XVI IMEKO World Congress
Measurement - Supports Science - Improves Technology - Protects Environment ... and Provides Employment - Now and in the Future
Vienna, AUSTRIA, 2000, September 25-28

IEEE 1241 VERSUS IEEE 1057: WHAT'S THE DIFFERENCE?

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Abstract. The new IEEE Std 1241, "Standard Terminology and Test Methods for Analog-to-Digital Conversions" (1241) is about to be released by IEEE for general use. It builds on IEEE Std 1057-1994, "Standard for Digitizing Waveform Recorders" (1057). 1057 has been used to date throughout the world for ADC testing in lieu of a general ADC standard. This paper discusses similarities between 1057 and 1241 and emphasizes important differences.

Keyword: IMEKO, World Congress, ADC, Digitizing Waveform Recorder, Pulse Techniques, IEEE Std 1057, IEEE Std 1241, IEEE Std 181, IEEE TC-10,

1 PURPOSE AND SCOPE

1241 was written to provide a basis for evaluating and comparing analog-to-digital converters (ADCs), as well as providing a template for writing ADC procurement specifications. It identifies ADC error sources and provides test methods with which to perform the required error measurements. 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) as discussed further in clause 1.3, 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 nonuniform quantization.

When IEEE Technical Committee 10 (TC-10) completed 1057 in 1994, it turned a majority of its attention to developing a new standard for ADCs. We realized that many people were using 1057 as a basis for testing ADCs, even though1057 was not ideally suited to testing ADCs. 1057 deals with instruments without regard to internal components, as suggested in Figure 1. The recorder's performance is assessed by applying signals to its input connector and observing digital data at its output connector. 1057 does not even presume that we have access to the sampling clock or that a physical ADC component is contained in the recorder. Waveform recorder testing is generally performed on a test bench and may require relatively long periods of testing (e.g., fractions of hours to several hours). Long duration tests, even in production, are affordable for instruments that cost thousands of dollars.

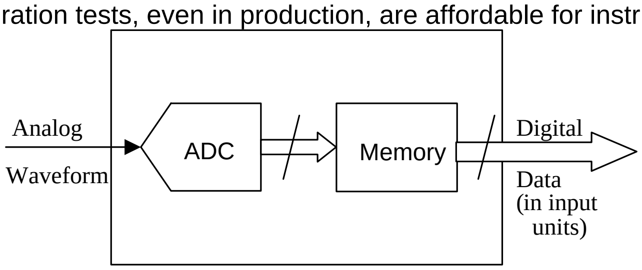

Figure 1. 1057 : Digitizing Waveform Recorder

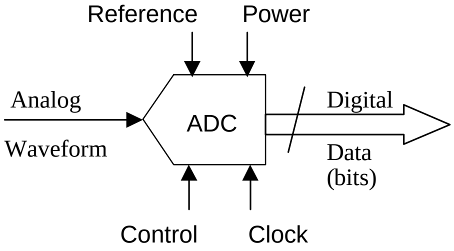

Figure 2. 1241 : Analog-to-Digital Converter (ADC)

In contrast, ADCs are components manufactured in high volume. Sophisticated ADCs may cost only a fraction of a dollar. Therefore, long duration, expensive testing is not affordable. In addition, we have complete access to all signal, clock, control, reference, power, and data pins of the ADC as shown in Figure 2. From several of the TC-10 members who were involved in ADC testing, we learned that ADC test methods generally differed from waveform recorder test methods. At the same time, we also recognized that many of the definitions and methods developed in 1057 certainly applied to ADCs. For example, 1057 makes extensive use of sine waves as precision input signals and sine-wave fitting to find errors. Fortunately, the convergence problems encountered by many users in four-parameter sine-wave fitting have been virtually eliminated by techniques developed by one of our members, Jerome Blair [Ref. 1], and translated into MATLAB by others [Ref. 2]. Discrete Fourier Transform (DFT) testing is the most prevalent technique used in the ADC manufacturing community. In 1241, DFT is used extensively for the extraction of frequency domain parameters because it provides numerous evaluation parameters from a single data record.

Our objective in writing 1241 was to tailor the applicable portions of 1057 to ADC testing and to develop others specifically for ADC testing. Our goal was to avoid arbitrary changes (i.e., change for the sake of change). Structurally, 1241 is very similar to 1057. Table 1 is the 1241 Table of Contents taken from the balloting draft of the standard. Note that the **clauses of 1241** have been cross-referenced to the ***clauses of 1057***. Most clauses appear in both standards, although the extent and content of the clauses may vary substantially. The remainder of this paper highlights noteworthy differences between 1241 and 1057.

Table 1. 1241 Table of Contents

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2 MAJOR 1241 DIFFERENCES

There are a number of notable differences between 1241 and 1057. Some of the differences stem from the fact that 1057 deals with instruments, while 1241 deals with components. Waveform recorders generally acquire data fast, then display and/or store the data slowly (i.e., fast-in/slow-out), while ADCs usually operate continuously in real time. Other differences are evolutionary: 1241 builds on 1057. Feedback on 1057 spurred development in 1241 to overcome shortcomings of 1057. Some specific differences are highlighted below.

2.1 Aimed for World-wide Users

Standard 1057 was written by IEEE members in the USA and Canada to address needs and issues perceived by TC-10. At that time, we had little exposure to thinking outside North America. From the beginning, 1241 was written to become an IEC standard accepted throughout the world. Since the ADC market is world wide, it is important that definitions have the same meaning throughout the world. This prompted us to attend meetings outside the USA. Working relationships were established through EUPAS with IEC and IMEKO working groups. Colleagues from Europe and the UK joined TC-10. EUPAS thoroughly critiqued an early draft of 1241. There was fruitful interaction with the DYNAD committee. One TC-10 member is currently reformatting 1241 into an IEC-acceptable format to begin its evolution toward becoming an IEC standard.

2.2 More Guidance

Both 1057 and 1241 are intended for use by graduate engineers (e.g., BSEE) who have little experience, special training, or advanced degrees. Some 1057 users have commented that it was hard to use. 1241 provides the user with more guidance in its application. The total number of errors and tests described in 1241 (or 1057) is daunting. It is most unlikely that any ADC and/or application will demand that all or even most of the tests be performed. 1241 contains a table (herein presented as Table 2) of common ADC applications. ADC parameters which are generally critical to each application are listed together with key performance issues. While the table contains only suggestions, we hope it will serve as a starting point for the user's test plan.

Table 2. Critical ADC parameters

Typical Applications	Critical ADC Parameters	Performance Issues
Audio	SINAD, THD	Power consumption. Crosstalk & gain matching.
Automatic control	Monotonicity Short-term settling, long-term stability	Transfer function. Crosstalk & gain matching. Temperature stability.
Digital oscilloscope/ Waveform recorder	SINAD Bandwidth Out-of-range Recovery Word error rate	SINAD for wide bandwidth amplitude resolution. Low thermal noise for repeatability. Bit error rate
Geophysical	THD, SINAD, long-term stability	Millihertz response.
Image processing	DNL, INL, SINAD Out-of-range recovery Full-scale step response	DNL for sharp-edge detection. High-resolution at switching rate. Recovery for blooming.
Radar & Sonar	SINAD, IMD SFDR Out-of-range recovery	SINAD and IMD for clutter cancellation and Doppler processing.
Spectrum analysis	SINAD SFDR	SINAD and SFDR for high linear dynamic range measurements.
Spread spectrum communication	SINAD, IMD SFDR, NPR Noise-to-distortion ratio	IMD for quantization of small signals in a strong interference environment. SFDR for spatial filtering. NPR for interchannel crosstalk.
Telecommunication Personal communications	SINAD, NPR, SFDR, IMD Bit error rate Word error rate	Wide input bandwidth channel bank. Interchannel crosstalk. Compression. Power consumption.
Video	DNL, SINAD, SFDR, DG, DP	Differential gain and phase errors. Frequency response.
Wideband digital receivers SIGINT, ELINT, COMINT	SFDR, IMD SINAD	Linear dynamic range for detection of low-level signals in a strong interference environment. Sampling frequency.

COMINT = communications intelligence
DNL = differential nonlinearity
ELINT = electronic intelligence
NPR = noise power ratio
INL = integral nonlinearity
DG = differential gain error

SIGINT = signal intelligence
SINAD = signal-to-noise and distortion ratio
THD = total harmonic distortion
IMD = intermodulation distortion
SFDR = spurious free dynamic range
DP = differential phase error

1241 also provides block diagrams of test setups where 1057 merely instructs the user to “arrange a network” or “connect an [instrument] to the input.” Three general setups are cited for most of the tests in 1241. For example, the setup for a sine-wave test is presented as Figure 3. The minimum, required elements and optional elements are presented. The need for optional elements depends on the nature and precision of the specified test. Block diagrams for specific methods are also provided. Figure 4 is a block diagram of a digital feedback loop method for locating code transitions.

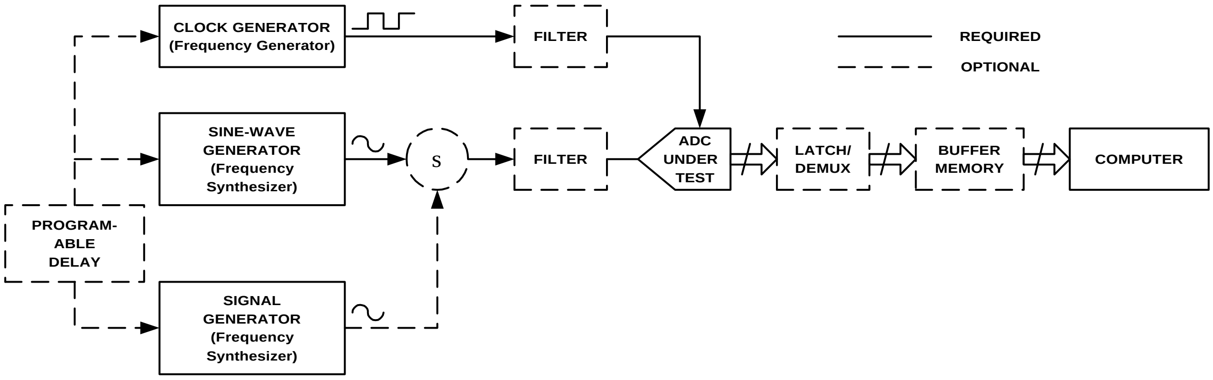

Figure 3. Setup for Sine-Wave Testing

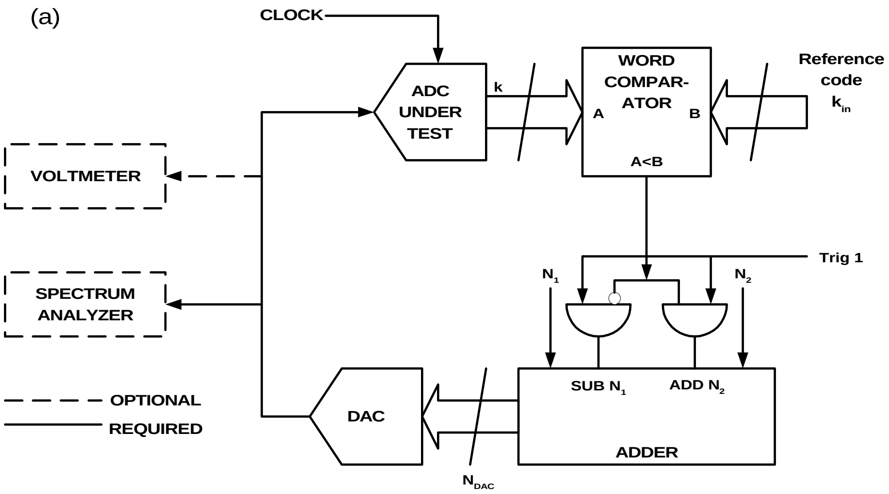

Figure 4. Block Diagram of Digital Feedback Loop Method for Locating Code Transitions

2.3 SINAD and SNHR

We discovered that various communities of users and manufacturers tended to assume different definitions for signal-to-noise ratio (SNR). Nine major categories of SNR definitions are listed in the New IEEE Standard Dictionary of Electrical and Electronic Terms (IEEE Std 100-1992). Most of the differences among these definitions involve the measure of signal and noise (e.g., peak, rms, amplitude, power). Within the ADC community, there is no single accepted definition of noise. In 1241, “noise” means “total noise,” which is defined as any deviation between the output signal (converted to input units) and the input signal, except deviations caused by linear time-invariant system response (gain and phase shift) or a DC level shift. For example, noise includes the effects of random errors, fixed pattern errors, nonlinearities, and aperture uncertainty. Notable examples of such effects and deviations here defined as noise include quantization error, harmonic and intermodulation distortion, and spurious distortion. Noise, or total noise, is distinguished from “random noise.” Random noise is a nondeterministic fluctuation in the output of an ADC, described by its frequency spectrum and its amplitude statistical properties, i.e., its power spectrum is flat (white noise), and its amplitude probability density function is stationary.

For clarity within 1241, two fundamental definitions of noise performance are used.

> **Signal-to-noise and distortion ratio (SINAD):** For a pure sine-wave input of specified amplitude and frequency, the ratio of the rms amplitude of the ADC output signal to the rms amplitude of the output noise, where noise is defined as total noise.
>
> **Signal to Non-Harmonic Ratio (SNHR):** For a pure sine-wave input of specified amplitude and frequency, the ratio of the rms amplitude of the ADC output signal to the rms amplitude of the output noise which is not harmonic distortion.

SINAD in 1241 is equivalent to SNR in 1057. SNHR in 1241 is equivalent to the definition of SNR used by many manufacturers and users. To avoid ambiguity, SNR is not used in 1241.

2.4 Emphasis on Frequency Domain Tests

Generally speaking, ADC manufacturers tend to use frequency-domain testing more than time-domain testing. In drafting 1241, TC-10 supplemented the tests presented in 1057 with alternate tests for the same errors. Often these were frequency domain tests. Also, more attention was devoted to errors observed in the frequency domain. For example, in 1057, the discussion of linearity includes differential nonlinearity (DNL), integral nonlinearity (INL), maximum static error (MSE), and total harmonic distortion (THD), in Clause 4.4. Hysteresis and monotonicity are covered in other clauses of 1057.

All of these errors are discussed in 1241 (except MSE). In addition, total spurious distortion (TSD), spurious free dynamic range (SFDR), and intermodulation distortion (IMD), and noise power ratio (NPR) are presented. Additional tests are also presented, such as the alternate method of determining INL for interleaved ADCs.

3 NEXT

Now that 1241 has been successfully balloted, we expect it to be published late in the year 2000. Next we hope to carry 1241 forward as a world-wide standard. At this time Dr. R. Allan Belcher is adapting 1241 to a format suitable for IEC standards. TC-10 will meet in conjunction with the International Test conference (ITC) during the first week of October 2000. Part of the ADC subcommittee’s meeting will be devoted to deciding what to do next. Possibilities for new work include a user’s guide, development of architecture-specific methods, and promoting 1241. Pasquale Arpaia is organizing a special session on 1241 for the IMTC in Budapest in May 2001.

In the meantime, 1057 is being revised. Digitizing Waveform Subcommittee Chairman Bill Boyer is leading the effort. Just as 1241 built on 1057, now 1057 will build on 1241. The subcommittee on Pulse Techniques (SCOPT), led by Chairman Otis Solomon, is revising IEEE Std 181 and IEEE Std 194. Revised pulse parameter definitions will be incorporated into 1057. In addition, work developed too late in the 1241 process to be included in this version of 1241 will be considered for the next version of 1057. Examples include work by Konrad Hejn [Ref.3] on an improved definition of ADC effective resolution, and by Fred Irons on faster, simpler means of finding bandwidth [Ref. 4]. If you know of work that we should consider for future inclusion in 1057 or 1241, please forward it to us.

4 SUMMARY

In this paper we have shown many of the differences between IEEE Std 1057-1994 and the soon to be published IEEE Std 1241. We hope you will use each of these standards in your daily work and suggest ways to improve either or both of these “**living**” standards. Please contact us through our websites, http://grouper.ieee.org/groups/1057/, and http://grouper.ieee.org/groups/1241/, and http://grouper.ieee.org/groups/181/.

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