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Measurement setup with dual channel simultaneous sampling A/D converter - uncertainty of jitter estimation

***Abstract**. Dual channel sampling measurement methods for calculating such parameters as power, phase angle or impedance are highly affected by the jitter of the A/D converter. Thus it is necessary to determine this parameter in the validation procedure of a particular measurement method using chosen set of analog to digital converters or data acquisition card. The article discuses analysis results and practical findings based on research carried out.*

***Streszczenie.** W dwukanałowych pomiarach próbkujących duży wpływ na niepewność wyznaczenia wielkości takich jak moc, kąt fazowy, czy impedancja, może wywierać szum fazowy (jitter) układu próbkowania. Wyznaczenie jego wartości jest zatem niezbędnym krokiem przy walidacji danej metody pomiarowej z zastosowaniem wybranego zestawu (karty) przetworników analogowo-cyfrowych. Referat przedstawia wyniki analizy i praktyczne wnioski z przeprowadzonych badań. (**Niepewność oszacowania szumu fazowego w dwukanałowym układzie pomiarowym z przetwornikami A/C**)*

Keywords: dual channel analog-digital conversion, jitter, phase noise.
Słowa kluczowe: dwukanałowe przetwarzanie analogowo-cyfrowe, jitter, szum fazowy.

Introduction

A large impact on the uncertainty of power, phase angle, impedance in the two-channel sampling measurements can have a jitter [1-10]. Determination of its value is therefore an essential step in the validation of the measurement methods using the selected high-resolution, analog-digital I/O board. The articles present the methods to determine jitter but there is small focus on uncertainty of the estimated value of the jitter, e.g. [2-4]. Although jitter is the result of mathematical operations on the samples obtained with the error many times greater than the estimated jitter. The jitter, or aperture uncertainty, in digitizers, is a random variation in the instant of sampling. An uncertainty on the instant of sampling, denoted mainly as timing jitter (or simply jitter), or as aperture uncertainty, or even as phase noise, is treated as strongly defined parameter. One can imagine that jitter may be measured as single parameter. In contrast to that different methods give different results. So the problem is in jitter taxonomy. From "the sampling circuit is usually the dominant source of error and logic gate-delay jitter creates an aperture time uncertainty" [1] to "numerous methodologies have been proposed and discussed, since jitter performance still is one of the most challenging issues in state-of-the-art sampled systems" [5] and now, we have not in common use proper validation methods of sampling systems in respect of jitter effect. The authors take advantage of the two existing double-channel techniques [2-4] and analyzes the uncertainty obtainable with the exemplary instrumentation. The first step of autors' investigation was presented in [10]. This paper comprises the results of following experiments and practical conclusions.

The considered methods

The two methods used the double-beat technique based on a dual-channel system we investigate in our work:

1) the method according to [2] we call cycle to cycle method,
2) the method according to [3,4] we call undersampling method.

Both methods require coherent sampling and at least a hundred of signal cycles in averaging. The double-beat technique depends on such operation - once the acquisition of all samples is complete, the second period is substracted from the first one, point to point. Such results are obtained from repeated measurements for internal triggering and averaging. This action eliminates systematic errors such as differential non linearities and quantization noise. Non-coherent noises are quadratically added.

The well known equation for coherent sampling is

$$f_{in} = \frac{M}{N} f_s \quad (1)$$

where: f_s - sample frequency, f_{in} - test signal frequency, N - number of samples taken (N must be an integer), M - number of signal cycles over which samples are taken (M must be an integer).

To provide a simple discrimination principle, an approach based on timing jitter sources correlation was successfully developed by Y. Langard *at al.* [2]. In cycle to cycle method relatively prime *N* and *M* assures unique sample points. When taking samples of a sine wave over more than one period, it is possible to sample at the same place on the wave only in a different signal period. The cycle to cycle method is based on the possibility of simultaneously measuring the jitter of two converter channels driven by the same clock source. The number of samples *N* must be in accordance with the Shannon-Nyquist criterion that takes into consideration the highest frequency from the spectrum of the processed signal. In many professional digital measuring instruments it takes values of 16, 32, 64 or 128 samples.

R. Rosing *at al.* presents an improved technique [3, 4] based on Y. Langard *at al.* proposals [2] for measuring aperture jitter using an off-chip measurement platform. This new version uses the concept of apparent frequency and the under-sampling principle. Referring to equation (1), note that *N* samples may be taken from a waveform over *M* test signal periods. If $M = 1$, all samples are taken in a single test signal period. If $M > 1$, the samples are spread over more than one test signal period. The total time required to take all samples is called the *Unit Test Period* (UTP) and requires *M* cycles of the test signal, which has frequency f_{in}. A Unit Test Period (UTP) is defined as the time required taking all samples and is given by

$$UTP = \frac{M}{f_{in}} = \frac{N}{f_s} \quad (2)$$

A test can be performed that captures two UTPs. This test captures 2*N* samples over 2*M* periods of the input signal, where *M* and *N* are relatively prime. In such a test the set of output values obtained from the second UTP is essentially equal to the set of values obtained from the first UTP. This is a form of coherent testing in which $M = N + 1$. In the under-sampling method, the ratio between the input and the sampling frequencies is chosen so as to acquire two beat periods with the same initial phase, i.e.,

(3) $$\frac{f_s}{f_{in}} = \frac{N}{N+1}$$

The systematic errors are eliminated by subtracting the second period from the first one. Assuming input signal generator is ideal (jitter is near 0); the method gives aperture jitter + internal clock jitter. Therefore if the clock signal has some jitter, this technique measures the sum of the aperture, the input and the clock jitter, instead of measuring aperture jitter separated from other jitters. A disadvantage of the under-sampling method is that the sample frequency has to be N/N+1 times the input frequency, which puts high quality demands to the clock generator in the digitizer.

The results of the consecutive subtractions in both above methods is the amplitude of noise Δv which is equal to the jitter Δt modulated by the slew rate of the input signal

(4) $$\Delta v = \frac{dv}{dt}\Delta t$$

Input signal

(5) $$v(t) = V_m \sin(2\pi f_{in} t + \varphi)$$

After differentiation

(6) $$\Delta v = 2\pi f V_m \cos(2\pi f t + \varphi)\Delta t$$

For conceptual clarity, if we relabeled Δv as V_{err} and Δt as J (jitter) and rearrange the factors, we get

(7) $$J = \frac{V_{err}}{2\pi f V_m \cos(2\pi f_{in} t + \varphi)}$$

and

(8) $$J_{\max} = \frac{V_{err(\max)}}{2\pi f_{in} V_m}$$

It should be noted that total jitter $J_{\max}$ in equation (8) is the root-sum-square (rss) value of the generator output jitter and the internal digitizer clock jitter (called aperture jitter).

Measurement set-up

Measurement set-up consists of Keithley 194A, dual channel 16-bit high speed sampling voltmeter and Hewlett Packard 33120A function generator serving as a signal source (jitter ≤ 25 ns). Both inputs of the voltmeter are connected in parallel to the signal output of the function generator. In addition there is a trigger line used to initiate signal generation. This line is stimulated by the voltmeter. The measurement system includes PC running Virtual Instrument, which controls, over the GPIB bus both voltmeter and generator (fig. 1).

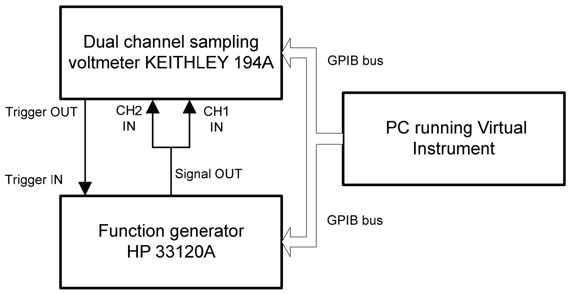


Fig. 1. Measurement circuit scheme

By means of the application of the Virtual Instrument, written in LabVIEW one can set parameters of both the measurement devices. For the voltmeter, the configurable parameters are: voltage ranges of two channels set independently, number of samples, sampling frequency and trigger mode. Voltage ranges are set in the way, so that the amplitude of the input signal covers the full scale of the voltmeter A/D converters in both channels. Sampling frequency is determined based on the frequency of the input signal and the requirement of: 8, 16, 32, 64 and 128 samples per a single period. Trigger mode of the sampling voltmeter is programmed with the fulfillment of the simultaneous initiation of acquisition for both voltmeter channels requirement. In that case input signal acquisition starts concurrently in both channels and is carried out in the same conditions. As far as the generator is concerned, it is programmed to work in burst mode, so that each generation triggered (voltmeter Trigger OUT line is used) results in periodic signal (sine, triangle or square) of a constant amplitude, frequency, phase and defined number of periods. Configured parameters guarantee reproducible signal shape for each measurement iteration. What is more, generated signal duration time is accordant, longer than the one of the acquisition sequence. That satisfies signal presence during acquisition process.

A single acquiring iteration starts from parameters setting for the voltmeter and generator used in measurement circuit (fig. 1). Trigger mode of the voltmeter is programmed to wait for GET command on the GPIB bus. As it appears, the voltmeter in turn, triggers (Trigger OUT line in fig. 1) the generator action and by itself starts the two channel simultaneous acquisition of the input signal, connected in parallel to the both inputs of the device. After that acquired data buffer is sent to the personal computer and saved to the mass storage, which ends a single iteration. The measurements were repeated in series, for the narrow number of samples possible to acquire by the voltmeter in a single iteration and on the other side, the demand for relatively extensive data set.

Data processing of the acquired signal, namely determining the period to period and channel to channel differences was calculated in Matlab and Excel environments.

Discussion of the results

We carried out the investigation at constant input signal amplitude (3,1V) and constant resolution (16 bit, 100 μV) by varying the parameters which values can be found in Table I. The analysis is performed in the time-domain.

For all measured values, the standard deviations were calculated and averaged data are reported in figure 2 and figure 3. An estimate of the standard deviation is given by classic calculation formula. The obtained results show that these deviations are much higher than the main signal. It is so because double-beat technique does not separate jitter from additive noise.

We present the results for one set of the difference voltage Δv that we judge were the most representative in selecting the right number of samples in a cycle (fig. 4). Differences between channels are similar and they are averaged for both methods.

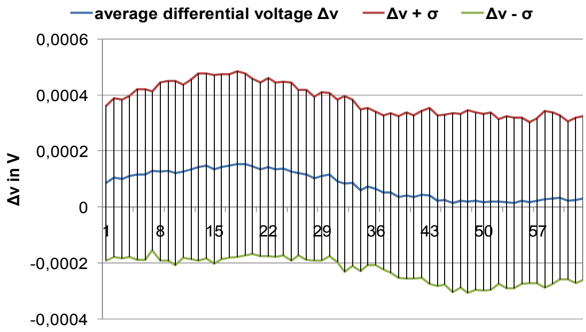
The jitter obtained for two methods under investigation can be shown in figure 5. The values of the jitter suggest the presence of big systematic difference between the two methods.

If we compare both this graphs it is obvious that jitter values obtained in the under-sampling method are approximately 4,5 times greater than in the cycle to cycle method. And it is regardless of input waveform frequency selection or number of samples in one cycle. Observed growth have multiplicative property, so it is systematic suitability of jitter phenomenon. The long-term jitter fundamentally must be greater than the cycle-to-cycle jitter because it is made of the same components. The matter is how much greater? This growth illustrates the basic fact that under-sampling methods have fundamental limitations with respect to their ability to process wide dynamic range signals.

Table 1 The values of the input signal and sampling frequencies used in the investigation

Signal frequency	Sampling frequency for different number of samples per one period (cycle to cycle meth./undersampling meth.)			
	16	32	64	128
78,125 Hz	1250 Hz/73,529 Hz	2500 Hz/75,758 Hz	5000 Hz/76,923 Hz	10000 Hz/77,519 Hz
156,25 Hz	2500 Hz/147,059 Hz	5000 Hz/151,515 Hz	10000 Hz/153,846 Hz	20000 Hz/155,039 Hz
312,5 Hz	5000 Hz/294,118 Hz	10000 Hz/303,030 Hz	20000 Hz/307.692 Hz	40000 Hz/310,078 Hz

a)



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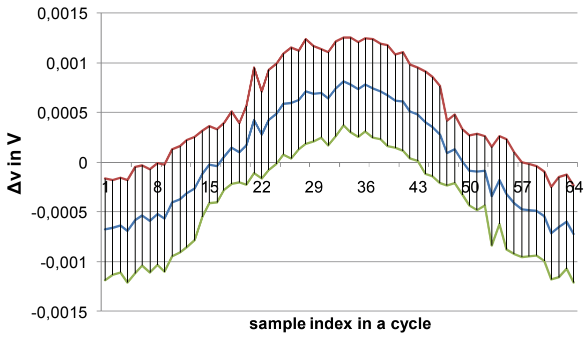
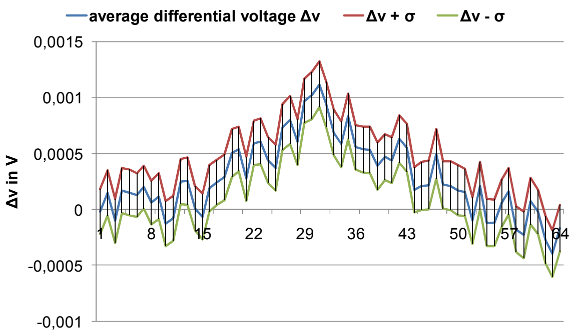


Fig. 2. Standard deviations associated with the determination of mean value of the differential voltage *Δv* (averaged for both channels) in function of sample index (number of samples = 64) for (a) cycle-to-cycle method (σ_{avg}=0,3 mV) & (b) undersampling method (σ_{avg}=0,5 mV);
σ – standard deviation.

a)



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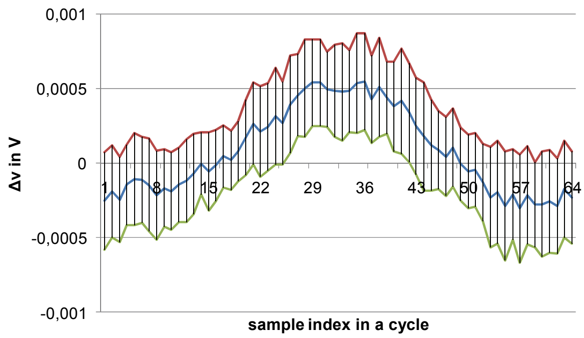
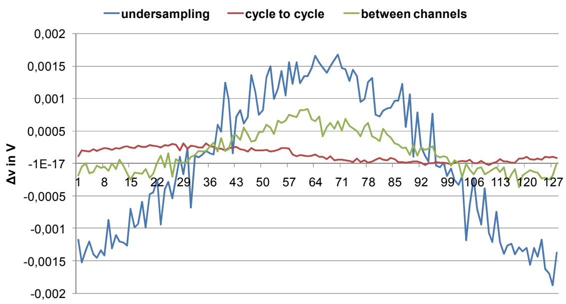
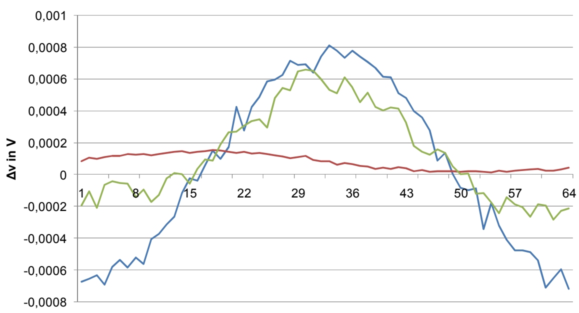


Fig. 3. Standard deviations associated with the determination of mean value of the differential voltage *Δv* between channels in function of sample index (number of samples = 64) for (a) cycle-to-cycle method (σ_{avg}=0,2 mV) & (b) undersampling method (σ_{avg}=0,3 mV); σ – standard deviation.





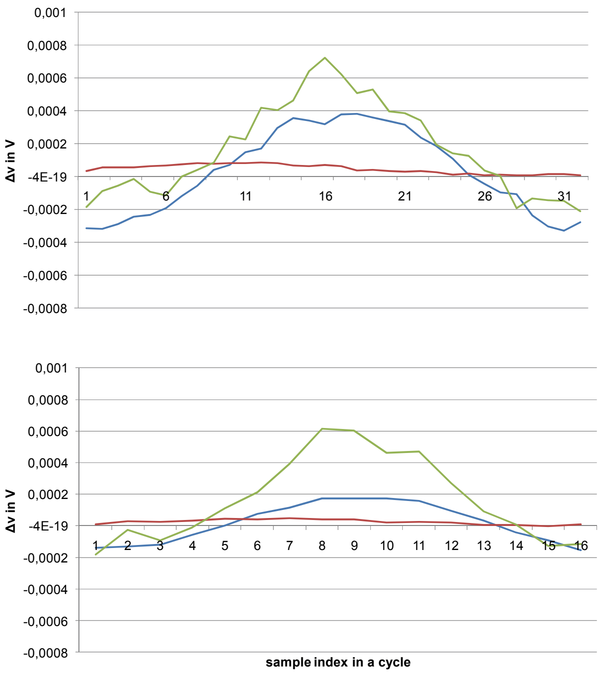


Fig. 4. Averaged results of the difference *Δv* (all input signal frequencies) for selected different numbers of samples per one cycle (defined in Table 1)

a)

b)

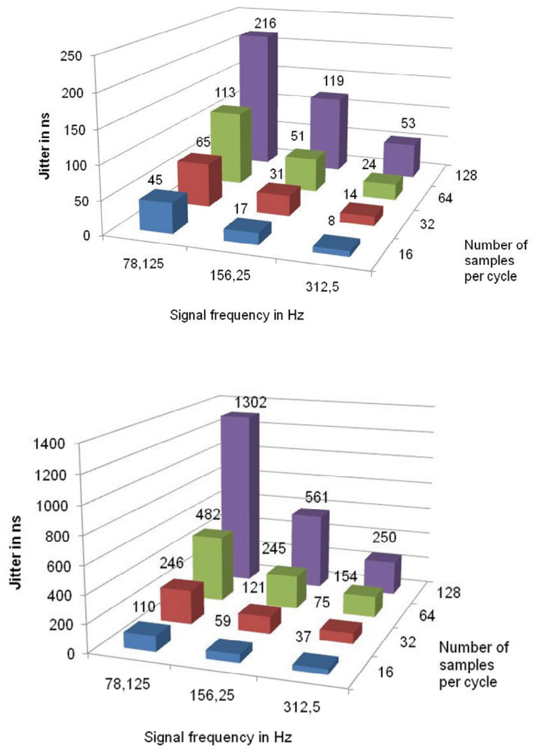


Fig. 5. Jitter acquired by (a) cycle-to-cycle method and (b) undersampling method - averaged for both channels

Conclusions

The presented results show that the double-beat technique based on a dual-channel system may be useful in various measurement method validations when using sampling processes.

How high the sampling frequency will be better for input signal, it is often decided by process of measurement method validation with respect to jitter.

When using measurement method with under-sampling technique we should take into account long term jitter obtained by under-sampling method. In sampling methods fulfilled the Shannon-Nyquist criterion short term jitter obtained by cycle-to-cycle method can be more effective.

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