 ps to about 7 ps. The nominal uncertainty in t_d of 3 ps is no longer acceptable for the manufacturers of high-speed pulse generators and samplers. In addition, customers have become interested in waveform aberrations, such as settling errors, overshoot, and undershoot. Overshoot and undershoot may each occur before and after a waveform transition. These two waveform aberrations are now included in the 65200S. (The terms undershoot and overshoot are used as presently defined by the IEEE Subcommittee on Pulse Techniques. Fall time and rise time are deprecated terms, transition duration is the accepted term.)

II. Parameter Measurement Process

The 65200S was recently revised to incorporate higher bandwidth samplers, to introduce a new measurement process

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0-7803-7218-2/02/$10.00 ©2002 IEEE

or sequence, to introduce new calibration methods, and to include a new uncertainty analysis. This document reports the improved measurement system and process and the corresponding published waveform parameter ranges and uncertainties.

The waveform parameter measurement process consists of a set of measurements of the customer's pulse generator or sampler (the device under test, or DUT) and a set of measurement instrument calibrations. Some of these instrument calibrations are done during the DUT measurement sequence and some are not. This is a departure from the original process wherein all instrument calibrations were performed during the DUT measurement process. This modification to the original measurement process of measuring all these calibration parameters does not reduce the accuracy of the measurement process but does reduce the time for test. Reduction in test time is beneficial not only in possible cost reduction/maintenance but also to reduce or eliminate the effects of instrument drift cause by temperature changes or other environmental influences.

The calibrations include measurements of time-base errors, sampler gain, jitter, and sampler impulse response. A diagram of the NIST waveform parameter measurement system is shown in fig. 1. Measurements that are used to estimate the sampler step response, system jitter, and dynamic gain of the sampler are taken routinely, but not necessarily as part of the DUT measurement sequence. From these routine measurements, a control chart is maintained for the mean value and standard deviation of the variables that are used to compute the reported waveform parameters. These parameters are the transition duration of the sampler step response, the transition duration of the equivalent jitter step response[2], and the sampler dynamic gain. The reason the measurements of these parameters are not part of the DUT measurement sequence is that the sampler step response, the system jitter, and the sampler dynamic gain are stable (small observable

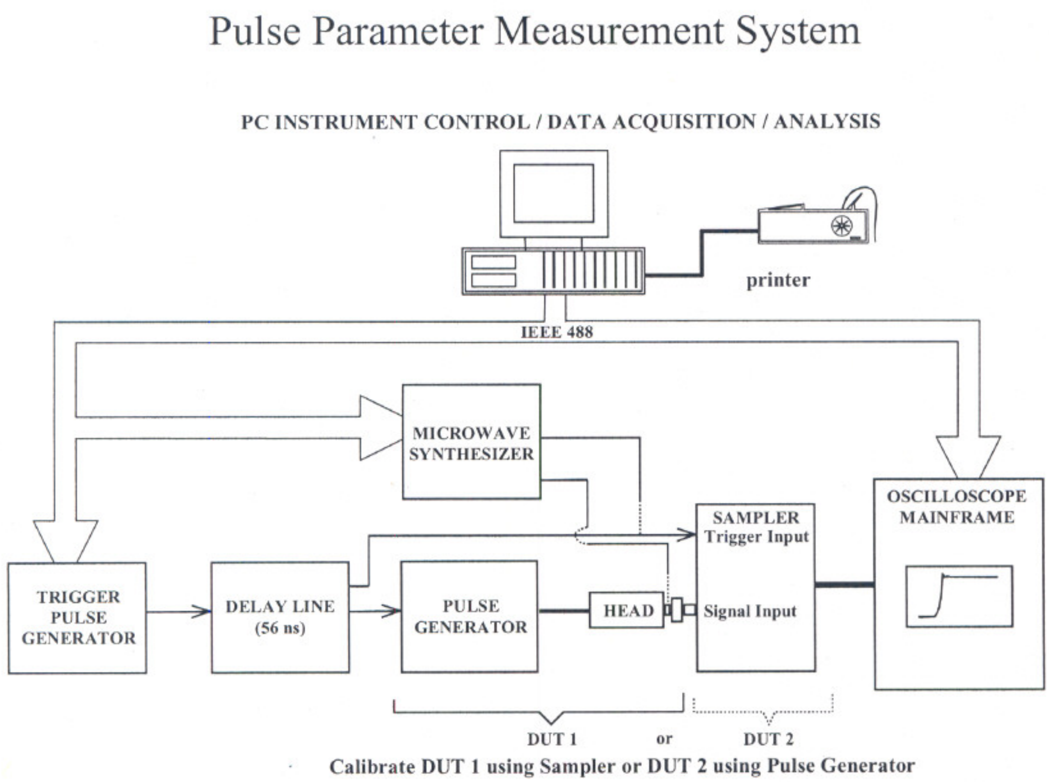

Figure 1 Diagram of NIST waveform measurement system. The dotted lines indicate insertion of instruments used in time-base calibration.

variation) and the variations in these parameters are represented in their associated control chart data. The DUT jitter is purposefully not included as part of the system jitter because DUT jitter affects the DUT parameters of transition duration, overshoot, and undershoot and will be exhibited in customer measurements. The control charts are also useful in providing an indication on the performance of various measurement instruments. For example, if the dynamic gain of the sampler suddenly changes, the sampler may be damaged even though it appears to be functioning properly. Several sets of data are acquired for the customer's DUT. For brevity, the discussion that follows assumes the DUT is a pulse generator. A set of data consists of M_1 sampler-acquired DUT waveforms and one measurement of the measurement system time-base errors. Measurements of the time-base errors[3] are done routinely as part of the DUT measurement procedure. The DUT measurement sequence is as follows: (1) acquire one independent measure of the time-base error and (2) acquire M_1 independent measurements of DUT output.

The DUT waveforms are subsequently corrected for gain and time-base errors only if these errors are significant relative to the reported uncertainties. The corrected or uncorrected waveforms are then used in a reconstruction process to obtain a waveform that is an accurate estimate of the pulse measured by the sampler. The accuracy of this estimate (the reconstructed waveform) is dependent on the reconstruction process and the accuracy of the estimate of the sampler impulse response. The waveform reconstruction process uses an iterative deconvolution of the sampler impulse response from the measured data. From each reconstructed waveform, waveform parameter values are computed. The set of waveform parameter values thus computed is used to determine the mean value and standard deviation for the given parameter.

An estimate of the step response of the NIST 50 GHz sampler used to measure the DUT is obtained using the "nose-to-nose" method[4,5], the results of which have been compared to results using swept frequency and optoelectronic methods[6]. We have examined the "nose-to-nose" method and its limitation in sampler calibration[7,8].

The waveform parameter computations are based on histogram methods[9,10,11]. The first step in the calculations is to compute the histogram of the waveform. Next the topline (V_{S2}) and bottomline (V_{S1}) values are obtained from the histogram. Then using V_{S2} and V_{S1}, the waveform parameters are obtained for the waveform.

The uncertainty analysis that was developed[12,13], because it is applied to acquired waveforms, is applicable for both the measurement of the output of pulse generators and the step response of samplers with the appropriate change in reference measurements and waveforms. When measuring the output of a pulse generator it is assumed that the sampler step response is the reference, and when measuring the sampler step response it is assumed that the output of the pulse generator is the reference. The uncertainty analysis emulates the measurement process and introduction of higher bandwidth samplers is easily accommodated.

The NIST measurement service presently uses commercially available, high-bandwidth sampling oscilloscopes (3 dB attenuation bandwidths of approximately 50 GHz) and pulse generators (3 dB attenuation bandwidths of approximately 20 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 explored[14] 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.

III. Results and Summary

The previous published[1] uncertainties (95 % confidence interval) for transition duration (t_d) were $\pm$ (3 ps + $0.005t_d$) with typical values reported to customers more like -2.2 ps / + 4.4 ps. After completion of the new measurement system, the uncertainties were computed for several measurements and were observed to be below $\pm$ 1 ps. Consequently, the published uncertainties have been conservatively improved to $\pm$ (1.5 ps + 0.1 t_s), where t_s is the sampling interval, which for our work is typically 2 ps (see Table 1).

The published[1] uncertainty (95 % confidence interval) for waveform amplitude (A_p) was $\pm$ (2 mV + $0.005A_p$). Using the new measurement tools and uncertainty analysis, the computed uncertainties for several measurements were observed to be approximately $\pm$ 1 mV. Consequently, the

Parameter	Parameter Range	Typical Expanded Uncertainty
Waveform Amplitude (A)	-400 mV $\leq$ A $\leq$ 400 mV	1 mV + 1.4ΔA
Transition Duration (t_d)	7 ps $\leq t_d \leq$ 100 ns	1.5 ps + 0.1 Δt
Pulse Duration (t_P) (between 50 % reference level instants)	10 ps $\leq t_P \leq$ 100 ns	2.1 ps + 0.14Δt
Overshoot	$\leq$ 50 %	2 %
Undershoot	$\leq$ 50 %	2 %

Table1. Uncertainty for Calibration of
Fast Repetitive Waveform Transition Parameters

published uncertainties have been improved to ± (1 mV + 0.7 V_{res}), where V_{res} is the resolution of the NIST measurement system.

Previously, values for undershoot and overshoot were not reported because of the lack of an uncertainty analysis. (Undershoot and overshoot aberrations are confined near the transition region of the pulse; this region is defined by the user.) Now, however, the service provides these parameters and the published uncertainty in these parameters is ± 2 %.

The percentages indicated in the last two rows in Table 1 are percentages of waveform amplitude. ΔA is the amplitude discretization interval and is calculated using the full-scale amplitude range set on the sampler (for example, the full scale amplitude range is100 mV for an amplitude sensitivity setting of 10 mV/div and a full scale display of 10 vertical divisions) and the resolution of the analog-to-digital converter at the input of the sampler. The sampler resolution is based on the actual number of bits of the converter and signal averaging where the noise level exceeds the range of the least significant bit of the converter. Δt is the sampling interval, that is, the interval between sampling instances, used during acquisition of the DUT waveform. For example, a waveform epoch of 1 ns where the waveform contains 1000 elements gives a sampling interval of 1 ps. By definition, undershoot and overshoot are positive values, therefore, the lower uncertainty bound is limited to a value such that undershoot and overshoot are greater than 0 %.

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