Frequency Spectrum Correction Test – Practical Experience

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Abstract – The main problem of the high resolution ADC testing within the frequency range hundreds of kHz to several MHz is the spectral purity of a testing signal. Commercially produced low-distortion generators have the spectral purity sufficient for testing of 16 bits ADCs only up to frequencies of tens of kHz; at higher frequencies the spectral purity of generators is generally worse. Some improvement can bring signal filtering. However, most of the LC filters use coils with ferromagnetic cores for the frequency range up to several hundreds of kHz, which can cause a rise of odd harmonic components. Nevertheless, these components can be measured and subtracted from the spectrum calculated from ADC output data. In the ideal case, only the frequency spectrum corresponding to the ADC non-linearity remains. An ADC measurement system was designed and built for the verification of this method in the frequency range 200 kHz to 1 MHz. The practical experience of its application is described in this paper.
Keywords: ADC testing, frequency spectrum correction, phase spectrum, FFT

I. Measurement method and system description

The method uses the testing signal filtering. It applies LC filters and the following digital correction of residual harmonic components. It demands an exact determination of these components and their subtraction from the frequency spectrum calculated from the digital output of the tested ADCs or AD modules (ADMs). This operation must be done in the complex form (as vectors), because the phases of higher harmonic components are not defined and have to be computed as well as the amplitudes. So, in the ideal case, the frequency spectrum corresponding to dynamic parameters of the ADC remains. More detailed description can be found in [1] and [2].

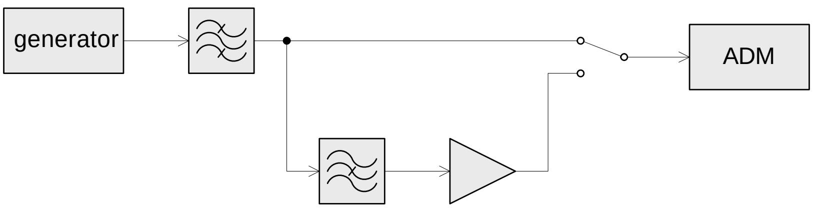


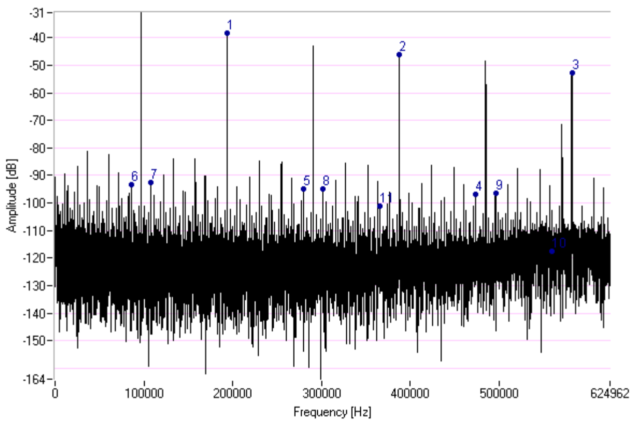
Figure 1. Block diagram of the testing system

The system displayed in the Figure 1 was used for the application of the designed method. The signal produced by a common generator is filtered using the simple pass band filter based on coils with ferromagnetic cores. The filtered testing signal, which is distorted by odd harmonic components, but nearly free of other disturbance, is connected to the input of a tested ADM. The stop band filter suppresses the fundamental in the filtered testing signal; thus it increases the resolution of higher harmonic components' measurement, which is necessary for achievement of sufficient accuracy of the frequency spectrum calculation. The signal amplitude on the stop band filter output is optimised for the ADM input range by the preamplifier. In this case, the tested ADM can be used also for the digitalisation of this signal and no other device is necessary.

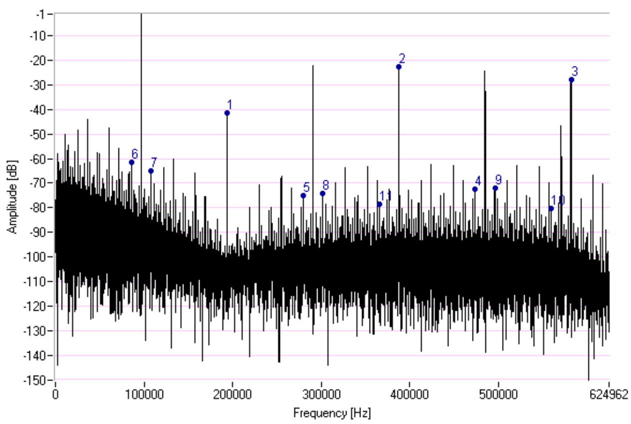
A. Identification of stop band filter characteristics

Since the frequency spectrum of a testing signal is determined from the sampled signal modified by both the stop band filter and the amplifier, so their characteristics have to be considered. They can be measured e.g. in the frequency domain. Only several separate frequencies – those corresponding to higher harmonic components – have to be determined. Other frequencies (spurious components) are not important because their amplitude is negligible due to application of the pass band filtering.

Two ways of higher harmonic components‘ determination were applied. First, that uses a signal containing the fundamental and one harmonic component, which was gained from the sum circuit supplied by two synchronised generators. Second, that uses a simple saw signal. This signal contains all harmonic components with sufficiently high amplitudes, which is advantageous for the implementation. Amplitudes of first several harmonic components and the phase differences between higher harmonic components and the fundamental were measured at the filter input and output. Their differences correspond to the transfer parameters of the filter measured at the frequencies of harmonic components. An example of the results of the correction coefficients’ measurement using saw signal is displayed in the Figure 2 and in the Table 1.



a) at the filter’s input



b) at the filter’s output

Figure 2. Amplitude spectra of a saw signal at the input and output of stop band filter with amplifier

Table 1. Correction for the stop band filter with amplifier using a saw signal

		at the input		**at the output**		**correction**	
harmonic component	frequency (Hz)	amplitude (dBfs)	rel. phase (rad)	amplitude (dBfs)	rel. phase (rad)	amplitude (dBfs)	rel. phase (rad)
1	194015.50	–38.41	0.000	–41.54	0.000	–3.13	0.000
2	387992.86	–46.00	–1.254	–22.48	–1.842	23.52	–0.588
3	582008.36	–52.62	–2.440	–28.03	0.984	24.59	–2.859
4	474014.28	–96.83	–0.175	–72.58	–1.946	24.25	–1.771
5	279998.78	–94.88	0.064	–74.97	–2.674	19.91	–2.738
6	85983.28	–93.18	0.303	–61.58	0.628	31.60	0.325
7	107994.08	–92.74	–2.155	–64.84	–2.112	27.90	0.043
8	302009.58	–94.80	2.860	–74.06	3.038	20.74	0.178

The notch filter and the amplifier were considered to be only one part of the system for this measurement. The digitalisation of input and output signals was performed by the tested ADM using the same input range. The harmonic components were rather low; despite of this fact they were much higher than the noise. Half of the required basic frequency was used because of the generator's frequency limitation. This fact does not influence results, only the needed harmonics have to be correctly signed.

The main problem appeared by the spectral lines' determination of both in-phase and quadrature components. As usual in the most applications, all mentioned signals have been sampled non-coherently. Therefore a leakage appeared in the frequency spectrum computed by common FFT algorithm. The rectangular window (no leakage elimination) was used for the first experiments concerning the phase differences determination. Results were not always correct – side lobes of this window are high and they influence neighbouring amplitude spectrum. The leakage is often suppressed by Blackman-Harris 7 term window in the ADC testing up to 16 bits. However, this window was designed for the amplitude frequency spectrum and its influence on the phase spectrum is not usually taken into account (the detailed analysis of this problem was not found in currently accessible publications - see [5]). Thus, an algorithm of phase differences determination using Blackman-Harris 7 term window was theoretically derived and then successfully applied. This algorithm was implemented into the software Digester developed for the ADC testing; the phase differences are computed automatically there.

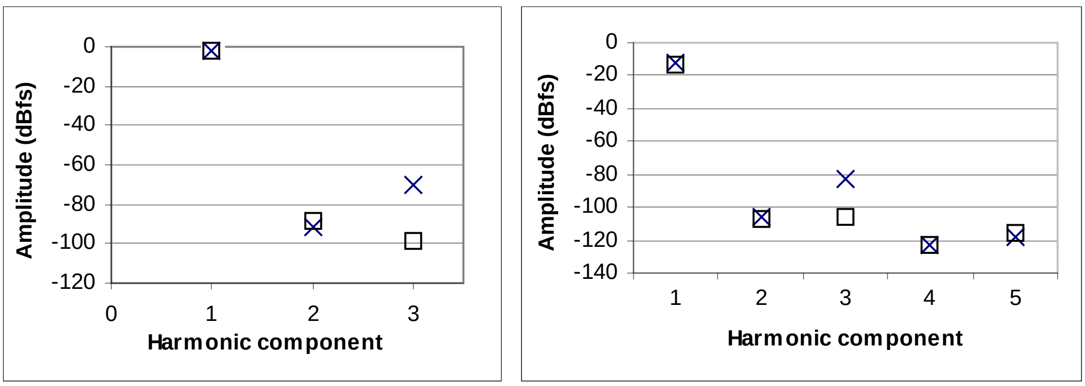
II. Results

Two experiments using testing signal with frequency 194 kHz and 1 MHz were executed. The frequency of 194 kHz was chosen because it corresponds to the highest frequency generated by low distortion generators, which are commercially produced. The frequency about 1 MHz corresponds to the central frequency of special high quality filters developed at the Dept. of Measurement. A common low-cost LC filter was designed and built for this frequency, too, so that the comparison measurement could be executed.

A. Experiments for the frequency of the testing signal of 194 kHz

Measurements at this frequency were performed with AD Transfer Standard 2 (ADTS2, see [3], [4]) using two ADC 16 bit evaluation kits: Σ-Δ ADC AD7723 and SAR AD977A. The results are presented in the Figure 3.

Firstly, the frequency spectrum correction method was tested with the Σ-Δ ADC AD7723 evaluation kit using the sampling frequency of 1 250 kSa/s. The simple pass band and stop band filters applying coils with ferromagnetic cores were used for the frequency of the testing signal of 194 kHz. The correction about 20 dB of the third harmonic component was reached whilst the second harmonic component was even about 3 dB higher after the correction. It confirmed the theory – the ADC error vector of the second harmonic component can partially compensate the corresponding component (vector) of the testing signal in this case (see [2] in detail). It occurs when the testing signal vector has the opposite direction than the ADC error vector at the specific frequency.



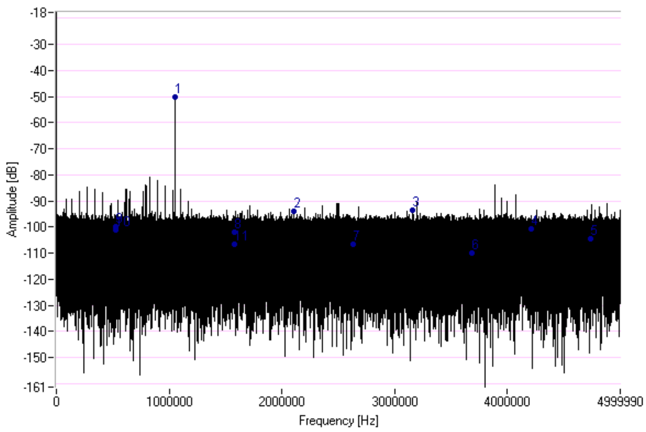
a) Σ-Δ ADC AD7723 b) SAR ADC AD977A

Figure 3. Higher harmonic components' correction (× before correction, □ after correction)

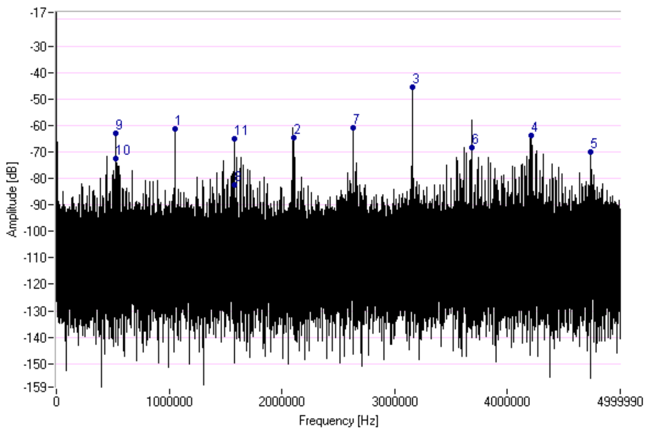
Secondly, the evaluation kit SAR ADC AD977A was applied. It operated at the sampling frequency of 187 kHz (oversampling). This evaluation kit contains an antialiasing filter, which causes the attenuation of higher harmonic components. Therefore the frequency characteristic of this filter had to be measured and compensated (the same way of the frequency characteristic measurement as by the stop band filter was used). The correction of the third harmonic component about 10 dB was reached. However, the accuracy of the correction was lower than for the ADM AD7723, because higher harmonic components were suppressed by the antialiasing filter by the measurement of the frequency spectrum of testing signal (the higher harmonic components approached to the noise level).

B. Experiments for frequency of testing signal about 1 MHz

The VXI digitizer HP E1430A was used in this case as the tested ADM. The testing signal with frequency of 1053 kHz was sampled by the frequency of 10 MHz. Two LC filters were available: a common pass band filter using coils with ferromagnetic cores (Q = 21) and a high quality pass band filter based on air coils wounded on teflon tubes (Q = 35, linearity near ideal). The frequency spectra of filtered signal (after 110 dB suppression of the fundamental by high-quality stop band filter) are shown in the Figure 4. Whilst at the signal, filtered by the common pass band filter, the 3rd harmonic component reached about – 95 dB and the others about – 110 dB, all higher harmonic components were negligible at the signal filtered by the high-quality pass band filter.



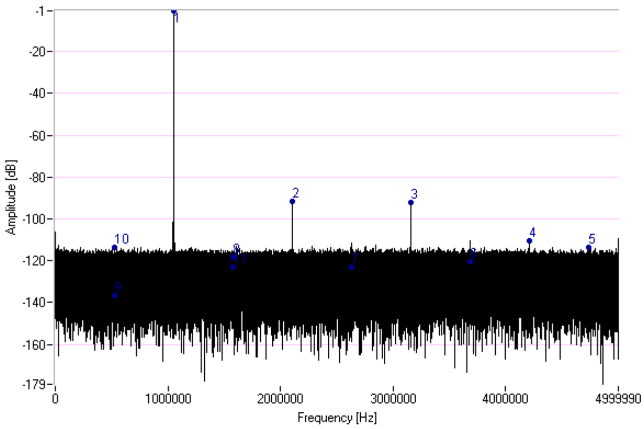
a) high quality pass band filter



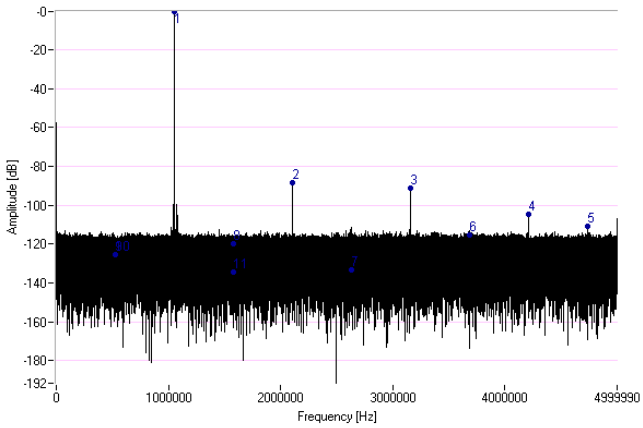
b) common pass band filter

Figure 4. Frequency spectra of filtered signal measured without antialiasing filter (fundamental harmonic suppressed by 110 dB by the stop band filter)

Both signals were used for the ADM testing to compare the result achieved by near ideal testing signal and the result obtained by application of the spectrum correction test. The frequency spectra calculated from the output data of tested ADM (VXI digitizer) are shown in the Figure 5. Even thought the quality of the signal filtered by the pass band filter based on air coils was evincible better (see above), both frequency spectra were very similar. It can be assumed that the non-linearity of the ADM caused a greater distortion then the distortion of both testing signals. A common (cheap) LC filter is evidently sufficient for the testing signal filtering in this case (ADM with ENOB < 12 bits) and no additional correction is needed. Nevertheless, this correction would be necessary for the testing of ADMs with higher ENOB.



a) high quality pass band filter



b) common pass band filter

Figure 5. Frequency spectra calculated from the output data of the tested ADM

III. Conclusion

The results proved the applicability of the frequency spectrum correction test. The experiments showed some problems concerning the application of this method and possibilities of their solving. It could allow to replace expensive high quality filters (which have to be applied in order to get a spectral pure testing signal for the frequencies higher then several tens of kHz) by designed method for testing the digitisers with ENOB higher than 12 bits in the frequency range up to several MHz. (Unfortunately, no better digitiser then HP E1430A is at disposal at the Dept. of Measurement of CTU-FEE now to verify it.) In the further research a more extensive verification and an uncertainty analysis of this method are planned.

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References

[1] Pokorny M., Haasz V.: "Alternative Methods of A/D Conversion Quality Verification". IMTC/99 Proceedings, Venice, May 1999, pp. 1421-1424

[2] Haasz V., Slepicka D.: "Frequency spectrum correction method for the ADC testing". IMTC 2004 – Instrumentation and Measurement Technology Conference, Como, Italy 2004, pp. 671-674.

[3] Haasz V., Roztocil J., Slepicka D.: "Evaluation of ADC Testing Systems Using ADC Transfer Standard". IMTC 2003 – Instrumentation and Measurement Technology Conference, Vail, CO, USA 2003, pp. 1340-1344.

[4] Fischer J., Haasz V., Slepicka D., Vedral J.: "Transportable Reference AD Device – New Innovated Version". XVII IMEKO World Congress, Dubrovnik 2003, pp. 768-773.

[5] Slepicka D.: "Phase Differences Determination between the Fundamental and Higher Harmonic Components at Non-coherent Sampling". IMEKO TC4 Symposium, Athens 2004