IEEE TC-10: Update 2011

Thomas E. Linnenbrink[1], William B. Boyer [2], Travis Ellis [3],
Nicholas G. Paulter, Jr.[4], Steven J. Tilden[5]

[1]*Chair, Waveform Generation, Measurement, and Analysis Committee (TC-10)*
Hittite Microwave Corporation, Colorado Springs, CO, 80907, (719) 590-1112, toml@hittite.com
[2] *Chair, Subcommittee on Digital Waveform Recorders*
Sandia National Laboratories (SNL), Albuquerque, NM 87104, (retired) (505) 899-3044, wbboyernm@comcast.net
[3]*Chair, Subcommittee on Probe Standard (SCOPS)*
Samtec NW Design Center, Vancouver, WA 98683, travis.ellis@samtec.com
[4]*Chair, Subcommittee on Pulse Techniques (SCOPT)*
National Institute of Standards and Technology (NIST), Gaithersburg, MD, 20899, (301) 975-2405, nicholas.paulter@nist.gov
[5]*Chair, Subcommittee on Analog-to-Digital Converters (ADCs),*
Chair, Subcommittee on Digital-to-Analog Converters, (DACs)
LTX Credence, 408-635-4851, Steve_Tilden@ltxc.com

Keywords-IEEE Std 181™, IEEE Std 1057™, IEEE Std 1241™, IEEE Std 1658™ (Draft) IEEE Std 1696™ (Draft), Digitizing Waveform Recorder, Pulse, ADC, DAC, Measurement[1]

Abstract-There is a world-wide need to standardize terms, test methods, and the computation of performance parameters for devices that generate, measure, and analyze waveforms. Users need to be able to unambiguously specify the device performance required for particular applications. Manufacturers need to be able to unambiguously state the performance of their devices (e.g., instruments, components, etc.). Metrology facilities need to perform calibrations with well-defined methods to produce reliable data expressed in clear terms. Measurement instruments need to acquire data with well-defined methods and present it clearly. Technical Committee 10 (TC-10), the Waveform Generation, Measurement, and Analysis Committee of the IEEE Instrumentation and Measurement (I&M) Society, is tasked to develop standards to address these needs. TC-10 comprises an international group of electronics engineers, mathematicians, professors and physicists with representatives from national metrology laboratories, national science laboratories, component manufacturers, the test instrumentation industry, academia, and end users.

I. Introduction and Objectives

The world needs standard terms, test methods, and computational procedures to facilitate economic growth through technology evolution. Users, manufacturers, instrument makers, and metrology labs need to communicate with universally understood terms. To that end, Technical Committee 10 (TC-10), the Waveform Generation, Measurement, and Analysis Committees of the IEEE Instrumentation and Measurement (I&M) Society has been developing standards for pulse terminology, waveform recorders, analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and electronic probes. We also hope to develop a standard for jitter. TC-10's diverse international membership of engineers, physicists, and mathematicians from industry, academia, and national laboratories ensures that our standards reflect a broad range of perspectives and interests. Our activities include developing new standards, revising existing standards, and promoting the awareness of TC-10's standards.

TC-10's progress has been reported periodically at IEEE and IMEKO conferences, most recently at IWADC 2008 in Florence, Italy [1]. That paper presented the historical development of the TC-10 standards from its TC-10 inception in 1977 through the middle of 2008. This paper emphasizes activity from the middle of 2008 through the first

[1] IEEE Std 181, IEEE Std 1057, IEEE Std 1241, IEEE Std 1658 (Draft) IEEE Std 1696 (Draft) are trademarks of the Institute of Electrical and Electronic Engineers, Inc., (IEEE). This paper is not endorsed or approved by the IEEE.

quarter of 2011. Section II presents the title and scope of each of TC-10's projects. Continuing activity on each project is discussed in Section III. This paper focuses on more recent activity and changes in current versions of standards relative to prior versions.

II. Scope of TC-10 Standards

TC-10 is currently engaged in six projects. Three standards have been published to date. All three have been or are currently being improved; "(-20xx?)" shows the anticipated acceptance date by the IEEE. Three new standards are in various stages of development at this time. The titles and scope of each of the standards is listed below.

A. **IEEE Std 181-2003 (-2011?), "Standard on Transitions, Pulses, and Related Waveforms"**

This standard defines parameters describing characteristics of transitions, pulses, and related signals and defines procedures for estimating the value of these parameters, which is necessary to facilitate accurate and precise communication concerning these parameters and the techniques and procedures for measuring them. Because of the broad applicability of electrical pulse technology in the electronics industries (such as computer, telecommunication, entertainment, and test instrumentation industries), the development of unambiguous definitions and computation methods for these parameters is important for communication between manufacturers and consumers within the electronics industry. The enabling of accurate communication through this standard promotes product comparison and improvement.

B. IEEE Std 1057-2007, "Standard for Digitizing Waveform Recorders"

This standard defines specifications and describes test methods for measuring the performance of electronic digitizing waveform recorders, waveform analyzers, and digitizing oscilloscopes with digital outputs. The standard is directed toward, but not restricted to, general-purpose waveform recorders and analyzers.

C. IEEE Std 1241-2010, "Standard for Terminology and Test Methods for Analog-to-Digital Converters"

The material presented in this standard is intended to provide common terminology and test methods for the testing and evaluation of analog-to-digital converters (ADCs). This standard considers only those ADCs whose output values have discrete values at discrete times, i.e., they are quantized and sampled. In general, this quantization is assumed to be nominally uniform (the input-output transfer curve is approximately a straight line), and the sampling is assumed to be at a nominally uniform rate. Some but not all of the test methods in this standard can be used for ADCs that are designed for non-uniform quantization.

D. IEEE Draft Std P1658 (-2011?), "Draft Standard for Terminology and Test Methods for Digital-to-Analog Converters"

This standard defines terminology and test methods to clearly document prevalent world-wide terms used to describe and test digital-to-analog converters (DACs). It is restricted to monolithic, hybrid, and modular DACs and does not cover systems encompassing DACs.

E. IEEE Draft Std P1696 (-2014?), "Draft Standard for Terminology and Test Methods for Circuit Probes"

This standard provides test method(s) and describes transfer (artifact) standards for characterizing electrical circuit probes and probes systems. The systems may include waveform acquisition hardware and software and signal/waveform analysis software. The probe will include the mechanism by which the circuit is contacted. This method and standard will be applicable to all individual probes having one signal conductor and one ground conductor or two signal conductors, and having input impedance greater than the impedance of the circuit under test.

F. Potential Jitter Standard

A subcommittee is being formed to seek authorization from the IEEE to develop standard terms and test methods for jitter in sampled-data systems (e.g., ADCs, DACs, digital waveform recorders, etc.) and in digital data communications.

III. Continuing Activity

Activity is ongoing within TC-10's subcommittees. Beyond developing new standards, existing standards are reviewed every five years and then revised as appropriate. We also promote awareness of these standards through magazine articles and conference papers. These continuing activities are discussed in the following subsections.

A. **Subcommittee on Pulse Technology (Std 181)**

SCOPT began revising the IEEE Std 181-2003 in May 2008. The draft revision was completed in November 2010 and balloted in January 2011. The balloting committee provided suggested changes that were implemented by SCOPT. The revised standard was re-balloted and subsequently approved by the balloting committee in February 2011. The revision of the Std 181 was completed well ahead of schedule, more than 18 months early, primarily due to the extensive use of electronic collaboration. In May 2011, the IEEE RevCom (http://standards.ieee.org/about/sasb/revcom/index.html) will vote on whether or not to recommend the use of the revised Std 181 to the IEEE Standards Association.

The revision to the IEEE Std 181-2003 was undertaken to include additional terms and definitions, correct errors discovered in the Std 181-2003, and add information for generating reference waveforms that can be used in algorithm comparison. The fundamental waveform parameters are shown, as an example, in Figure 1. A discussion of this standard is found in [2].

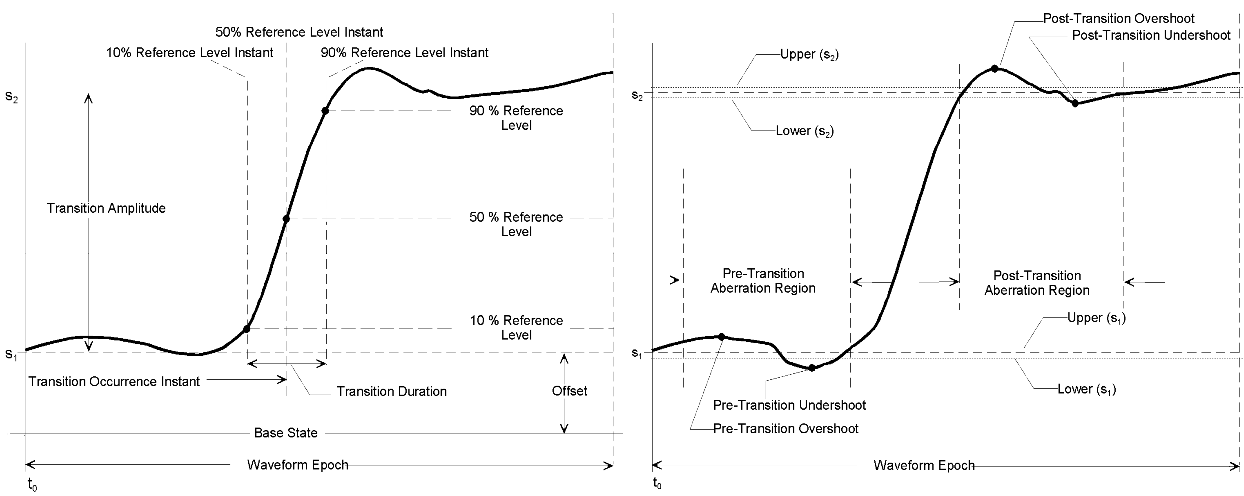

Figure 1. Two figures displaying various parameters used to describe the characteristics of a waveform. The figure on the left shows the fundamental waveform parameters on which all other parameters are derived. The figure on the right shows parameters used to describe aberrations of a waveform.

SCOPT is promoting awareness of IEEE Std 181 through publications and communication at technical meetings. It is seeking assistance in this process and welcomes your suggestions and participation. SCOPT members are also participating in the revision of the IEC 60469-1 and IEC 60469-2, which are almost verbatim copies of the now obsolete IEEE Std 194-1977 and IEEE Std 181-1977. SCOPT is participating in this IEC revision process by membership with the IEC working group responsible for maintenance of IEC 60469-1 and -2.

B. **Subcommittee on Digital Waveform Recorders (Std 1057)**

The original standard IEEE Std. 1057-1994 was heavily revised and the new version, IEEE Std 1057-2007, was approved in 2007 and published in summer 2008. Before starting on the revision, the subcommittee had spent several years developing a user guide for 1057. The material developed for the user guide has been included in the new version of 1057. Much of this new material covers selecting and evaluating test sources for various test methods, especially sinewave sources for sine-fit tests. Another major change was incorporating several applicable portions of IEEE Std. 1241-2000.

The definition of noise has been changed in the new version of 1057. In the new standard, noise does not include the effects of harmonic distortion. This was done to support the use of the common waveform recorder and ADC metric –Signal to Noise and Distortion, or SINAD.

Several changes were made in the new standard to make pulse measurements and descriptive terms compatible with IEEE Std 181-2003. The subcommittee generated improved definitions and test methods for critical metrics, such as, Effective Number of Bits (ENOB), total harmonic distortion, noise, locating code transitions, etc.

The TC-10 Subcommittee on Waveform Recorders has been largely inactive since IEEE Std 1057-2007 was published in 2008. The committee members have generally been working in support of developing standards for the other TC-10 subcommittees.

C. **Subcommittee on Analog-to-Digital Converters (ADCs) (Std 1241)**

Work on 1241 originally started soon after TC-10 had finished its development of IEEE-STD-1057-1994 for waveform recorders. It was completed and the first publication of 1241 occurred in late spring of 2001 after approval in December 2000. Subsequent to the publishing of IEEE Std 1241-2000 and at the request of the IEEE, an effort began to create an IEC standard based on 1241-2000. This effort resulted in the international standard IEC 60748-4-3 dated August 2006 entitled "Semiconductor devices – Integrated circuits – Part 4-3; Interface integrated circuits – Dynamic criteria for analogue-digital converters (ADC)" which was written to include dynamic criteria for ADCs to complement the previously published IEC standard developed for only static ADC parameters. At the conclusion of the five-year cycle, the Analog-to-Digital Converter Subcommittee was granted a Project Authorization Request (PAR) by the IEEE Standards Association to develop an updated version of the standard to improve and expand its content. The subcommittee began that work in 2005. An updated version of the ADC standard, IEEE Std 1241-2010, was approved in June 2010 and was then published on January 14, 2011.

Now that 1241 has been updated and most terms and test methods are well documented, the next challenge will be how to provide standardization for embedded ADCs. At the 2010 I2MTC conference held in May in Austin, Texas, USA, several embedded-circuit providers and users held a workshop to discuss how to standardize performance of ADCs in embedded applications. The challenge here is how to obtain advertised performance of embedded circuits in user applications when surrounded by hostile system-on-a-chip (SOC) environments, not easily obtained due to interference from nearby switching transients and coupling mechanisms. This will be the next chapter in ADC test collaboration to solve real world problems.

D. **Subcommittee on Digital -to-Analog Converters (DACs) (P1658)**

Developing a standard for DACs followed TC-10's progression of standards. The waveform recorder standard (1057) led to the ADC standard (1241). Then the ADC standard led to the DAC standard (1658).

Like ADCs, DACs serve an important and ever increasing role in signal processing today. Real world signals are conditioned and transformed into digital data by ADCs, sent to a processing computer where digital adjustments are made, and then sent back to the real world through DACs and analog signal processing. As in the case of ADCs, DACs have many terms and definitions that were described in numerous ways. The 1658 working group set about to resolve these disparities with a body of international experts at universities, laboratories and industry with extensive and diverse experience in data converter design, modelling and test.

DACs and ADCs perform complementary functions. DACs receive a digital signal and generate an analog equivalent, while ADCs receive an analog signal and generate a digital equivalent. There are subtle but important differences in the behavior of ADCs and DACs. As an example, consider the difference in their transfer functions illustrated in Figure 2. For a DAC, each digital input corresponds to single average analog output amplitude. For an ADC, each digital output corresponds to an interval of analog input values. The analog quantity defined in the transfer function of an ADC, the code edge, is usually defined to occur at the point where 50% of the output codes are greater than a specified digital output.

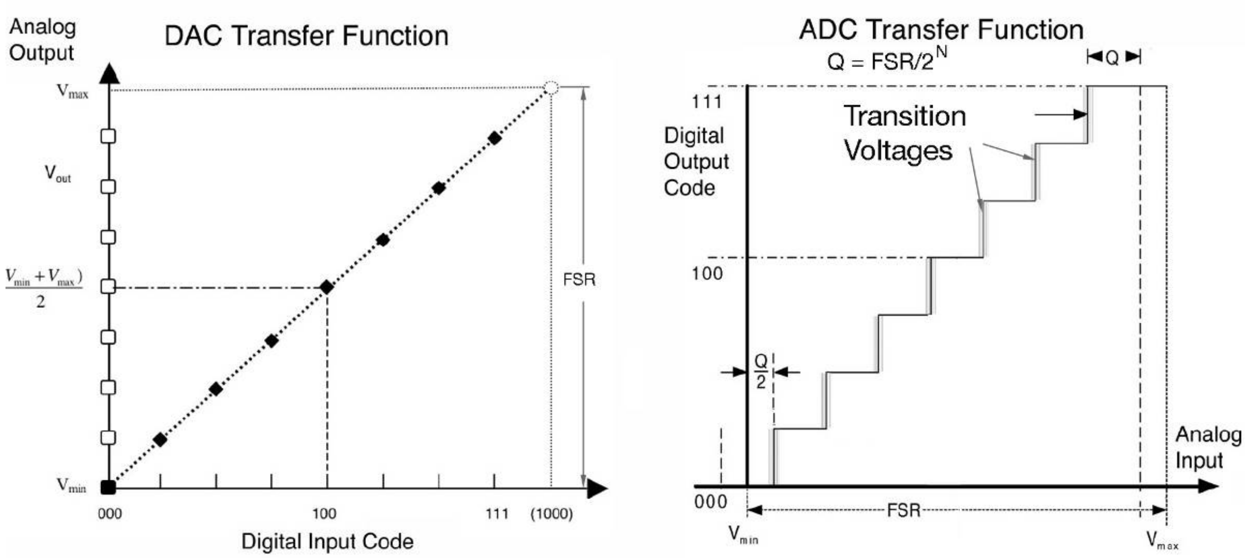

Figure 2. Transfer functions of ideal 3-bit unipolar DAC and ADC.

ADCs and DACs also differ in their quantization process and in their time-domain and frequency-domain responses. There are also some subtle differences between ADCs and DACs in the area of aliasing and image frequency generation. Aliasing is a phenomenon usually associated with ADCs while the generation of image frequencies is usually associated with DACs. The two phenomena are very closely related. In both cases we there is a sampling frequency, f_s. For an ADC this is the clock rate, the rate at which samples are taken. For a DAC this is the update rate, the rate at which the DAC creates sampled-analog outputs.

E. **Subcommittee on Probe Standard (SCOPS) (P1696)**

SCOPS was formed in 2006 to address the discrepancies in the characterization of circuit probe performance. The 1696 working group is small and asked for and received a four-year project extension from the IEEE. The group expects to make use of all of the allotted time in order to complete the work on circuit probe characterization by the end of 2014.

Observing electrical waveforms in circuits becomes increasingly difficult as their frequency content moves into the multi-gigahertz region. Probing high frequency signals is exacerbated by the fact that these systems operate at low impedances. Intrinsic system properties coupled with the fact that the readily available equipment for testing circuits has its own frequency-dependent electrical properties makes distortion-free probing challenging.

The ability to accurately characterize circuit probes will enable probe users to fully appreciate a circuit probes effect on their circuits. Circuit probe characterization can be carried further and, with the proper methodology, probing affects can be systematically removed from the measured data. Then the user is left with an accurate and complete representation of their system's electrical performance.

Circuit probe characterization starts with the careful the design and characterization of the fixture being used to characterize the circuit probe. The quality of the test fixture directly affects the probe measurements, which can literally be lost in the noise. Figure 3 shows an example of a probe characterization fixture and its block diagram.

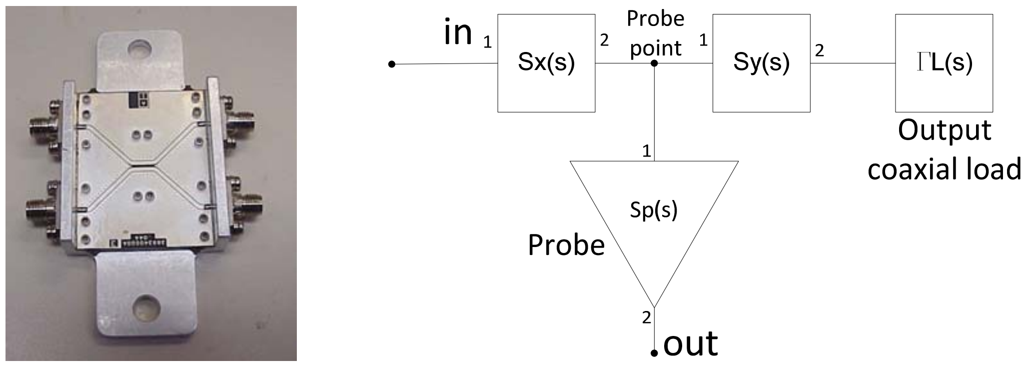

Figure 3. Example fixture (differential fixture shown) and block diagram for probe measurement.

With a properly designed test fixture, the next step is to accurately measure the probe and fixture's electrical characteristics. The block diagram shows the S21 through-measurement approach. The through measurement can be performed on any two-port network analyzer. With careful consideration, these results can be converted to a probe-only response when accurate data is available from the high quality test fixture. Once equipped with the probe's frequency-dependent properties, its effects on the circuit can then be accurately quantified and/or removed from the electrical measurements of the system response.

F. Subcommittee on Jitter

TC-10 is forming a subcommittee to address jitter in electronic circuits. Jitter impacts the performance of mixed-signal circuits (e.g., ADCs) by varying the instant at which a sample of a continuous-in-time waveform is taken. In digital data transmission, jitter contributes uncertainty in data bit transitions thus impacting bit-error rate. TC-10 hopes to develop a standard (or standards) for both forms of jitter. Sergio Rapuano of the University of Sannio, Benevento, Italy, has agreed to chair the jitter subcommittee. People interested in helping develop a standard for jitter terms and test methods are encouraged to contact Dr. Rapuano via email at rapuano@unisannio.it or by telephone at +39 0824 305804-305600. Initially, the jitter subcommittee will draft a Project Authorization Request (PAR) that will define the scope of the future standard.

IV. Conclusion

TC-10 continues to refine its existing standards and develop new ones. By policy, all IEEE standards are reviewed every five years. In the course of these reviews, TC-10 clarifies terms and test methods, and sometimes adds new material to assist users. In addition, new standards are developed to address unmet needs. TC-10 encourages fresh ideas and new perspectives. If you are interested in TC-10's work and would like to join one or more of its subcommittees, please visit our home page at https://grouper.ieee.org/groups/1057 or contact the subcommittee chairs. Contact information for subcommittee chairs follows the title of this paper: all are authors. We welcome your interest and participation.

References

[1] T.E. Linnenbrink, W.B. Boyer, R.M. Graham, N.G. Paulter, Jr., S.J. Tilden, "IEEE TC-10: Update 2008," 16th IMEKO TC4 Symposium & 13th Workshop on ADC Modelling and Testing, Florence, Italy, 22-24 Sept 2008.

[2] N.G. Paulter, D.R. Larson, J. J. Blair, "The IEEE Standard on Transitions, Pulses, and Related Waveforms, Std-181," IMTC 2003 -Instrumentation and Measurement Technology Conference, Vail, CO, USA, 20-22 May 2003, pp. 110-112.