NIST Service for Measuring the Step Response of High-Speed Samplers and the Output of High-Speed Pulse Generators

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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 ≥5 ps) samplers and the signals output by high-speed pulse generators. These parameters include transition duration (rise time and/or fall time), waveform amplitude, overshoot, and undershoot.

Introduction

The NIST measurement service, the 65200S[1] (NIST service identification number), "Fast Repetitive Pulse Transition Parameters," provides traceable measurements of the waveform parameters of waveform amplitude, A_p, transition duration, t_d, pre-transition and post-transition overshoot, OS, and undershoot, US, and settling parameters. These terms are defined by, and methods for their computation given in, the IEEE Standard on Transitions, Pulses, and Related Waveforms, IEEE Std-181-2003 [2]. The range and typical expanded uncertainty (u) for these parameters are [1]:

$-400 \text{ mV} \le A_p \le 400 \text{ mV}$,	$u_A = 1.5 \text{ mV} + 1.4\,\Delta A$
$7 \text{ ps} \le t_d \le 100 \text{ ns}$,	$u_t = 1.25 \text{ ps} + 0.1\,\Delta t$
$OS \le 0.5\,A_p$,	$u_{OS} = 0.02\,A_p$
$US \le 0.5\,A_p$,	$u_{US} = 0.02\,A_p$,

where ΔA 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 bits [3] of the analog-to-digital converter at the input of the sampler. Δt 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. The uncertainty in settling parameters depends on the duration from the 50 % reference level instant [1].

The NIST measurement system (see Figure 1) presently uses commercially available, high-bandwidth sampling oscilloscopes and pulse generators (3 dB attenuation bandwidths of >80 GHz) to measure the waveform parameters of short transition-duration (high-speed) pulse generators and the impulse response of high-speed samplers. 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 [4].

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 a measurement transfer using the NIST-developed sampling voltage comparator [5].

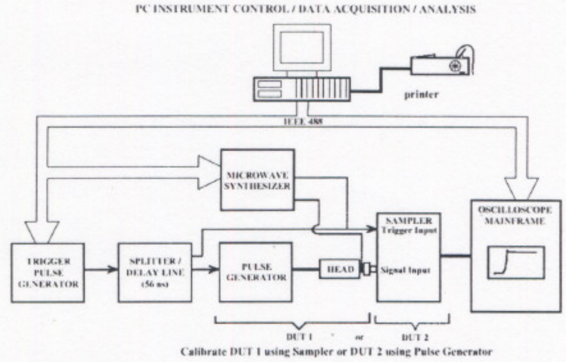

Figure 1 Diagram of NIST waveform measurement system. The dotted lines indicate insertion of instruments used in time-base calibration.

Common Measurement Considerations

Temperature Temperature affects the measurement of pulse amplitude and transition duration for both pulse generators and samplers [6] and the results must be corrected. The correction is done in the 65200S by acquiring parameter versus temperature data and correcting subsequently measured waveforms using this information.

System Jitter 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 an appropriate delay [7]. This reduces the system jitter to two components, the trigger jitter of the sampler and of the pulse generator. The combined system jitter of the 65200S is ≤ 1 ps. The jitter affects the

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bandwidth of the measurement system and can be modeled as a low-pass filter [8].

Timebase Errors These are gain errors and nonlinearities. Timebase gain describes the expansion or contraction of the timebase relative to what is expected, and is measured using sinewaves of known frequency. This error is easily corrected by multiplying the time values by the ratio of the expected and measured values of Δt. Timebase nonlinearities are also measured using sinewaves [9]. These nonlinearities describe local variations in the timebase error that exist after removal of that caused by timebase gain.

Noise Noise is typically assumed to be zero-mean, normal, independent and identically-distributed 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. However, we have observed deterministic noise that is caused by coupling of timebase signals into the sampling channel. Although this noise is small in amplitude, it can affect waveform values if not corrected.

Computational Parameters The methods used to compute the pulse parameters affect pulse parameter uncertainty. Uncertainties from the following have been included in the 65200S uncertainty analysis: histogram effects (including position of transition within epoch and number of bins), interpolation to find reference instants, and the waveform reconstruction process (including the effects of Fourier transforms, the computation precision, and the value of stopping criterion parameter)[7].

Other General Considerations The duration of the waveform epoch is important for two reasons. First, the epoch should be short enough for the pulse transition duration and waveform epoch to minimize aliasing. 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, significant aliasing error in the spectrum of the DUT will occur. Second, averaging is necessary to reduce the effect of noise in the measurement system on the data. However, it is important to determine that drift does not occur over the epoch for the DUT measurement acquisition time. Our observations have been that drift does not occur during the time required to perform a measurement [10].

Sampler Considerations

The primary measurement consideration that is unique to samplers is sampler gain, which 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. The gain correction factor is 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.

References

1. NIST Calibration Services Users Guide, NIST Special Publication, SP250, U.S. Department of Commerce, Washington, DC, January 1998, pp. 189 to 193.
2. IEEE Std. 181-2003, "Standard on Transitions, Pulses, and Related Waveforms," 445 Hoes Lane, Piscataway, NJ, 08855, USA.
3. IEEE Std. 1057-1994, "Standard for Digitizing Waveform Recorders," 445 Hoes Lane, Piscataway, NJ, 08855, USA.
4. N.G. Paulter and D.R. Larson, "Pulse parameter uncertainty analysis," Metrologia, Vol. 93, pp. 143 to 155, 2002.
5. O. B. Laug, T. M. Souders, and D. R. Flach, "A Custom Integrated Circuit Comparator for High-Performance Sampling Applications," IEEE Trans. Instrum. Meas. 41 (6), 850 (Dec. 1992).
6. D.R. Larson and N.G. Paulter, "Temperature Effects on Measurement Results from 50 GHz Digital Sampling Oscilloscopes," International National Conference of Standards Laboratories, Proceedings of the 2000 Workshop and Symposium, 16-20 July 2000, Toronto, Canada.
7. N.G. Paulter and D.R. Larson, "Measuring the Response of High-Speed Pulse Generators and Samplers," NCSL 2003 Conference and Workshop, Tampa, FL, USA, 17-21 August 2003.
8. W.L.Gans, "The measurement and deconvolution of time jitter in equivalent-time waveform samplers," IEEE Trans. Instrum. Meas., Vol. IM-32, pp. 126 to 133, March 1983.
9. G.N. Stenbakken and J.P. Deyst, "Time-base nonlinearity determination using iterated sine-fit analysis," IEEE Trans. Instrum. Meas., Vol. 47, pp. 1056 to 1061, October 1998.
10. D.R. Larson and N.G. Paulter, "The effects of offset voltage on the amplitude and bandwidth of kick-out pulses used in the nose-to-nose sampler impulse response characterization method," IEEE Transactions on Instrumentation and Measurement, Vol. 50, August 2001, pp. 872 to 876.

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