CRYSTAL
instruments

Define and Measure Dynamic Range

Introduction

One of the breakthrough features of the CoCo-80, Spider-80X, and Spider-81 is their outstanding dynamic range performance of 150 dBFS. This kind of performance has never before been achieved with such small, portable, and low cost devices. The main advantage of this high dynamic range is that it eliminates the need to adjust the input gain/range settings on the front end, thus simplifying the setup and measurement process. Both full scale 10 volt signals and very small microvolt signals are measured at the same time with no adjustments. This capability makes setup and testing more simplified in comparison with an instrument capable of only a lower dynamic range. This document describes the concept of dynamic range, the different methods used to assess it, and how Crystal Instruments assesses dynamic range of the instruments.

Dynamic range is one of the critical performance specifications of a dynamic measurement system. If the dynamic range is too low, large signals will typically be clipped and distorted, while small signals are buried in system noise. This noise is inherent in the electronics associated with transducer elements and transducer signal conditionings. Maximizing dynamic range is paramount in instrumentation design, so that both small and the large signals are measured accurately.

Understanding dynamic range is complicated by the fact that different vendors describe and measure it differently. This is understandable because there is no universally accepted technical definition. Instead, dynamic range is loosely defined as _the ratio between the largest and smallest signal a system can accurately measure at the same time_. There are several issues with this vague definition:

1. What does the "same time" mean? Do we compare the small signal on top of a large signal to the large signal, or a small signal to a large signal that is present at the same time record but at different periods?
2. What does _the "largest signal"_ mean? There are three commonly used measures of the largest signal and they each have a place.
   a. Peak-to-Peak or Full-Scale Range. This value is the difference between the two most extreme signals.
   b. Zero-to-Peak. This value is the difference between the mid-value and the maximum value;
   c. RMS Full-scale. This is the root-mean-square value of the largest possible sine wave signal (=0.707 x its peak amplitude)
3. What does the "_smallest signal_" mean? Does this refer to noise? Does it only include a fixed band-limited range, or the full analysis band? This is important because the measured RMS noise level will depend on the bandwidth over which it is measured.

In order to understand a dynamic range specification you must understand these issues and know how the manufacturer measures the dynamic range so that you can compare one device to another.

Full-Scale Dynamic Range (dBFS)

In Crystal Instruments' tests of the CoCo-80 and Spider systems, we apply one of the most commonly used definitions, dBFS, Full Scale Dynamic Range, measured in dB. This is the ratio between the maximum measurement range peak to peak (V_{FS}) and the RMS value of the system base noise (V_N) given in dB. V_N is usually measured with the input channel terminated so that a standard non-floating ground condition exists.

$$dBFS = 20 * Log\left(\frac{V_{FS}}{V_N}\right)$$

For a data acquisition system, the dBFS is a frequency dependent variable. The wider the frequency range the instrument uses, the smaller the dBFS. This is because the noise typically has a flat characteristic in its power spectral distribution. Therefore the more of the spectrum that is included in the RMS calculation the larger the V_N becomes. Consequently, the dBFS of the measurement is artificially improved by reducing the measurement bandwidth.

The dBFS is measured in either the time domain or the frequency domain with each giving different values. Time domain dBFS compares the noise signal summed over some broad range of frequencies in the RMS calculation. Frequency domain dBFS compares the noise signal energy at a specific frequency point. If the system noise has a flat spectrum then the frequency based dBFS reports a lower value for V_N and therefore a higher dBFS.

dBFS Measured in Time Domain Measurement

Figure 1 shows a long time domain capture with a sampling rate of 1 kHz. Initially a full-scale sine wave with ±10 V amplitude was fed into the CoCo-80. While the acquisition was in progress, the input was disconnected and terminated. Therefore the second half of this time capture shown below was measured only the system noise.

Using software to observe the noise signal, the RMS reading is 1.81 µV. Therefore the dynamic range is computed as:

$$dBFS = 20 * Log\left(\frac{10Vpk}{1.81\mu V}\right) = 134.846\,dB$$
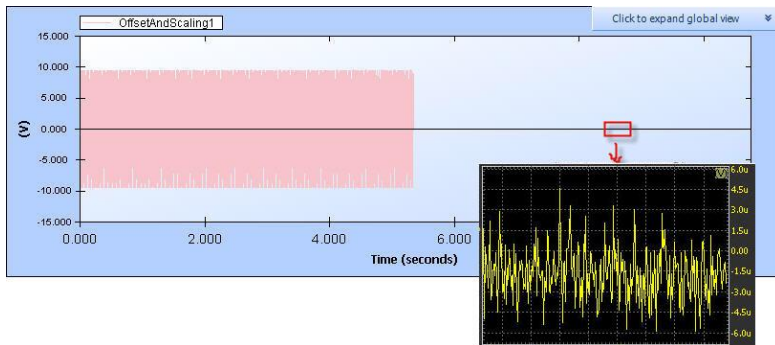

Figure 1: Long waveform capture with a zoom-in view to the noise in time domain

The test above is repeated for different sampling frequencies and the dBFS values are measured as:

Sampling Rate	102.4 kHz	51.2 kHz	12.8 kHz	1 kHz	100 Hz
dBFS	120.44 dB	130.12 dB	129.08 dB	134.85 dB	145.37 dB
Noise RMS	9.50 µV	3.12 µV	3.51 µV	1.81 µV	0.54 µV

dBFS Measured in Frequency Domain Measurement

The previous table shows that the dBFS depends on the sampling rate or sampling frequency. This leads us to investigate the noise floor characteristics of the instrument in the frequency domain. In the frequency domain, we can use the auto power spectral measurement and scale the display as dBFS. Since the CoCo-80 full scale input range is 10 V_{pk}, scaling the display to dBFS means that a sine-wave with the amplitude of 10 V_{pk} will show a peak with a magnitude of 0 dB.
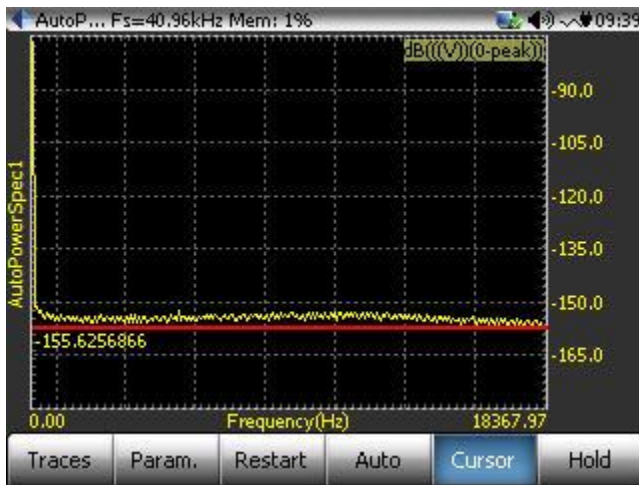
Figure 2: dBFS display for the noise floor in the FFT mode

Using a 50 Ω terminator connected to the input channel, Figure 2 shows the noise floor to the instrument is below -150 dB. This measurement is conducted by 4,096 point FFT and 64 spectral averaging to the auto power spectra. This means that with this instrument we can measure a small sine wave signal with amplitude as low 1 µV and claim the dynamic range as 150 dB!
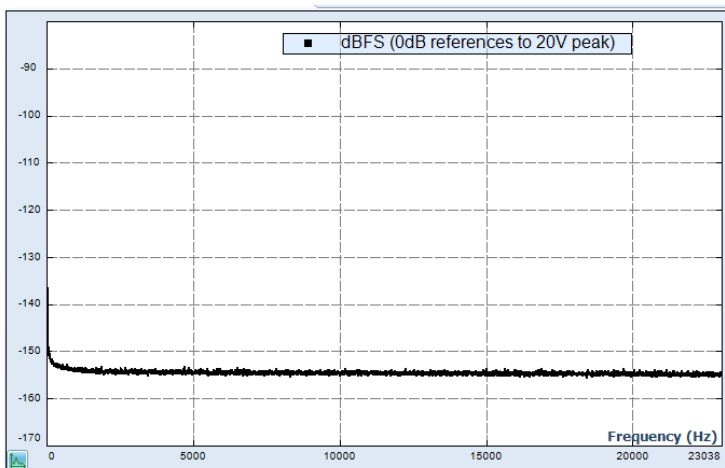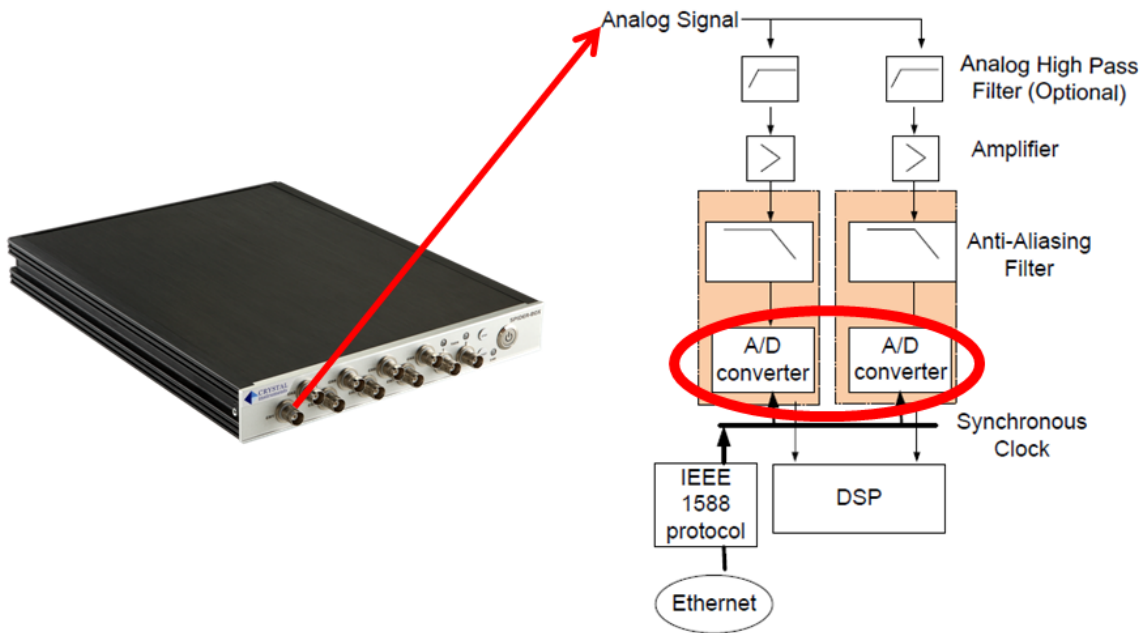

Figure 3: dBFS display for the noise floor in the FFT mode of Spiders

Notice that dBFS provides better numbers of dynamic range in the frequency domain than in time domain because in the frequency domain, a full scale sine wave is compared against the "floor" of the noise instead of the summation of the noise. The second reason is that spectral averaging reduces the variance of the noise spectrum estimation. In the time domain a 1 µV sine wave would be completely buried in the noise while in the frequency domain it is still visible after the averaging.

To conclude, dynamic range is a loose term and the numerical value will vary depending on which method was used to make the measurement. The CoCo-80 provides a dynamic range defined by the dBFS term with a value of 130 dB for the time based dBFS; or 150 dB for the frequency based dBFS.

How do CI products achieve such high dynamic range?

Crystal Instruments achieves its very high dynamic range for all its measurement instruments by using a unique patented technology that uses two A/D converters in each measurement channel.

This unique technology uses two A/D converters per measurement channel. During the period of data acquisition, the time streams from both A/D converters are forwarded into the digital processor. The digital processor will pick the appropriate ones.

With such high dynamic range of each input, the gain settings (voltage range settings) are very much eliminated.

Crystal Instruments was awarded a United States patent for this invention.

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(12) **United States Patent**

Zhuge

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(54) **CROSS-PATH CALIBRATION FOR DATA ACQUISITION USING MULTIPLE DIGITIZING PATHS**

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See application file for complete search history.

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(57) **ABSTRACT**

The present invention utilizes multiple A/D (analog-to-digital) paths and cross-path calibration to provide accurate and reliable measurements for each input channel in a data acquisition system. When the system and method are applied, user and automated methods of selecting among a number of alternative input range settings can be reduced, or even eliminated. That is, there is a significant reduction or complete elimination of input range settings in a measurement system. For each measurement channel of interest, the input signal is directed to at least two paths, e.g., Path A and Path B. The first path measures the full range (e.g., +/−10 volts), while the second path includes a high-gain amplifier.