SANDIA REPORT
SAND2007-5037
Unlimited Release
Printed July 2007

Test Definitions for the Evaluation of Digital Waveform Recorders

Version 1.0

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Test Definitions For the Evaluation of Digitizing Waveform Recorders

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Abstract

This Test Definition for the Evaluation of Digitizing Waveform Recorders (DWR) defines the process that can be performed as part of the evaluation and testing of geophysical sensors, digitizers, sensor sub-systems and geophysical station/array systems.

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INTRODUCTION

Scope

This Test Definition for the Evaluation of Digitizing Waveform Recorders (DWR) defines the process that can be performed as part of the evaluation and testing of geophysical sensors, digitizers, sensor sub-systems and geophysical station/array systems.

Background

A Digitizing Waveform Recorder can consist of a single channel element or multi-channel elements of geophysical digitizers/data acquisition systems. The DWR converts analog signals from the interfaced geophysical sensor(s) to a digital representation of this analog signal without introducing unacceptable distortions. It contains one or more High-Resolution Digitizers (HRD) to convert the analog signals to digital form. The digital samples are either stored on local recording media and/or sent to a central collection point for storage and/or analysis.

Objectives

The objectives are to (1) evaluate the overall technical performance of the DWR, measure the distortions introduced by the high resolution digitizers and provide a performance check of the internal calibrator if provided and (2) evaluate the technical performance of the DWR for a specific sensor application.

The results of these evaluations can be compared to the manufacturer's specifications and any relevant application requirements or specifications.

TEST AND EVALUATION PROGRAM

Test and Evaluation Background

Sandia National Laboratories (SNL) Ground-based Monitoring R&E Department has the capability of evaluating the performance of digitizing waveform recorders that utilize analog-to-digital converters/ high-resolution digitizers for geophysical applications.

Standardization/Traceability

Most tests are based on the Institute of Electrical and Electronics Engineers (IEEE) Standard 1057 [Reference 1] for Digitizing Waveform Recorders and Standard 1241 for Analog to Digital Converters [Reference 2]. The analyses based on these standards are performed in the frequency domain or time domain as required. When appropriate, instrumentation calibration is traceable to the National Institute for Standards Technology (NIST).

DWR Tests

The following set of tests has been developed to evaluate DWR performance.

DWRs with Internal Pre-amplifiers

DWRs may have internal preamplifiers. Some may have selectable-gain pre-amplifiers and some may have a fixed-gain preamplifier to match the sensitivity of an application sensor. Access to the internal HRD may or may not be available. If access to the internal HRD is not available, it may <u>**not**</u> be possible to perform all the General DWR Tests.

Some the internal preamplifiers may be intended to interface with a sensor with complex output impedance. This complex impedance may not be modeled easily and some tests may not predict the actual digitizer performance with sensor attached.

General DWR Tests

- Static Performance Tests
  - DC Accuracy Nominal (DWR-DCA)
  - DC Accuracy Full-Scale (DWR-DCFS)
  - DC Accuracy Over-Scale (DWR-DCOS)
  - AC Clip (DWR-ACC)
  - Input Terminated Noise (DWR-ITN)
  - Maximum Potential Dynamic Range (DWR-MPDR)
  - Bandwidth Limited Dynamic Range (DWR-BLDR)
- Tonal Dynamic Performance Tests
  - Total Harmonic Distortion (DWR-THD)
  - Crosstalk (DWR-CTK)
  - Common Mode Rejection Ratio (DWR-CMR)
- Broadband Dynamic Performance Tests
  - Relative Transfer Function (DWR-RTF)
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  - Modified Noise Power Ratio (DWR-MNPR)
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  - Step Calibrator Amplitude/Duration (DWR-SCA)
  - White-noise Calibrator Amplitude/Duration (DWR-WCA)
  - RBT Calibrator Amplitude/Duration (DWR-RCA)

DWR Seismic Sensor Application Tests

- Seismic System Static Performance Tests
  - DWR Seismic System Resolution (DWR-SSR)
  - DWR Seismic System Noise (DWR-SSN)

DWR Infrasound Sensor Application Tests

- Infrasound System Static Performance Tests
  - DWR Infrasound System Resolution (DWR-ISR)
  - DWR Infrasound System Noise (DWR-ISN)

Temperature Tests

High-resolution digitizers with resolution in the microvolt range can be affected by small temperature changes. A DWR may be required to operate over a range of environments from arctic to desert. Also, depending on the type of installation, the seasonal and diurnal variation can be significant. Tests can be performed at SNL to determine the DWRs sensitivity to temperature over a range from -65° C to +125° C.

Temperature testing can be performed at the high and low end of the manufacturer's temperature specifications or over the range for the application requirements. Unless otherwise specified, the temperature is changed slowly and the DWR internal temperature is allowed to stabilize before testing.

DWR TEST DEFINITIONS

General DWR Tests

Static Performance Tests

Static tests provide a constant or non time-varying stimulus to the DWR under evaluation. The purpose of these tests is to determine specific parameters such as: gain (accuracy at nominal, full-scale and over-scale), DC offset, short-term and long-term stability, relationship to quantizing noise floor, and correlated/uncorrelated spurious signals. The results of these tests include measurement of dynamic range and resolution.

DC Accuracy, Nominal (DWR-DCA)

Purpose: The purpose of the DC accuracy test is to determine and verify the accuracy of the DWR. The bit-weight (LSB) of a non-gain-ranged digitizer is its resolution.

Configuration: The DWR inputs are connected to a +/- DC voltage source, usually set to +/- 1 volt.

Evaluation: The DC gain (accuracy) of the DWR, DC offset, bit-weight (LSB)/resolution and counts/volt are measured.

DC Accuracy, Full-Scale (DWR-DCFS)

Purpose: The purpose of the DC full-scale test is to determine and verify the accuracy of the DWR at full-scale. The full-scale value is used in calculating Maximum Potential Dynamic Range (MPDR).

Configuration: The DWR inputs are connected to a +/- DC voltage source set to the manufacturers specification for full-scale.

Evaluation: The DC gain (accuracy) of the DWR, DC offset, bit-weight (LSB)/resolution and counts/volt at full-scale are measured.

DC Accuracy, Over-Scale (DWR-DCOS)

Purpose: The purpose of the DC over-scale test is to determine and verify the accuracy of the DWR at a specified value over full-scale.

Configuration: The DWR inputs are connected to a +/- DC voltage source set to the manufacturers specification for over-scale.

Evaluation: The DC gain (accuracy) of the DWR, DC offset, bit-weight (LSB)/resolution and counts/volt at over-scale are measured.

AC Clip (DWR-ACC)

Purpose: The purpose of the AC clip test is to determine and verify the maximum signal or clip level of the DWR.

Configuration: The DWR input is connected to an AC voltage source set to 1 Hertz. The amplitude of the sinusoid is increased until the value of hard clip is reached.

Evaluation: The AC clip voltage is measured.

Input Terminated Noise (DWR-ITN)

Purpose: The purpose of the input-terminated noise test is to verify the static parameters of the DWR. These static parameters are dominated primarily by the random noise generated within the digitizer (self-noise) and from other components within the digitizer package.

Configuration: The DWR inputs are terminated (typically 50-100 ohms).

Evaluation: A power density spectrum of the input-terminated noise provides a measure of the noise floor of the digitizer. RMS noise in the appropriate bandwidth, short term and long term stability, relationship to quantizing noise floor and correlated and uncorrelated spurious signals are measured.

Maximum-Potential Dynamic Range (DWR-MPDR)
Purpose: The purpose of the maximum-potential dynamic range test is to measure the "best case" signal-to-noise ratio capability of the DWR. This is the ratio of the largest signal that the DWR can measure without clipping (RMS of a full-scale sinusoid) to the rms noise of the DWR.

Configuration: The DWR inputs are terminated (typically 50 ohms) or the input-terminated noise (ITN) data set is used.

Evaluation: The Maximum Potential Dynamic Range (MPDR) of a DWR is determined by calculating the RMS value of a full-scale sinusoid and dividing by the RMS (standard deviation) of the Input Terminated Noise (ITN) test data.

Bandwidth-Limited Dynamic Range (DWR-BLDR)
Purpose: The purpose of the bandwidth-limited dynamic range test is to measure the "best case" signal-to-noise ratio capability of the DWR for a specified bandwidth. This is the ratio of the largest signal that the DWR can measure without clipping (RMS of a full-scale sinusoid) to the RMS noise of the DWR within a specified bandwidth.

Configuration: The DWR input-terminated noise (ITN) data set is used.

Evaluation: The bandwidth-limited dynamic range (BLDR) of a DWR is determined by calculating the RMS value of a full-scale sinusoid and dividing by the RMS of the Input Terminated Noise (ITN) test data taken over the specified bandwidth.

Tonal Dynamic Performance Tests

Dynamic tests are those that provide a time varying stimulus to the DWR under evaluation. The purpose of these tests is to determine the DWRs performance when digitizing time-varying signals. Multitudes of tests are available to determine the DWR digitizer's self noise, deviation from ideal performance and conversion distortions.

Tonal tests are dynamic tests that use sinusoids as stimuli. Sine waves are the most popular signals for evaluating analog-to-digital converter performance because of the ease of generation and mathematical analysis. The DWR under test is asynchronously sampled with respect to the signal source for all tonal tests.

Total Harmonic Distortion (DWR-THD)
Purpose: The purpose of the total harmonic distortion test is to verify the linearity and to identify sources of non-linearities of the DWR.

Configuration: The DWR inputs are connected to an ultra-low-distortion oscillator. The amplitude of the oscillator is set to greater than one-half full-scale of the DWR. The frequency of the oscillator is set to a frequency unrelated to the sample rate and with nine or more harmonics observable.

Evaluation: A power density spectrum provides a measure of the non-linearity of the DWR. THD is calculated by integrating the power density spectral peaks at the fundamental and all harmonics (up to nine) below the Nyquist frequency.

Crosstalk (DWR-CTK)
Purpose: The purpose of the crosstalk test is to determine the extent of crosstalk between channels on a multi-channel DWR.

Configuration: The DWR channel under test is terminated with 50 ohms. All other DWR inputs are connected to a large amplitude sinusoidal test signal.

Evaluation: A power density spectrum provides a measure of crosstalk. The ratio of test signal to crosstalk signal is calculated using integrated power density spectra around the test signal frequency.

Common-Mode Rejection Ratio (DWR-CMR)
Purpose: The purpose of the common mode rejection test is to determine the ability of the DWR to reject a common mode signal on differential inputs.

Configuration: The individual inputs of each channel of the DWR are connected to an isolated, large amplitude sinusoidal test signal. The test generator common is connected to the appropriate signal reference or signal common on the DWR.

Evaluation: A power density spectrum provides a measure of the un-rejected common-mode signal. The ratio of test signal to common-mode signal is the common-mode rejection ratio.

Broadband Dynamic Performance Tests

Dynamic tests are those that provide a time-varying stimulus to the DWR under evaluation. The purpose of these tests is to determine the DWR performance when digitizing time-varying signals. Multitudes of tests are available to determine the DWR digitizer's self noise, deviation from ideal performance and conversion distortions.

Broadband tests are dynamic tests that use Gaussian pseudo-random signal generators as stimuli.

Relative Transfer Function (DWR-RTF)
Purpose: The purpose of the relative transfer function test is to determine the relative gain, and phase between channels in a multi-channel DWR.

Configuration: The DWR inputs are connected to a bandwidth-limited Gaussian signal generator. The signal generator output amplitude is set to greater than one-half the full-scale range of the DWR.

Evaluation: Coherence analysis computation provides a measure of relative gain, and relative phase. Channel to channel time skew is calculated.

Analog Bandwidth (DWR-ABW)
Purpose: The purpose of the analog bandwidth test is to verify the bandwidth of the DWR analog/digital filter.

Configuration: The DWR inputs are connected to a bandwidth-limited Gaussian signal generator.

Evaluation: A power density spectrum provides a measure of the DWR bandwidth. The 3 dB point and relative attenuation at the Nyquist are measured.

Modified Noise Power Ratio (DWR-MNPR)
Purpose: The purpose of the modified noise-power-ratio test is to determine the DWR performance compared to n-bit ideal digitizers. This test determines the performance of the DWR at all amplitudes from small signal to clip level.

Configuration: The DWR inputs are connected to a bandwidth-limited Gaussian signal generator. The bandwidth of the signal generator is set to avoid aliasing the DWR and to maximize the power within the DWR passband. The signal generator output is varied from a low level to past the DWR clip level.

Evaluation: Coherence analysis computation provides a noise-power-ratio value for each level of input signal to the DWR. (Note that if the relative phase between the DWR channels is significant, it must be corrected to zero.) These estimated noise power ratios are compared to the performance model of n-bit ideal digitizers.

Broadband Signal-to-Noise Ratio (DWR-BSNR)
Purpose: The purpose of the broadband signal-to-noise ratio is to determine the maximum broadband dynamic range of a DWR. This test also provides the Large-Signal Noise (LSN) floor of the DWR. This is a relevant test for geophysical applications as signals are more approximated by Gaussian broadband signals than by sinusoids.

Configuration: The DWR inputs are connected to a bandwidth-limited Gaussian signal generator. The bandwidth of the signal generator is set to avoid aliasing the DWR and to maximize the power within the DWR passband. The signal generator output amplitude is set to approximately the full scale of the DWR inputs without clipping.

Evaluation: Coherence analysis computation provides a signal-to-noise ratio for each pair of digitizer channels. This Broadband SNR is an indication of the maximum broadband dynamic range of the DWR. Coherence analysis noise-power computation provides the signal-induced Large-Signal Noise (LSN) floor of the DWR for a full-scale broadband noise signal.

Broadband Large-Signal Noise Floor (DWR-BLNF)
Purpose: The purpose of the large-signal noise-floor test is to determine the DWR noise floor in the presence of a full-scale broadband signal.

Configuration: The DWR inputs are connected to a bandwidth-limited Gaussian signal generator. The signal generator output amplitude is set to the full scale of the DWR inputs without clipping.

Evaluation: Coherence analysis noise-power computation provides the signal-induced noise-floor of the DWR for a full-scale broadband noise signal.

Timing Tests

Geophysical digitizing waveform recorders utilize a Universal Time Code (UTC) source, typically GPS, to time-tag the digitizer data samples. The DWR internal clock is usually synchronized to or phase-locked to this UTC receiver. The following timing tests determine the accuracy of this time-tag, sample rate verification, the response of the DWR to UTC loss and power cycling, and the short-term stability of the DWR time base.

Time-Tag Accuracy (DWR-TTA)
Purpose: The purpose of the time-tag accuracy test is to verify the ability of the DWR to accurately time-tag the data samples with respect to the DWR inputs.

Configuration: The DWR inputs are connected to a 1 Pulse per Minute (PPM) or 1 Pulse Per Hour (PPH) output of an independent running GPS Timing Reference.

Evaluation: The time-tags of the data from the DWR are analyzed for correct time on the hour and minute transitions. DWR sample rate (samples per second/minute) is verified.

Time-Tag Accuracy Drift (DWR-TTD)
Purpose: The purpose of the time-tag accuracy drift test is to verify the ability of the DWR to accurately time-tag the data samples with respect to GPS receiver variations.

Configuration: The DWR input is connected to a 1 PPM output of an independent running GPS Timing Reference. The DWR GPS receiver is allowed to stabilize. Data are collected over an extended time-period. During this period, the GPS antenna is covered to "hide the sky" for approximately one hour and then uncovered. Data are acquired during the GPS recovery and re-lock period.

Evaluation: The time-tags of the data from the DWR are analyzed for correct time on the minute transitions while stable and during GPS interruptions.

Calibrator Performance Tests

Digitizing Waveform Recorders frequently include a programmable voltage or current calibrator source to calibrate the internal DWR or drive a sensor calibration input. The calibrator may generate sinusoidal, step, white/pink noise, random binary telegraph (RBT) or a combination of these. The calibrator performance can be tested to determine parameters such as amplitude accuracy, frequency/duration, and distortion.

Sine-Calibrator Amplitude (DWR-CAT)
Purpose: The purpose of the calibrator amplitude test is to determine and verify if the DWR accurately programs the correct amplitude for sensor calibrations.

Configuration: The DWR calibrator output is connected to a signal source measurement system. The amplitude and frequency of the DWR calibrator are set to known levels.

Evaluation: Measured amplitudes are compared to the programmed amplitudes.

Sine-Calibrator Frequency (DWR-CFT)
Purpose: The purpose of the calibrator frequency test is to determine and verify if the DWR accurately programs the correct frequency for sensor calibrations.

Configuration: The DWR Calibrator output is connected to a frequency counter. The calibrator is programmed through its range of frequencies.

Evaluation: Measured frequencies are compared to the programmed frequencies.

Sine-Calibrator THD (DWR-CHD)
Purpose: The purpose of the calibrator THD test is to determine and verify the linearity of the sensor calibration generator.

Configuration: The DWR calibrator output is connected to a signal source measurement system. The amplitude and frequency of the DWR calibrator are set to known levels.

Evaluation: A power density spectrum provides a measure of the linearity of the calibrator. THD is computed.

Calibrator Loopback THD (DWR-CLB)
Purpose: The purpose of the calibrator loop back THD test is to determine and verify the linearity of the sensor calibration generator using the DWR.

Configuration: The DWR calibrator output is looped back to the DWR input. The amplitude and frequency of the DWR calibrator are set to known levels.

Evaluation: A power density spectrum provides a measure of the linearity of the calibrator. THD is computed. The THD using the DWR should be the same as the CHD test.

Step-Calibrator Amplitude/Duration (DWR-SCA)
Purpose: The purpose of the step calibrator amplitude/duration test is to determine and verify if the DWR accurately programs the correct amplitude and duration for sensor calibrations.

Configuration: The DWR calibrator output is connected to a signal source measurement system. The amplitude and duration of the DWR calibrator are set to known levels.

Evaluation: Measured amplitudes and duration are compared to the programmed amplitudes/duration.

White-Noise-Calibrator Amplitude/Duration (DWR-WCA)
Purpose: The purpose of the white-noise amplitude/duration test is to determine and verify if the DWR accurately programs the correct amplitude and duration for sensor calibrations.

Configuration: The DWR calibrator output is connected to a signal source measurement system. The amplitude and duration of the DWR calibrator are set to known levels.

Evaluation: Measured amplitudes and duration are compared to the programmed amplitudes/duration.

Random-Binary-Calibrator Amplitude/Duration (DWR-RCA)
Purpose: The purpose of the RBC amplitude/duration test is to determine and verify if the DWR accurately programs the correct amplitude and duration for sensor calibrations.

Configuration: The DWR calibrator output is connected to a signal source measurement system. The amplitude and duration of the DWR calibrator are set to known levels.

Evaluation: Measured amplitudes and duration are compared to the programmed amplitudes/duration.

DWR Seismic Sensor Application Tests

Sensor application tests are those that provide a stimulus to the DWR or interpret data from the DWR that is related to a specific sensor application. The DWR selected for an application should match the characteristics of the interfaced sensor and the expected sensor signals and background. Seismic applications can use all of the available bandwidth when interfaced to broadband seismic sensors or just a part of the available bandwidth when interfaced to long-period or short-period seismic sensors. The choice of system parameters is partially determined by the background that is expected at the location of the sensor. A properly matched DWR/sensor can resolve the expected seismic signals and backgrounds while nearly maximizing the system dynamic range.

DWR Seismic System Resolution (DWR-SSR)

Purpose: The purpose of the seismic signal resolution test is to determine the ability of the DWR to resolve small seismic signals using a specific seismometer. The theoretical minimum level of ground motion that the DWR can sense is determined by its bit-weight (LSB). This is the Calib value.

Configuration: Use the bit-weight as determined by the DC Accuracy (DCA) test. If a sensor preamplifier has been installed, rerun the DCA test using an appropriate DC voltage source.

Evaluation: For a specific sensor application, convert the bit-weight of the DWR to ground motion using the application seismometer response mathematical model and determine the Calib value at the frequency of interest (typically nM/count @1Hz).

DWR Seismic System Noise (DWR-SSN)

Purpose: The purpose of the seismic system noise test is to determine ability of the DWR to resolve the expected seismic background using a specific seismometer. The DWR self-noise should be below the expected seismic background and the self-noise of the seismometer.

Configuration: The DWR inputs are terminated with the equivalent output impedance of the application sensor. For typical active sensors this is 50-100 ohms. For complex impedance sensors, a range of values may be appropriate.

Evaluation: For a specific sensor application, convert the system noise of the DWR to ground motion using the application seismometer response mathematical model. The result of this computation can be overlaid with the USGS Low Earth Noise Model or a site specific seismic background to demonstrate the ability of the DWR to resolve the local seismic background.

DWR Infrasound Sensor Application Tests

Sensor application tests are those that provide a stimulus to the DWR or interpret data from the DWR that is related to a specific sensor application. The DWR selected for an application should match the characteristics of the interfaced sensor and the expected sensor signals and background. Infrasound applications can use all of the available bandwidth when interfaced to infrasound sensors. The choice of system parameters is partially determined by the background that is expected at the location of the sensor. A properly matched DWR/sensor can resolve the expected infrasound signals and backgrounds while nearly maximizing the system dynamic range.

DWR Infrasound System Resolution (DWR-ISR)

Purpose: The purpose of the infrasound signal resolution test is to determine the ability of the DWR to resolve small infrasound signals using a specific infrasound sensor. The theoretical minimum level of infrasound pressure that the DWR can sense is determined by its bit-weight (LSB). This is the Calib value.

Configuration: Use the bit-weight as determined by the DC Accuracy (DCA) test. If a sensor preamplifier has been installed, rerun the DCA test using an appropriate DC voltage source.

Evaluation: For a specific sensor application, convert the bit-weight of the DWR to infrasound pressure using the application sensor response mathematical model and determine the Calib value at the frequency of interest (typically Pa/count @1Hz).

DWR Infrasound System Noise (DWR-ISN)
Purpose: The purpose of the infrasound system noise test is to determine the ability of the DWR to resolve the expected infrasound background using a specific infrasound sensor. The DWR self-noise should be below the expected infrasound background and the self-noise of the infrasound sensor.

Configuration: The DWR inputs are terminated with the equivalent output impedance of the application sensor.

Evaluation: For a specific sensor application, convert the system noise of the DWR to pressure using the application infrasound sensor response mathematical model. The result of this computation can be overlaid with an infrasound background noise model to determine the ability of the DWR to resolve the expected infrasound background.

SIGNAL SOURCE PERFORMANCE VERIFICATION

The performance of the signal sources used for DWR evaluation need to be verified independently from the DWR under test. For most tests, a Hewlett Packard HP3458A Multi-meter/ Precision DC Voltmeter can be used as a Secondary Standard or signal source measurement system.

The HP3458A can be calibrated for linearity at SNL using a Josephson Junction Array as a Primary Standard (Calibration Procedure JV-A1). Using this procedure, traceability to National Institute for Standards Technology (NIST) is provided. Existing HP3458As have been calibrated to .032 parts per million (PPM) linearity (150 dB) and .5 PPM accuracy (0.00005 %)

REFERENCES

1. IEEE Standard for Digitizing Waveform Recorders, IEEE Std. 1057-1994.

2. IEEE Standard for Analog to Digital Converters, IEEE Std. 1241-2001.

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