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The IEEE TC-10 Standards: Update 2019

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Abstract-**There is a global need to standardize the terms and the test and computational methods that are used to describe and/or measure the parameters that characterize and define the performance of devices that generate signals and subsequently measure and analyze the waveforms acquired of those signals. This standardization is essential for accurate, reproducible, reliable, and communicable characterization of the performance of these devices, which supports technology and product advancement, product comparison and performance tracking, and device calibration and traceability. Users of the devices need to unambiguously specify the device performance required for particular applications. Manufacturers need 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 their results clearly. Technical Committee 10 (TC-10), the Waveform Generation, Measurement, and Analysis Committee of the IEEE Instrumentation and Measurement (I&M) Society, develops documentary standards to address these needs. The 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. The published standards developed and maintained by the TC10 include: IEEE Std 181-2011, "Standard on Transitions, Pulses, and Related Waveforms;" IEEE Std 1057-2017, "Standard for Digitizing Waveform Recorders;" IEEE Std 1241-2010, "Standard for Terminology and Test Methods for Analog-to-Digital Converters;" IEEE Std 1658-2011, "Standard for Terminology and Test Methods for Digital-to-Analog Converters;" and the IEEE Std 1696-2013, "Standard for Terminology and Test Methods for Circuit Probes." In development is the IEEE Draft Std. P2414 "Draft Standard for Jitter and Phase Noise." The status of these standards are described herein.**

I. INTRODUCTION AND OBJECTIVES

The global economy relies on standard terms, reproducible test methods, and accurate computational procedures to facilitate economic growth through technology evolution. Users, manufacturers, instrument makers, and metrology labs need to communicate with universally understood and accepted 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 documentary standards for pulse terminology, waveform recorders, analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and electronic probes. We are in the process of developing a standard for jitter, its terms, definitions, and models. The TC-10's diverse international membership of engineers, physicists, and mathematicians from industry, academia, and national

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laboratories ensures that our standards reflect a broad range of perspectives and interests. Our activities include developing new standards, revising and maintaining existing standards, and promoting the awareness of the TC-10's standards.

The TC-10's progress has been reported periodically at IEEE and IMEKO conferences[1-4]. This paper emphasizes activity since around 2011 through the second quarter of 2019. Section II presents the title and scope of each of the TC-10's projects. Continuing activity on each project is discussed in Section III. This paper focuses on the recent activity of the technical committees and changes in current versions of the documentary standards relative to their prior revisions.

II. SCOPE OF TC-10 STANDARDS

TC-10 is currently engaged in six projects, one for each of the documentary standards promulgated by the IEEE TC-10. Five documentary standards have been published to date. Three of these have been recently revised and improved, and two are new standards. Additionally, the TC-10 is drafting a new standard on jitter. The titles and scopes of each of the standards are listed below.

II.A. IEEE Std 181-2011, "Standard on Transitions, Pulses, and Related Waveforms" [5]

This standard defines the parameters that describe the basic characteristics of transitions, pulses, and related signals and defines the computational procedures for estimating the value of these parameters. Having well-defined computational procedures are necessary to facilitate accurate and precise communication concerning these parameters and providing a means for adjudicating any discrepancies between differing measurement results. 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 and technology advancement.

II. B. IEEE Std 1057-2017, "Standard for Digitizing Waveform Recorders" [6]

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.

II. C. IEEE Std 1241-2010, "Standard for Terminology and Test Methods for Analog-to-Digital Converters" [7]

The IEEE Std 1241provides common terminology and test methods for the testing and evaluation of analog-to-digital converters (ADCs). It 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 presented in the IEEE Std 1241 can be used for ADCs that are designed for non-uniform quantization.

II. D. IEEE Std 1658-2011, "Standard for Terminology and Test Methods for Digital-to-Analog Converters" [8]

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 that incorporate DACs.

II. E. IEEE Std 1696-2013, "Standard for Terminology and Test Methods for Circuit Probes" [9]

This standard provides test methods 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.

II. F. IEEE Draft Std. P2414 "Draft Standard for Jitter and Phase Noise"

The standard defines specifications, modeling methods and terminology for the dispersion of specified instants of repetitive and/or periodic signals in electronics, telecommunications and measurement, which is referred to as jitter and phase noise. The purpose of the standard is to facilitate accurate and precise communication concerning jitter and phase noise and the methods for measuring them. Because of the broad applicability of such terms in the electronics industries (such as computer, telecommunication, and measurement instrumentation industries), developing unambiguous definitions and the presentation of models for their measurement is important for communication between manufacturers, users and consumers.

III. CONTINUINT ACTIVITY

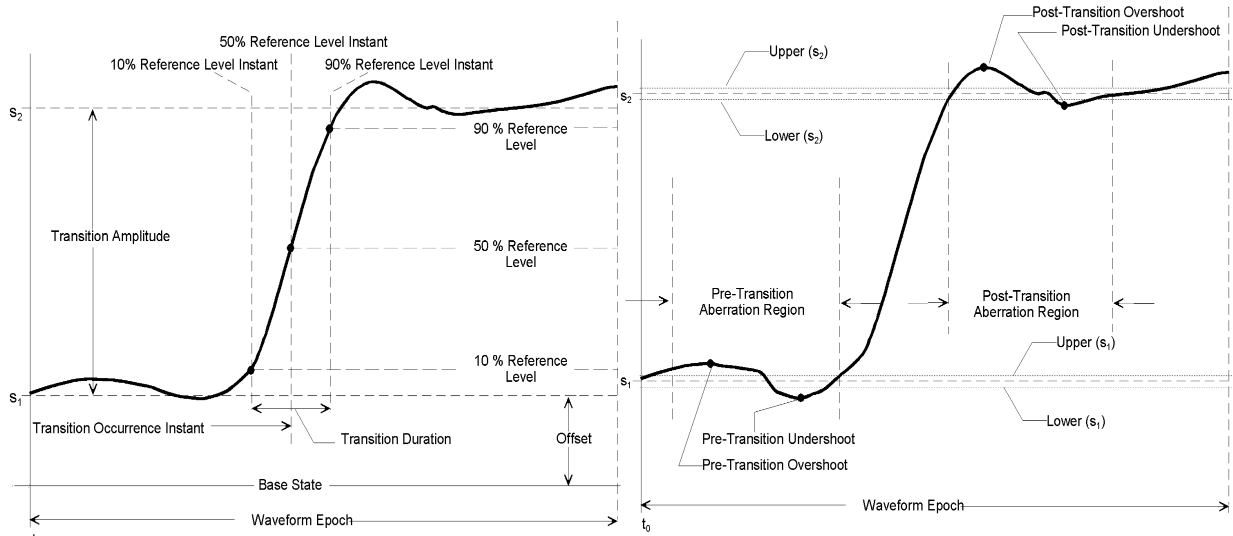

Fig. 1. Two figures displaying various parameters used to describe the characteristics of a waveform. The figure on the left shows the fundamental waveform parameters on which all other parameters are derived. The figure on the right shows the parameters that are used to describe aberrations of a waveform.

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

III. A. Subcommittee on Pulse Technology (SCOPT) (Std 181)

The SCOPT published the latest revision to the IEEE Std 181 in January 2011[5]. A discussion of this standard is found in [10]. The 2011 revision was undertaken to include additional terms and definitions, correct errors discovered in the 2003 revision, and add information for generating reference waveforms that can be used in algorithm comparison. The largest single change to the IEEE Std 181 was the introduction of the shorth method[11] for computing state levels, where the states are shown as s_1 and s_2 in Figure 1. The state level, *level*(s_i), is the value associated with s_i. The primary method for computing *level*(s_i) has historically been, and still is, the histogram mode method[12]. The shorth method was introduced for pulse metrology in 2009[13]. The shorth method is more computationally intensive than the histogram-mode method. Comparative studies on the performance of the shorth method and histogram-mode method for estimating *level*(s_i) has shown that the shorth-method typically provides smaller estimation errors and measurement uncertainties than the histogram-mode method[14,15]. However, these estimation errors and measurement uncertainties are typically much less than the signal noise and, consequently, have minimal influence on the measurement uncertainties of *level*(s_i).

SCOPT promotes awareness of IEEE Std 181 through publications and communication at technical meetings. It seeks assistance in this process and welcomes your suggestions and participation. SCOPT members also participated in the revision of the IEC 60469, Transitions, pulses and related waveforms - Terms, definitions and algorithms[16]. Because the Std 181 was last revised in 2011, the SCOPT is now seeking inputs, and interested participants, for a new revision or its reaffirmation.

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

An updated version of IEEE Std 1057 on waveform recorders was published in 2018, the IEEE Std 1057-2017, IEEE Standard for Digitizing Waveform Recorders. The subcommittee spent approximately five years modifying the previous version, the IEEE Std 1057-2007. Many of the changes were made to make the IEEE Std 1057 more consistent with IEEE Std 1241 on Analog to Digital Convertors.

The latest revision of the Std 1057 reflects a few new general information clauses that were added to match those in IEEE Std 1241. A clause titled Waveform Recorder Background briefly describes what the recorders are and what they do. Another clause was added for generic test setups similar to those described in the IEEE Std. 1241. A new table was introduced that lists pertinent waveform recorder characteristics for different applications.

A number of new and revised test methods were added based on information in 1241. The following are some of test methods adapted from IEEE Std 1241 to the waveform recorder standard: total harmonic distortion, monotonicity, hysteresis, static and dynamic gain, frequency response and dynamic gain, and aperture duration.

Several parameter definitions were changed to match those in the IEEE Std 1241. These included: aperture, aperture duration, common-mode signal, differential input recorder, dynamic range, full-scale signal, harmonic distortion, and transfer curve.

There were several cases where there were differences in a definition between the Std 1057 and the Std 1241, and we chose to use the Std 1057 definition because we thought it was more applicable for waveform recorders. Some of these definitions were for: ac coupled recorder, coherent sampling, crosstalk, differential input impedance, effective number of bits, equivalent time sampling, large signal, least significant bit, and noise.

The TC-10 Subcommittee on Waveform Recorders has been largely inactive since IEEE Std 1057-2017 was published. The committee members have generally been working in support of developing standards for the other TC-10 subcommittees.

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

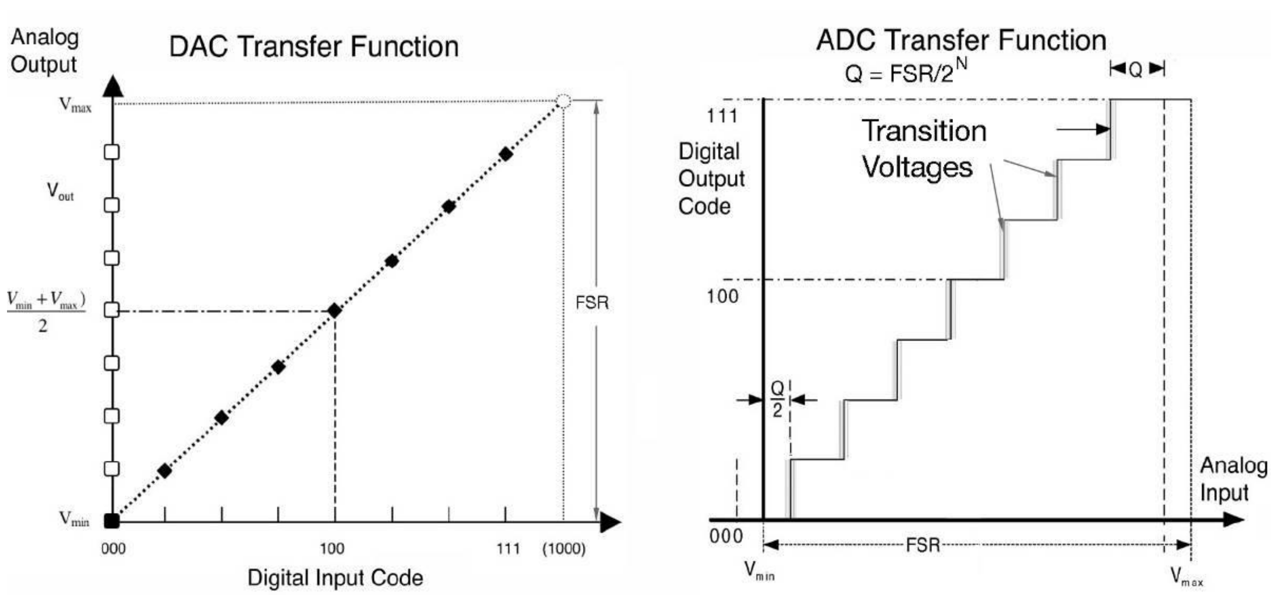

Fig. 2. Transfer functions of ideal 3-bit unipolar DAC and ADC.

The current draft of the IEEE Std 1241 was published in 2010. Relative to the pervious revision, which was published in 2000, the 2010 revision reflects improved and expanded content. The Subcommittee on ADCs also led the development of a complementary IEC standard, the IEC 60748-4-3 "Semiconductor devices – Integrated circuits – Part 4-3; Interface integrated circuits – Dynamic criteria for analogue-digital converters (ADC)" that was published in 2006 [17]. This IEC standard was written to include dynamic criteria for ADCs that complement the previously published IEC standard developed for only static ADC parameters.

The next challenge that was identified by the Subcommittee on ADCs was regarding 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 for this case is measuring and verifying the advertised performance of embedded circuits in user applications in which the ADC is surrounded by hostile system-on-a-chip (SOC) environments, which make accurate and reliable measurements difficult due to interference from nearby switching transients and coupling mechanisms. However, this activity did not obtain the needed interest to establish an IEEE Project Authorization Request in 2010 and was subsequently deferred.

A work effort to revise and update the content of the IEEE Std 1241 and to adopt the latest IEEE Standards Association format was started in 2018. This activity is planned to complete by the end of 2019.

III. D. Subcommittee on Digital -to-Analog Converters (DACs) (1658)

Digital-to-Analog Converters (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 Subcommittee on DACs set about to resolve these disparities with a body of international experts at universities, government agencies, test 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.

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 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 timed analog outputs.

The DAC working group is currently involved in the revision of the Standard, after 10 years from the first publication.

III. E. Subcommittee on Probe Standard (SCOPS) (Std 1696)

The SCOPS completed work on the "Standard for Terminology and Test Methods for Circuit Probes" in 2013, and the standard was published in February 2014,

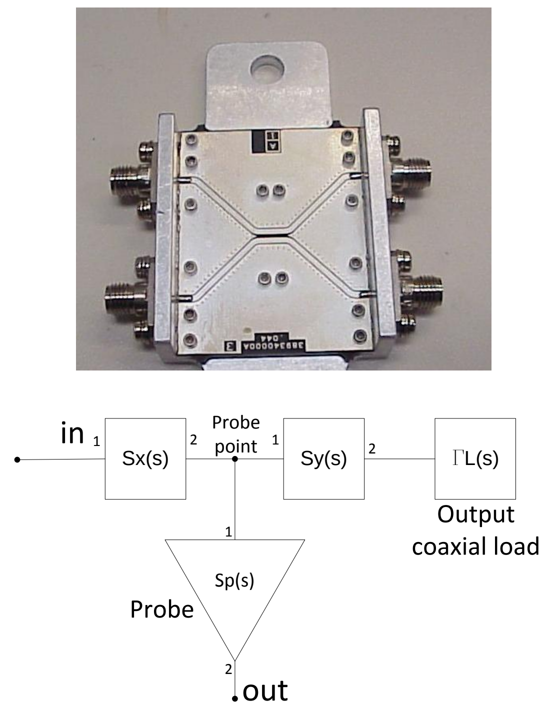

Fig. 3. Example fixture (differential fixture shown) and block diagram for probe measurement.

as IEEE Std P1696-2013.

Observing electrical waveforms in circuits becomes increasingly difficult as their frequency content moves into the multi-gigahertz region. The difficulty in 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 probe's effect on their circuits. Circuit probe characterization can, with the proper methodology, support the systematic removal of probing effects from the measured data. This would result in a more accurate and complete representation of a measurement system's electrical performance than if the probe effects were not removed.

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

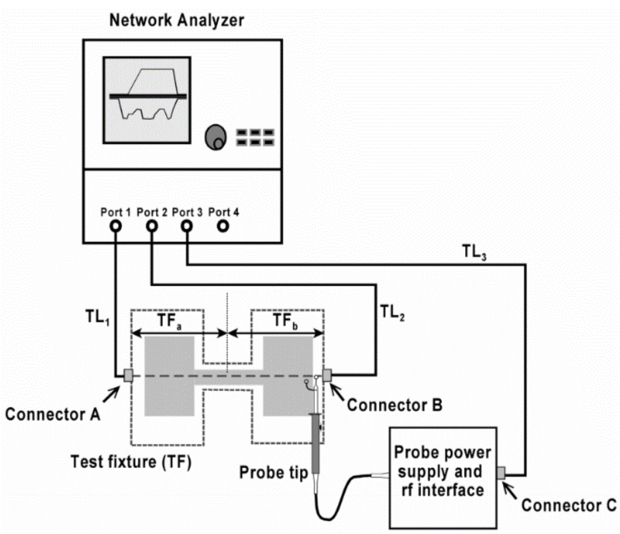

Fig. 4. Test setup for measuring the input impedance of single-ended stand-alone probe.

After a test fixture is properly designed and fabricated, the next step is to accurately measure the probe plus the test 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 probe-plus-test-fixture 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.

The IEEE Std 1696-2013 describes methods to use the test fixture to measure 20 different performance parameters such as input resistance, output resistance, gain, frequency response, step response, and many others. Furthermore, the standard describes test methods to perform these measurements for single-ended or differential probes as well as probe-only and probe-system techniques. Figure 4 shows an example from the standard of the test setup for measuring the input impedance of a single-ended stand-alone probe.

III. F. Subcommittee on Jitter (P2414)

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 to the uncertainty in data bit transitions, thus impacting the bit-error rate. Due to the wide impact of jitter, there has been a number of application-specific documentary standards developed by the IEEE and other standardizing bodies, such as [18-27]. The need for a harmonized, unitary approach to terminology and models for jitter led the formation of a TC-10 subcommittee, the Subcommittee on Jitter, to address jitter in electronic circuits that started at the IWADC held in Orvieto, Italy, in 2011. Since then, the Subcommittee has devoted a long study phase to analyze the existing world-wide literature, including standards. The IEEE approved a Project Authorization Request to initiate the development of a jitter standard in 2013, with an expected completion by the end of 2019. Several draft documents have been discussed and continuously improved during recent years.

The current version of the draft includes definitions and models for the most common types of jitter that are classified as random or deterministic ones. The deterministic jitter class is further divided in Data Dependent Jitter, Periodic Jitter and Bounded Uncorrelated Jitter. A general model for jitter is also provided considering it as a random variable and modeling it with its probability density function. A model is also provided, for each type of jitter, as a way to facilitate the construction of a complete jitter model from the contributions of all the different types of jitter. Currently, the final draft is being finalized before opening the balloting phase that should be completed within 2019.

IV. CONCLUSION

TC-10 continues to refine its existing standards and develop new ones. By policy, all IEEE standards are reviewed every ten years. In the course of these reviews, TC-10 clarifies terms and test methods, and adds new material, as requested and appropriate, to assist users. In addition, new standards are developed to address unmet needs. The TC-10 encourages fresh ideas and new perspectives. If you are interested in the TC-10's work and would like to join one or more of its subcommittees, please visit our home page at http://tc10.ieee-ims.org/tc10-home. Contact information for the subcommittee chairs can be found at this home page. We welcome your interest and participation.

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