

Pulse Parameter Dependence on Transition Position and Epoch Duration

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Abstract - The pulse parameters of amplitude and transition duration are dependent on the epoch duration and transition occurrence instant of the pulse transition in the epoch. The primary explanations for the observed variations are the pulse aberrations and settling behavior of both the pulse generator and the measurement instrument (sampling oscilloscope). Measurement results are included for two pulse generators and two sampling oscilloscopes.

Keywords - pulse parameter, sampling oscilloscope, transition duration, settling error, picosecond.

I. INTRODUCTION

High-speed electrical signals are found in all digital communications links. Following the terminology and procedures of IEEE Standard 181-2003 [1], these signals can be decomposed into step-like waveforms, each with a low state (s_1), a transition, and a high state (s_2). The parameters of amplitude (high state, s_2 , minus low state, s_1) and transition duration (often 90 % reference level instant minus the 10 % reference level instant) are used to describe these step-like waveforms, as shown in figure 1. The accurate determination

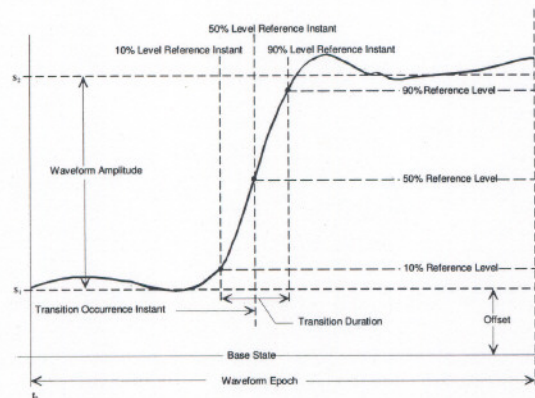


Fig. 1. Pulse terms from IEEE Standard 181-2003.

of these two pulse parameters is important when comparing pulse generators, transmission lines, and receivers or test and measurement instrumentation. These high-speed signals are the life blood of the information age.

NIST offers a pulse generator and a sampling head calibration service [2] in which we provide customers with

the parameters of amplitude, transition duration, and the uncertainties associated with them. This service is optimized for measuring the durations of very fast pulse transitions (transition durations less than 350 ps, i.e., 3 dB attenuation bandwidths greater than 1 GHz). The histogram algorithm we use to determine the pulse amplitude conforms to IEEE Standard 181-2003 [1]. Another method to determine the pulse amplitude, one that also conforms to IEEE Standard 181-2003, requires that the pulse generator provide two dc levels corresponding to the low state and the high state. These dc levels must be supplied at the pulse output connector and the levels must be selectable. The pulse amplitude is then defined to be the difference between the two dc levels and the ambiguities in amplitude and transition duration observed here are minimized. However, not all pulse generators provide the static levels. We have observed that the estimated values of amplitude and transition duration depend on the epoch duration and the transition occurrence instant in the epoch. It is also evident that the estimated value of the transition duration is dependent upon the estimate of the amplitude. With the motivation of reducing the reported uncertainties and improving the reproducibility of interlaboratory comparisons, we have undertaken a systematic examination of the variations in pulse parameters as a function of the transition occurrence instant (the 50 % reference level instant) in the epoch and the epoch duration. A poorly designed measurement, one where the epoch is too short and the transition occurrence instant is too near either end of the epoch, can yield an estimate of the pulse amplitude that is different from the actual amplitude by approximately 6 % for the pulse generators examined. The estimate of the transition duration also varies as much as 5 % under the same conditions.

II. EXPERIMENTAL SETUP

All measurements were performed in an rf shielded, temperature controlled room and all equipment was allowed to warm-up for at least two hours prior to making measurements. Our experimental setup consisted of two digital sampling oscilloscopes from different manufacturers, each with 50 GHz 3 dB attenuation bandwidth sampling heads. These measurement instruments have embedded routines for signal averaging and amplitude calibration. They also include embedded routines for determining the transition

duration and pulse amplitude, but these latter two routines were not used. Two different commercial pulse generators were also used and are representative of pulse generators frequently used to calibrate oscilloscopes. Examination of these pulse generators yielded respective transition durations (10 % to 90 %) of 13.7 ps $\pm$ 1.25 ps and 19.1 ps $\pm$ 1.25 ps. The pulse amplitudes were 245.9 mV $\pm$ 1.5 mV and 240.0 mV $\pm$ 1.5 mV respectively. The output of the pulse generators is provided through an SMA or 3.5 mm coaxial connector and the inputs of the sampling heads of each sampling oscilloscope are 2.4 mm coaxial input connectors. A precision 3.5 mm to 2.4 mm adapter was necessary to connect the pulse generators to the 50 GHz samplers, one adapter was used for all measurements. The sampling oscilloscopes require a trigger signal, which was available from one of the pulse generators tested. The other pulse generator was tested with a trigger pulse provided by a third pulse generator. That trigger pulse was split using a wide-band power splitter and one of the resulting two pulses was used to trigger the oscilloscope. The other pulse was delayed using a coaxial delay line and used to trigger the pulse generator. This allowed the oscilloscope and pulse generator to be triggered from the same pulse in the pulse stream, minimizing the trigger jitter [3].

The sampling heads were calibrated using the embedded amplitude calibration routine. The gain was checked using a transfer standard (pulse generator) calibrated with the NIST Sampling Comparator System (SCS) [4,5]. Corrections were not made for timebase errors although care was taken not to allow the transition to occur during the reset of the timebase vernier, which may cause a large error in the sampling instant [6].

The waveform epochs examined were in the range of 2 ns to 20 ns. When the duration of the waveform epoch was varied, the transition occurrence instant was fixed at an instant equal to 20 % of the epoch, measured from the beginning of the epoch. Additional data was acquired with the epoch fixed and the transition occurrence instant ranging from 5 % to 95 % of the epoch duration. This was done for three epoch durations, 2 ns, 4 ns, and 8 ns.

The embedded data averaging routines were used to acquire waveforms resulting from the average of 256 waveforms. Each acquired waveform consisted of between 1024 and 5120 samples. Three averaged waveforms were acquired at each setting and the results shown are the average of the three waveforms. A signal from Pulse Generator 1 that was acquired using Sampler A is depicted in figure 2. Figure 3 depicts the signal from Pulse Generator 2 as acquired by Sampler B. The base states (s_i) have been set to zero and the pulse amplitudes have been normalized. The NIST SCS was used to acquire reference waveforms from the two pulse generators. The NIST SCS waveforms are depicted in figures 4 and 5. Although the bandwidth of the SCS is lower, it settles to less than 0.3 % of its final value in the first 2 ns and to 0.1% after 5 ns. The known settling behavior of the SCS

allows us to separate the settling of the pulse generator from the settling behavior of the sampler.

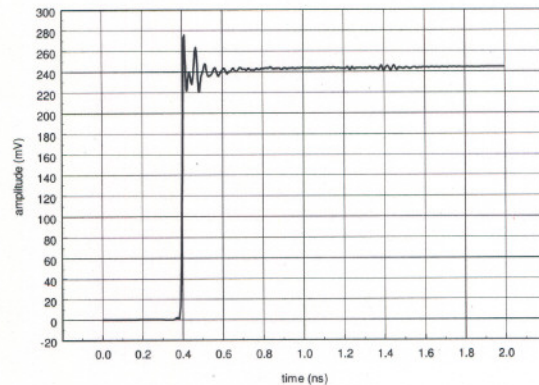


Fig. 2. Waveform from pulse generator 1 as acquired by sampling oscilloscope A.

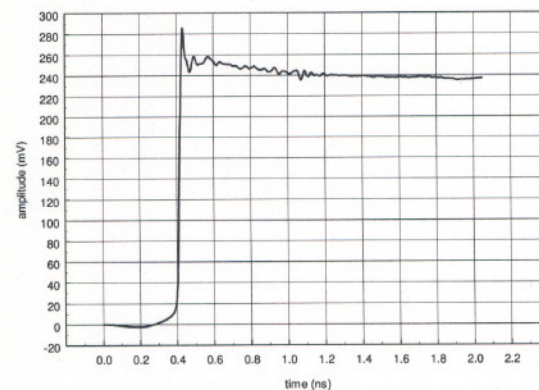


Fig. 3. Waveform from pulse generator 2 as acquired by sampling oscilloscope B.

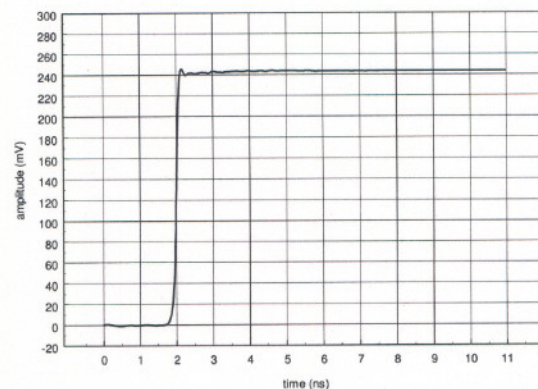


Fig. 4. Waveform from pulse generator 1 as acquired by NIST Sampling Comparator System.

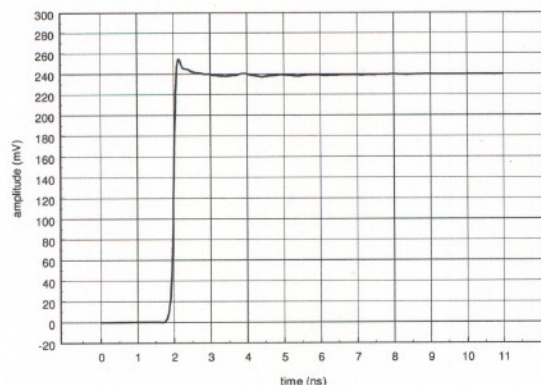


Fig. 5. Waveform from pulse generator 2 as acquired by NIST Sampling Comparator System.

III. MEASUREMENT RESULTS, AMPLITUDE

The state levels and amplitude of the acquired waveforms were obtained using a histogram method [1, 7]. All the waveforms used here consisted of 1024 points. Figure 6 depicts the variations of the measured amplitude as the duration of the epoch was increased. The values obtained

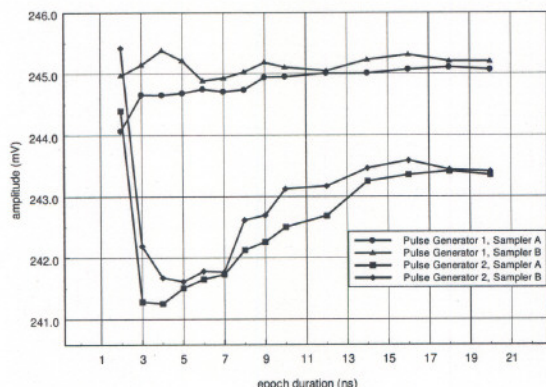


Fig. 6. Amplitude versus epoch duration, Pulse Generator 2 shifted.

from pulse generator 2 waveforms have been offset to fit on the same graph as the values from pulse generator 1 waveforms. The amplitude for pulse generator 1 exhibits a gradual increase with increasing epoch for both samplers. To see where this variation originated, the low state and high state are plotted versus epoch duration in figures 7 and 8. The low state decreases with increasing epoch duration and the high state increases with increasing epoch duration. These effects combine to create an even larger increase in amplitude with increasing epoch duration than either by itself. The output of this pulse generator was next examined using the SCS. This NIST designed and developed instrument provides a reference measurement of the output pulse but has a bandwidth of 2.3 GHz, much lower than the sampling oscilloscope. The waveform acquired with the SCS depicts a flat region after 2 ns where the pulse generator has

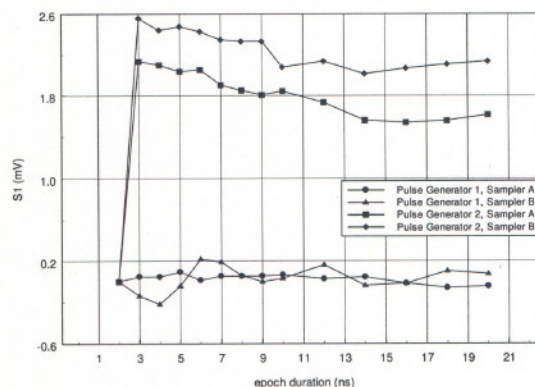


Fig. 7. Normalized low state (s_1) as a function of epoch duration.

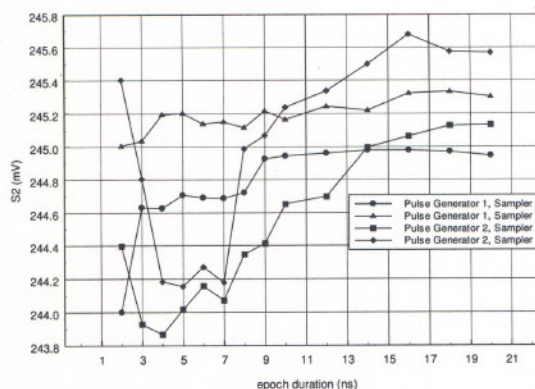


Fig. 8. Normalized high state (s_2) as a function of epoch duration.

settled. When compared with the continued increase in pulse amplitude depicted in figure 6, it can be concluded that the sampling head must contribute to this long settling time.

There are several waveform artifacts that may impact the measured amplitude as the transition occurrence instant or epoch duration is varied. In figure 2, an aberration is observed in the pre-transition region. This aberration has an amplitude of about 0.2 mV. The observed post-transition overshoot and settling are also anticipated to impact the measured amplitude. At about 1 ns after the transition, some additional structure in the waveform is noted. This is a reflection between the sampling head and pulse generator resulting from a small impedance mismatch between these two instruments. In figure 3, the pre-transition region includes a large undershoot of several millivolts and a reflection is observed about 0.7 ns after the transition. Although not shown, the pre-transition undershoot seen in figure 3 also occurs when Pulse Generator 2 is acquired using Sampler A. It is an aberration from the pulse generator.

Figures 9 and 10 depict the variation of the measured amplitude as a function of transition occurrence instant in the epoch for 2 ns and 8 ns epochs. The data has been normalized to the first data point. It is obvious that using an

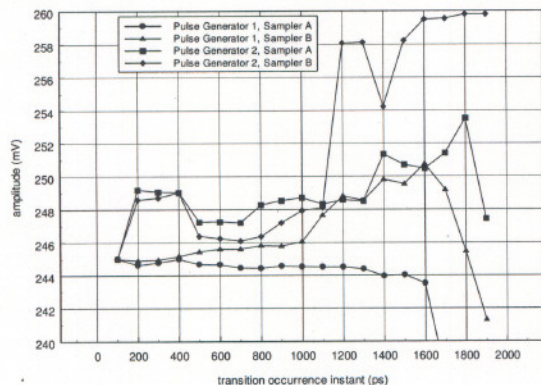


Fig. 9. Normalized amplitude as a function of transition occurrence instant in a 2 ns epoch.

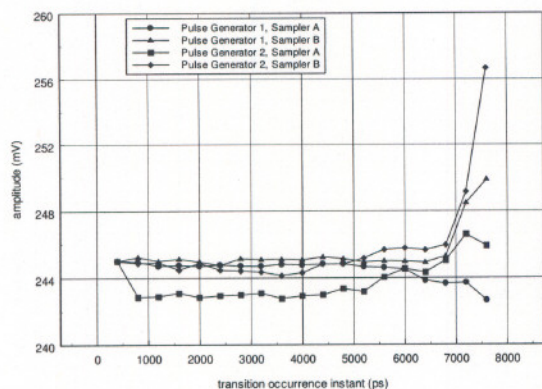


Fig. 10. Normalized amplitude as a function of transition occurrence instant in an 8 ns epoch.

8 ns epoch yields a much lower variation in amplitude with the transition occurrence instant than does a 2 ns epoch. This is a result of the settling behavior of the pulse generators due to the fact that the waveform aberrations near the transition occupy a greater percentage of the high state as the transition occurrence instant occurs later in the epoch.

IV. MEASUREMENT RESULTS, TRANSITION DURATION

Transition duration, as used here, is defined as the difference between the 90 % reference level instant and the 10 % reference level instant [1]. An estimate of the transition duration is dependent on the estimate of the amplitude, which we have shown is dependent on the epoch duration and transition occurrence instant in the epoch. Figure 11 depicts the change in the transition duration estimate as the epoch duration varies. The number of points that make up the waveforms was increased with increasing epoch duration to keep the sampling interval less than or equal to 2 picoseconds. It is evident that the estimated transition duration of pulse generator 2 shows a significant dependence on epoch duration. A dependence on epoch duration for

pulse generator 1 is not as apparent from Figure 11. From figure 6, for epoch durations greater than 4 ns, both pulse generators exhibit an increase in amplitude with epoch duration, with pulse generator 2 showing a much larger dependence. If the epoch duration is changed from 4 ns to 8 ns, for example, the estimate of the pulse amplitude increases.

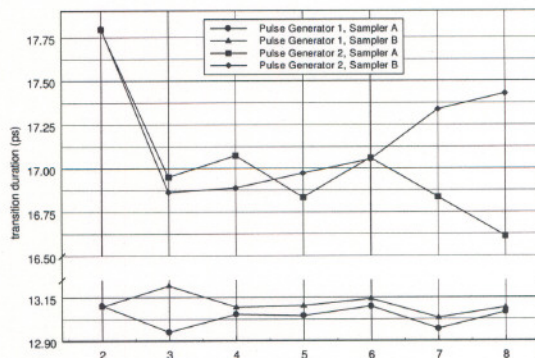


Fig. 11. Transition duration as a function of epoch duration.

The difference between the 90 % and 10 % reference levels would be increased by 80 % of the increase in pulse amplitude. This would cause the transition duration estimate to also increase. This expected behavior is evident in Figure 11 only for large changes in amplitude. The amplitude estimate for Pulse Generator 2 decreases by nearly 4 mV for epoch durations from 2 ns to 4 ns (figure 6). For these epochs, the transition duration decreased by approximately 0.9 ps or 0.225 ps/mV. Again, the uncertainty in our transition duration measurements is less than ± 1.25 ps. An amplitude increase of almost 1 mV is observed for Pulse Generator 2 for epoch durations between 4 ns and 8 ns (either sampler, figure 6). Using the 0.225 ps/mV rate of change, an increase in transition duration of about 0.2 ps might be expected. Although the transition duration estimates for Sampler B increases as expected, the transition duration estimates for Sampler A decreases over this same range (figure 11). This decrease, although unexplained, is not statistically significant. For pulse generator 1 and samplers A and B, the change in transition duration expected for the observed change in amplitude is less than can be reliably determined in this experiment.

V. CONCLUSIONS

It is obvious from the results presented here that the transition occurrence instant and the epoch duration must be specified for reproducible results. This is due in part to the settling of the sampler but more to the settling of the pulse generator. Appropriate selection of the epoch duration and transition occurrence instant can also minimize the pulse parameter uncertainty resulting from these two variables.

For the pulse generators and samplers examined here, the variation in the measured amplitude decreases with increasing epoch and a 4 ns epoch appears to be the minimum epoch that will yield consistent results. Currently, sampling oscilloscopes are only available with fixed record sizes, the maximum being 5120 points. Therefore, the epoch duration impacts the sampling interval and the epoch duration must be carefully chosen to maintain the smallest sampling interval necessary to obtain an accurate estimate of the transition duration. The pulse amplitude also varies significantly with the transition occurrence instant. Placing the transition occurrence instant at about 1 ns from the beginning of a 4 ns epoch appears to give the most reproducible results without increasing the sampling interval unduly.

Fortunately, the impact of a change in amplitude estimate on the transition duration estimate was less than expected for these samplers and pulse generators. Although large changes in amplitude will produce measurable changes in transition duration, these are not expected in the course of usual calibration work.

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