Dynamic Nonlinearity at Undersampling, Fast ADC

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Abstract - In the undersampling applications the quality of sample-and-hold circuit is cardinal. The beat frequency and envelope tests made with identical input signal and identical form of output data may determine the errors given by SAH. The increased power of higher (from 10th to 50th) harmonics terms was the most significant marker of SAH imperfections in our measurement of AD6644.

Keywords - Dynamic errors; harmonic distortions; sample-and-hold imperfections

I. INTRODUCTION

In some areas (nuclear magnetic resonance tomography and spectroscopy; radar; communication) the high dynamic range and high frequency range systems are needed. The very fast ADC's (fs over 100 MHz) have a limited dynamic range and the digital down converters have limited maximal input sampling rate; that is why it is very useful to do some part of frequency conversion by undersampling. In this case the dynamic errors of ADC corresponding to high carrier frequency are essential. They may be divided into two groups: the errors originated by the jitter [1-3] and the errors originated by the dynamic non-linearity [4-6]. Errors originated by the dynamic non-linearity may be at fast ADC divided to three sub-groups according to dependence on input signal and on origin of errors:

a) Errors that depend on input signal frequency and amplitude only. The main source of these errors is the input preamplifier (its frequency response and limited slew rate).

b) Errors that depend on the sampling frequency only. With higher sampling frequency the power dissipation increases and if some coupling between power supply and analog part exists, the ENOB decreases at maximal sampling frequency.

c) Errors that depend on the ratio of input signal frequency and sampling frequency. The main source is the dynamic non-linearity of the sample-and-hold circuit (SAH).

The ADC tests should provide the most stressful condition and analyze independently on the contribution of different dynamic non-linearity. In the case of undersampling applications the beat frequency and envelope tests are very useful and enable to determine the significance of different sources of errors.

II. THEORY

Both tests have been used for many years [4]. The beat frequency test supposes that the input signal frequency is chosen to be a multiple of the sample frequency plus a small incremental frequency. The period of incremental frequency should correspond to acquisition time. In this test the minimal differences between successive samples exist and the minimal influence of SAH occurs. The envelope test supposes the input frequency to be an odd multiple of one-half of sampling frequency plus a small incremental frequency. In this test the maximal differences between successive samples exist and the maximal influence of SAH imperfection occurs.

To preserve the most stressful conditions, the input signal amplitude should be full scale. The advantages of the tests occur if the acquisition time is sufficiently long to have more samples at each ADC code and if both tests are used with the same input signal.

Beat frequency test: Minimal influence of SAH; full influence of preamplifier occurs on output data. The output amplitude is decreased by the frequency response of preamplifier. The limited slew rate of the preamplifier distorts the output signal. If the fitted sinusoid is subtracted from the data, the distortion may be seen and also the un-symmetry of slew rate can be analyzed. The jitter noise is maximal round the zero level of the acquired data and minimal round the maximal/minimal amplitude of the sinusoid – this corresponds to slew rate of the sampled point. So if the low frequency components are filtered out from the data and the acquisition time is sufficiently long, we may analyze the noise contribution given by jitter from a time dependency of noise.

Envelope test: The same influence as at beat frequency test together with maximal influence of SAH. The influence of SAH is most significant in the data with maximal amplitude. It may manifest as harmonic distortion, noise or even as decreasing of amplitude.

Identical data at both tests: The identical data at both tests and so the identical basic influence of ADC is achieved if:

a) The input signal is identical at both tests.
b) The sampling frequency at envelope test is two times the sampling frequency at beat frequency test.
c) The data at envelope test are decimated by two after measurement.

In this case the basic error signals corresponding to ADC, input signal and aliasing are equal at both tests and the difference between data is given only by imperfection of SAH and possible coupling between analog and digital part that may depend on sampling frequency.

III. MEASUREMENT

We measured the two-channel acquisition system with two AD6644 (Analog Devices, 14 bits, fs up to 66 MHz). Sampling frequency were 30 and 60 MHz, the coherent input signal was 90.03 MHz. The basic period of measured data was 1000 samples (it was limited by FIFO). The basic data set represents 1000 periods, every measurement was repeated 10 times and more levels of input amplitude were used (from FS-1 dB to FS –5 dB). The dynamic range (channel 1 and 2) was 134.5 and 135.3 dBFS/√Hz at sampling frequency 30 MHz and 137.9 and 137.7 dBFS/√Hz at sampling frequency 60 MHz. Corresponding jitter of sampling signal was 1.3 ps (30 MHz) and 1.2 ps (60 MHz). Different data processing was used.

IV. RESULTS

According to histogram test, there are no missing codes, and no significant differences exist between histograms with 30 or 60 MHz sampling frequency. Maximal DNL are 0.9 LSB. The analysis of different noise levels in time domain was not possible owing to small size of basic period.

Harmonic distortion: The amplitude and the phase of low harmonic terms as a function of input amplitude were measured. In Fig. 1 the reproducibility of measurement is demonstrated. Clusters correspond to different input amplitude (from –1 dBFS to –5 dBFS). Marks '*' correspond to channel 1, marks '+' to channel 2. The amplitude and phase of harmonics terms were also analyzed as a function of input amplitude; the results correspond to [7].

The differences between measurements with sampling frequency 60 MHz and 30 MHz are in Fig. 2-4. The differences between complex low harmonic terms (harmonic terms with 60 MHz minus harmonic terms with 30 MHz) are in Fig 2. The amplitudes of higher harmonic terms at 30 and 60 MHz are in Fig. 3. The mean powers of harmonic terms (from 10th to 40th; from 40th to 70th and from 70th to 100th) as a function of input amplitude are in Fig. 4.

V. DISCUSSION

The beat frequency and envelope tests made with identical conditions represents the powerful possibility how to test the dynamic errors of SAH. The identical input signal at both tests preserves the same influence of input signal imperfection and the same influence of many ADC's errors. The same aliasing is given by the equal format of output data. So the differences in data at both tests are given by SAH and by coupling between analog and digital part only. In our case the coupling between analog and digital part is insignificant, it was tested by measurement of noise. The jitter of sampling signal was lower at 60 MHz than at 30 MHz. So we can suppose that differences in our data are the pure influence of SAH.

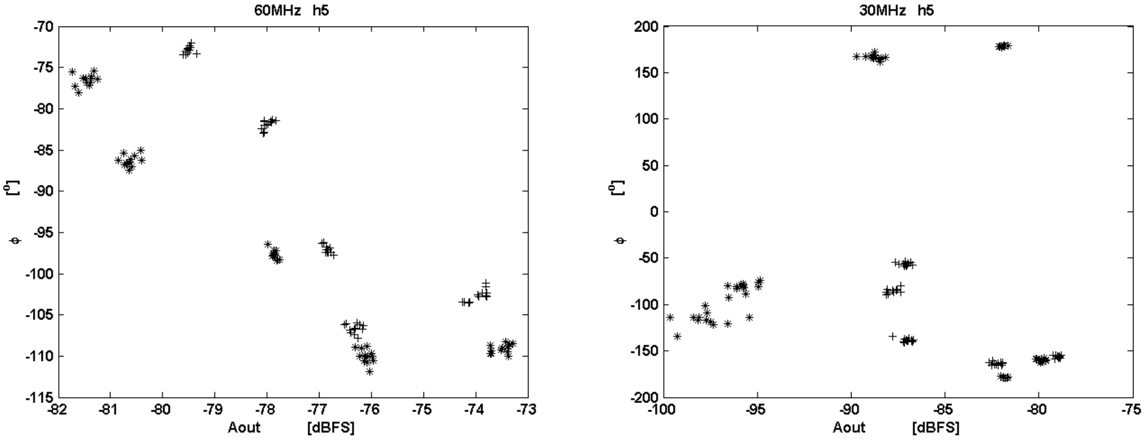


Fig. 1. The reproducibility and different behavior according to sampling frequency, the fifth harmonic term. Marks '+' the first channel; marks '*' the second channel. Clusters correspond to different levels of input signal amplitudes

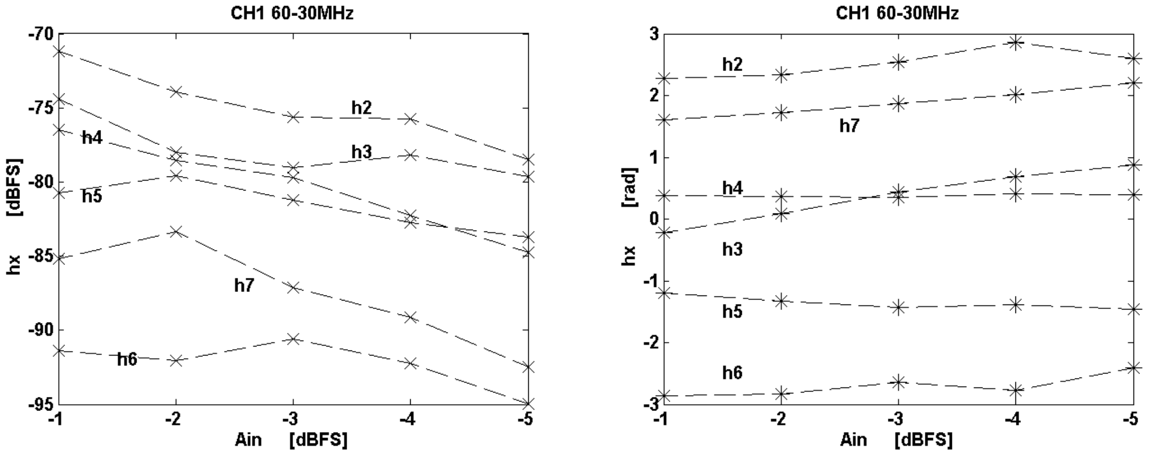
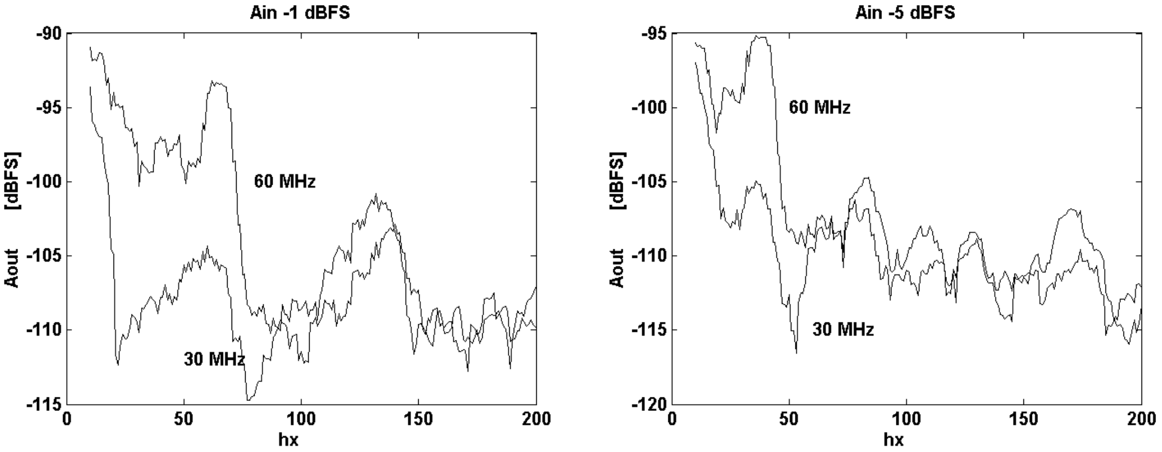
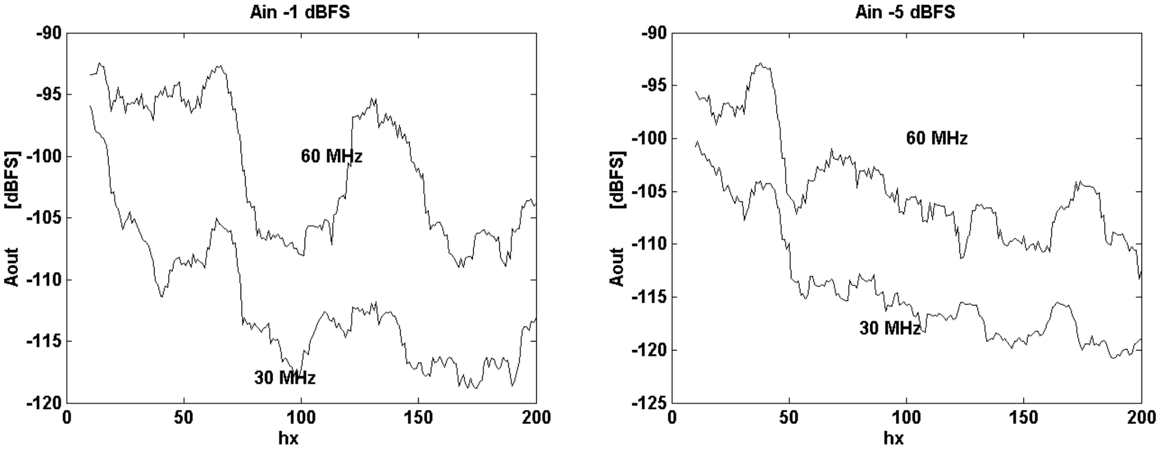


Fig. 2. The complex low harmonic terms at 60 MHz minus harmonic terms at 30 MHz. Channel 1.



a) Channel 1.



b) Channel 2.

Fig. 3. The power of high order harmonics terms (hx).

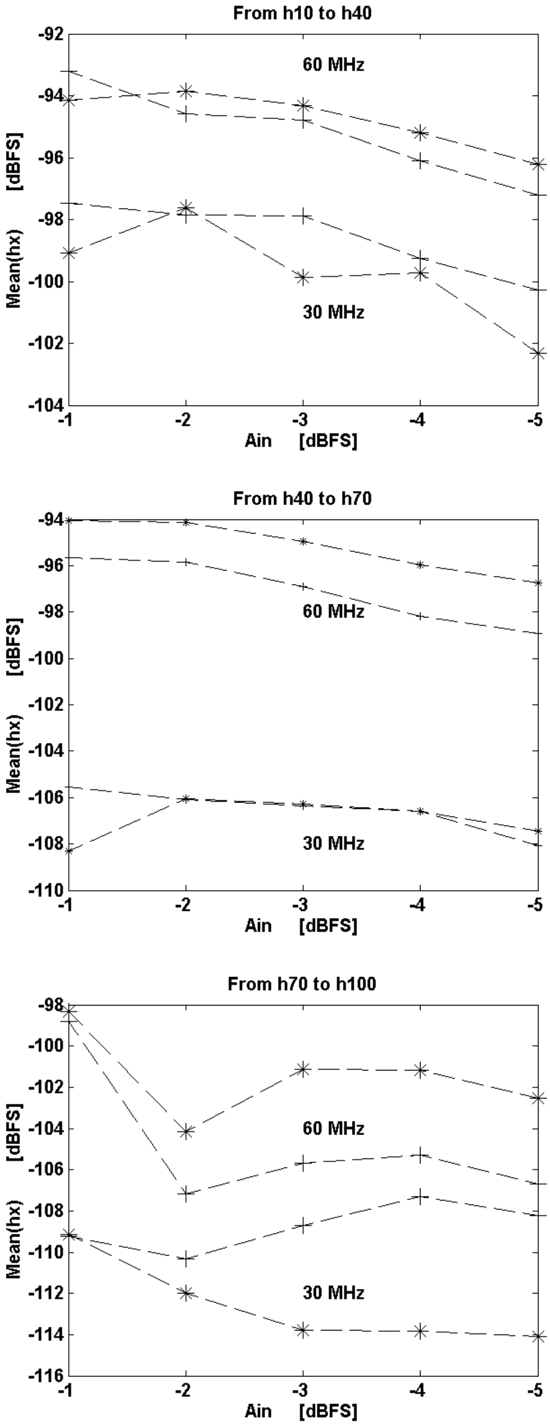


Fig.4. The mean power of harmonics terms from 10 to 40, from 40 to 70 and from 70 to 100 as a function of input amplitude. Marks '+' correspond to the first channel; marks '*' to the second channel.

The detailed data analysis in the frequency domain must be used at nowadays, good ADC. The histogram, as in [4], can't describe the small differences in data. No missing codes exist at undersampling applications of good ADC.

Our results demonstrate that no significant influence of SAH exist according to noise level or power of low harmonics terms. The amplitude and phase of low harmonic term is changed, but not too significantly. The amplitudes of low harmonic terms are similar at both tests; the influence of others ADC non-linearity is of the same level as of SAH.

The significant differences exist in the power of higher harmonic terms – Fig. 3,4. The change of this power at both tests can be used as a marker of SAH quality. The changes of power of high harmonics terms were in both channels similar and significant. The results correspond with theoretical assumptions, i.e. that imperfections of SAH occur as the high order dynamic non-linearity.

VI. CONCLUSION

The used ADC parameters describe mostly the Nyquist band and neglect undersampling application, even thought such applications are needed. In these applications the beat frequency and envelope tests with detailed data analysis are very useful to determine the dynamic errors corresponding to SAH imperfection. The most sensitive parameter at nowadays-good ADC according to SAH imperfection is the sum of power of high order harmonic terms.

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