Revisit to Accurate ADC Testing with Incoherent Sampling Using Proper Sinusoidal Signal and Sampling Frequencies

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***Abstract*— This paper describes that the mature ADC testing method with a simple test system using the incoherent sampling and the standard algorithm of windowing and FFT with 4K-point data can measure the SINAD of our target 12-bit SAR ADC accurately by proper setting of the input and sampling frequencies, which is industry-friendly. We show the input sinusoidal signal and sampling clock frequency relationship for accurate testing of the ADC dynamic characteristics with an incoherent sampling method using a flat-top window. We have clarified the measured SINAD accuracy of the input signal frequency dependency for a fixed sampling frequency, a specified resolution of the ADC under test and a given number of FFT points (data samples) in the incoherent sampling environment. Mature technology combinations with their optimal usage and without advanced methods can lead to the low-cost high-quality testing of the ADC, which can be well accepted in industry. Their analysis, simulation and experimental results are shown.**

Keywords— ADC testing, incoherent sampling, SINAD, flat-top window, FFT

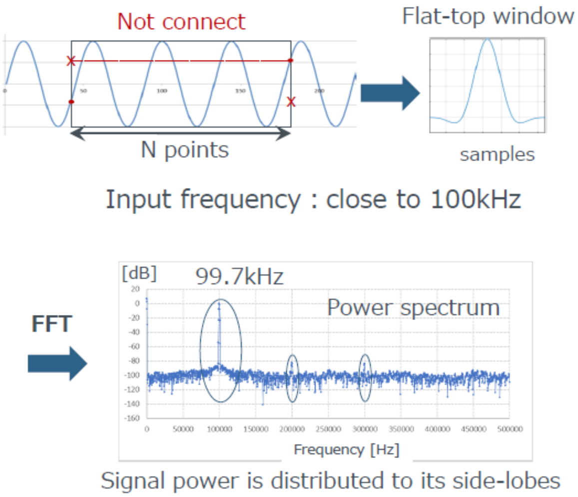
I. INTRODUCTION

The ADC is a key component in IoT systems and its accurate testing is very important in industry [1, 2]. Recently, high volume ADCs are shipped; their SINAD (Signal-to-[Noise + Distortion] ratio) testing at the mass production stage was often omitted due to the low test cost, but their high quality assurance is also demanded and hence the low-cost and high-accuracy SINAD testing method is required. This paper tackles the dynamics testing of the high-resolution ADC using a mature testing method of the windowing and FFT method in the incoherent sampling environment; this technology has a long history and has been widely used [3, 4], but still there are some new findings which we show in this paper. It is shown that even in the incoherent sampling case, if the input sinusoidal frequency is chosen as so-called a coherent sampling frequency, the SINAD can be measured accurately for the high-resolution ADC. However, if the input frequency is not chosen properly, its measurement accuracy degrades; the testing accuracy is shown quantitatively. Our investigation suffices the dynamics testing of our target 12-bit SAR ADC in an incoherent sampling system, which is relatively easy to implement.

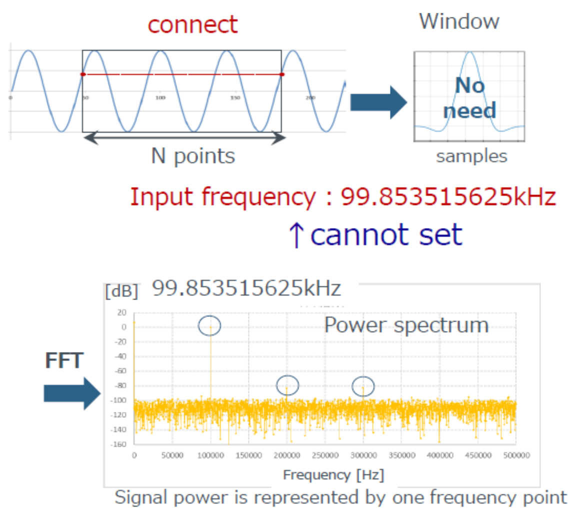
Fig. 1 shows the ADC testing problem. The coherent sampling ADC testing is desired, but the input frequency setting with an arbitrary waveform generator (AWG) [5] is often difficult due to its limited frequency resolution. Synchronization between the signal source and the pulse generator is rather complexed. Also, when the ADC is embedded in an electronic system, its testing in the coherent sampling environment is often difficult.

In the incoherent sampling case, a window is required but its SINAD measurement is often degraded due to the spectrum leakage, which is a problem for the high-resolution ADC testing. Then we consider here the incoherent sampling ADC testing with the flat-top window [6] by selecting the proper input frequency for a given sampling clock frequency and a given number of samples, to obtain accurate SINAD of the ADC under test. We show the measured SINAD accuracy of the input signal frequency dependency for a fixed sampling frequency, a specified resolution of the ADC under test and a given number of FFT points in the incoherent sampling environment quantitatively; if the input sinusoidal frequency approaches the coherency, the measured SINAD accuracy increases.

By choosing the input sinusoidal frequency close to the coherent frequency which is defined later, the dynamics testing accuracy of our target 12-bit SAR ADC is obtained in the coherent sampling environment. Its simple test system and the mature testing algorithm are suitable to industry mass production, even though advanced algorithms may obtain better accuracy [7].



(a) Incoherent Sampling.



(b) Coherent Sampling.

Fig. 1. 12-bit 1Msps ADC testing environment and problems.

II. Problem Statement

We consider here dynamics characteristics testing of a 12-bit 1MS/s SAR ADC in the incoherent sampling environment with the flat-top window and the FFT method [1, 2]. An AWG is used to provide a sinusoidal signal as the ADC testing input.

Its testing conditions for simulations and experiments are as follows:

- ADC under test: 12-bit 1MS/s SAR ADC
- Sampling: 1Msps
- Input frequency: 99.5kHz ~ 100.5kHz

  (1Hz step, 1001 points)
- Evaluation: 4K-point FFT with flat-top window

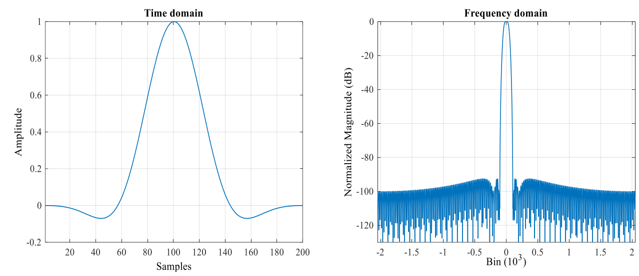
We here consider to use the flat-top window, because it is well established that the sinusoidal signal power can be calculated with ±5 bins as well as HD2 and HD3 with ±7 bins [7]. In other words, to obtain the signal power, the powers in 11 bins at the of the signal frequency bin are summed. Also, for HD2 and HD3, the powers in 15 bins are summed for each.

Fig. 2 (a) shows the flat-top window, and its equation is given by

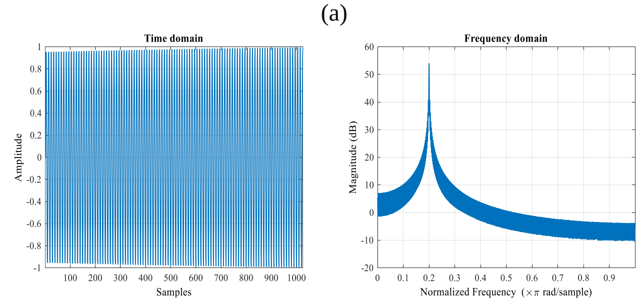
$$w[n] = a_0 - a_1\cos\left(\frac{2\pi n}{N}\right) + a_2\cos\left(\frac{4\pi n}{N}\right) - a_3\cos\left(\frac{6\pi n}{N}\right) + a_4\cos\left(\frac{8\pi n}{N}\right)$$

Here n=0, 1, 2, 3, …, N-1, a0=0.21557895, a1=0.41663158, a2=0.277263158, a3=0.083578947, a4=0.006947368.

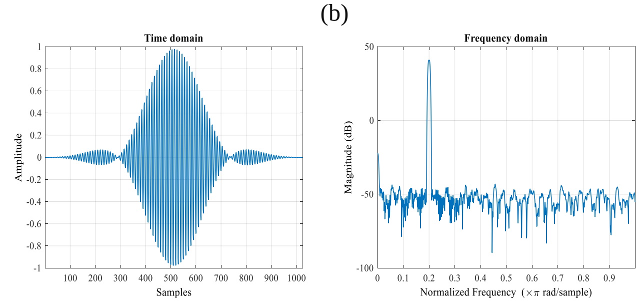
Figs. 2 (b), (c) show the waveforms and the power spectrum obtained by 4K-point FFT with and without the flat-top window.



(a)



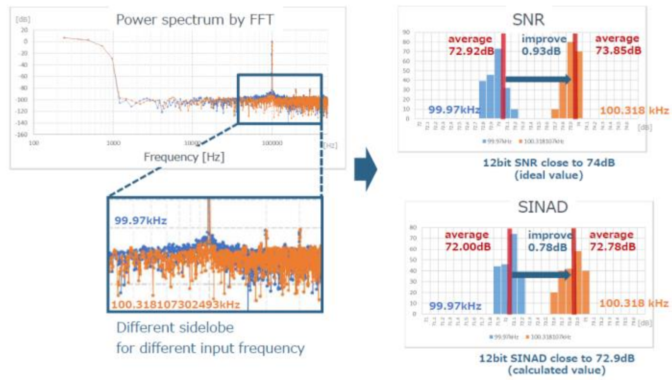
(b)



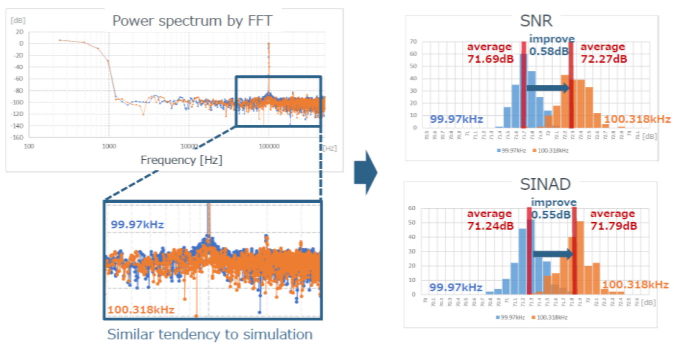
(c)

Fig. 2. (a) Flat-top window **(N**=200**)**. (b)Without the flat-top window for a sine wave. (c) With the flat-top window.

In these conditions, we found in preliminary simulations and experiments that the obtained SINAD for 100.318kH is about 0.58 dB better or closer to 74dB (which is the SINAD of the ideal 12-bit ADC) than the one for 99.97kH, as shown in Fig.3. Also Fig. 4 shows the ADC output power spectrum with the flat-top window for several input frequencies, and we see that the spectrum leakage depends on the input frequency, and then we consider that the accurate SINAD depends on the input frequency, and this motivates the present study.



(a) Simulation results. HD2 of -82.05dB and HD3of -82.65dB are added.



(b) Experimental results.

Fig. 3. Simulation and experimental results of the 12-bit ADC SNR and SINAD measurements for the input frequency for 99.97kH and 100.318107302493kHz. The flat-top window is used and the number of FFT point is 4096.

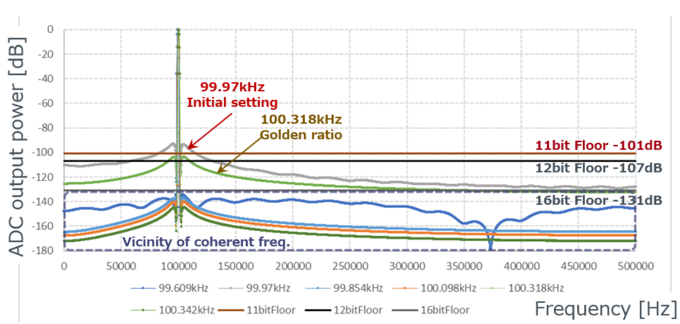


Fig. 4. Simulation results of ideal 12-bit ADC output power spectrum with the flat-top window.

III. Simulations and Experiments

The frequency characteristics of the flat-top window function is clarified by performing FFT of the sine function after applying the window, as shown in Figs. 4 and 5.

The followings are defined:

- fin: Input frequency
- fs: Sampling frequency
- N: Number of FFT points (samples)
- Nbit: ADC resolution (number of bits)
- Floor_ideal= -6.02・Nbit – 1.76 – 10 log10 (N / 2)

Here Floor_ideal means an ideal FFT noise floor.

We define the input sinusoidal signal frequency fin as the coherent frequency fcoherent when the following is satisfied:

$$fin = (m/N) fs$$

Here, fs is the sampling frequency, N is the number of FFT points and m is an integer which is relatively prime to N. In this case, there are m periods of the input sinusoidal signal in N samples.

Notice that the ideal FFT noise floor depends on the number of FFT points N; as the number increases, the FFT noise floor (Floor_ideal) decreases and here a fixed number of N=4096 is used.

The window function has its frequency characteristics. When the ADC dynamic characteristics are measured with the window function, its SNR/SINAD are accurately evaluated if the spectrum leak obtained by performing FFT to an ideal sine wave with the window is lower than the ideal FFT floor.

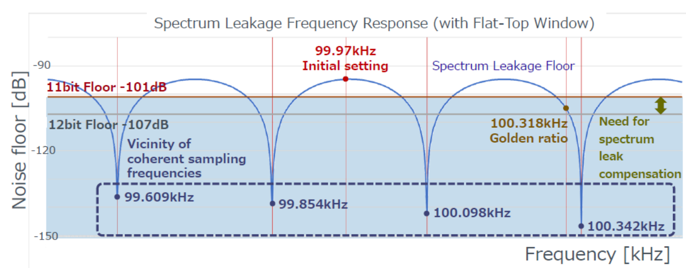


Fig. 5. Simulation results of the spectrum leakage frequency response with the flat-top window.

The coherent sampling can realize the coherent frequency signal, but the incoherent sampling cannot exactly. Our finding is that since the spectrum leakage is small for the input frequency close to the coherent frequency fcoherent, the input frequency is not necessarily to be the exact coherent frequency, but it is enough to be at the vicinity of the coherent frequency for the accurate ADC dynamics testing; this is quantitively shown in Figs. 6 and 7.

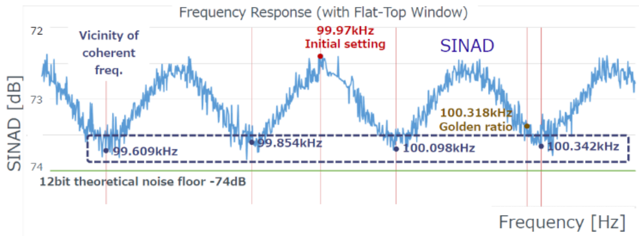


Fig. 6. Simulation results of SINAD for an ideal 12-bit ADC with the flat-top window

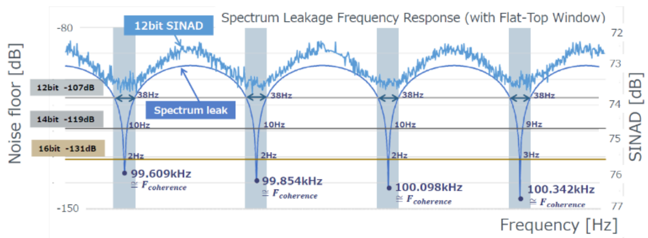


Fig. 7. Simulation results of SINAD for an ideal 12-bit ADC with the flat-top window and analysis of 1Hz resolution.

Fig. 8 shows simulation results of an ideal 12-bit ADC with the flat-top window to obtain the SINAD. We see that the SNR/SINAD measurement accuracy for the ADC with resolution better than 11-bit with 4K-point FFT is influenced by the window frequency response.

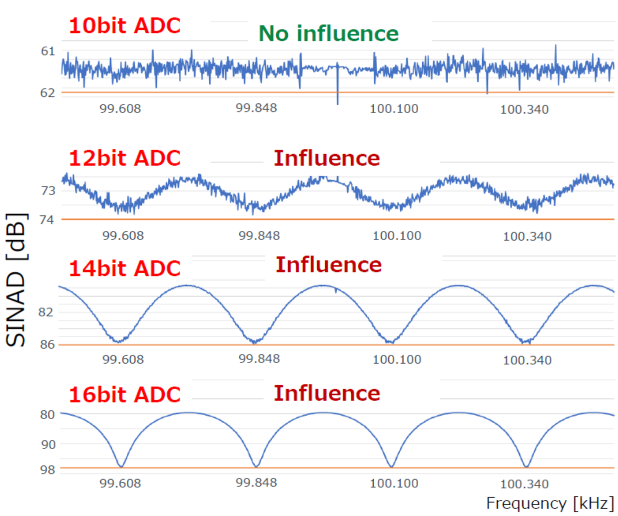


Fig. 8. Simulation results of the SINAD for an ideal 12-bit ADC with the flat-top window. The ADC resolution better than 11bit is influenced by the window frequency response for its SNR/SINAD measurement.

Fig. 9 shows that for any sampling clock frequency, there are some coherent frequencies for the ADC input to obtain accurate SINAD evaluation.

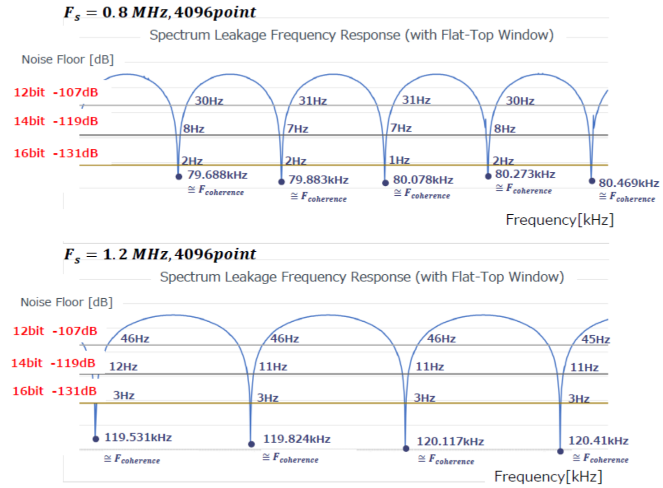


Fig. 9. For any sampling clock frequency, there are some coherent frequencies for the ADC input to obtain accurate SINAD evaluation.

Fig. 10 shows that the coherent frequencies depend on the number of the sampling points N. Even if it is small and the frequency resolution is coarse, we can find a good frequency close to the coherent frequency. It would be good to use the input sinusoidal frequency when the number of the sampling points N is small because it is also a coherent frequency for the large number of the sampling points N.

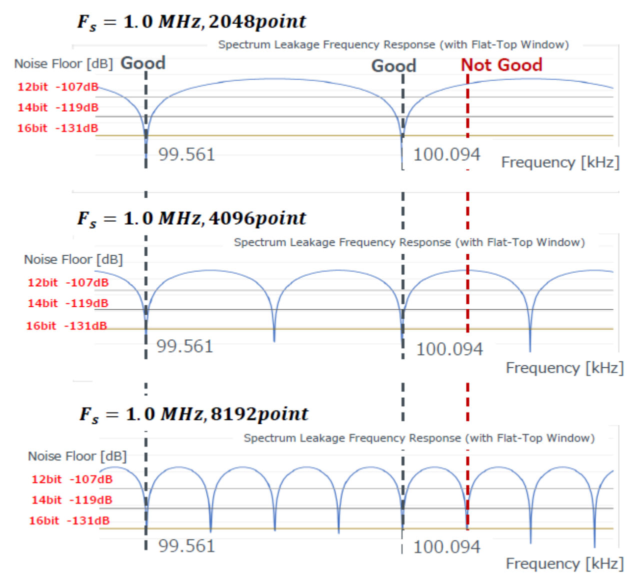


Fig. 10. Coherent frequencies depend on the number of the sampling points. Even if it is small and the frequency resolution is coarse, we can find good frequency close to the coherent frequency, and it would be good to determine the input frequency when the number of the sampling points is small because the frequency is good also for the large number.

Fig. 11 and Fig. 12 show the simulation and experiment results of the ADC testing for different input frequencies, in the incoherent sampling environment, respectively. We see that

SNR/SINAD close to the ideal ones can be obtained with the input frequency close to the coherent frequency.

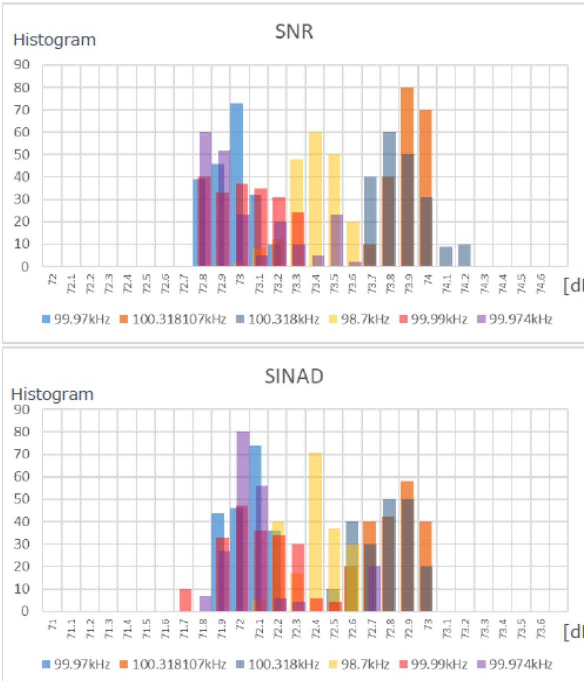


Fig. 11. Simulated SNR and SINAD histograms of ADCs with different input frequencies.

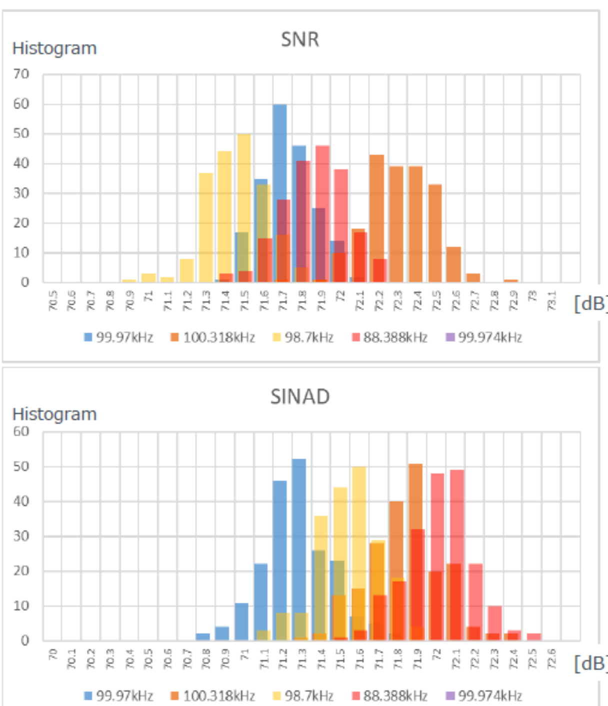


Fig. 12. Measured SNR and SINAD histograms of ADCs with different input frequencies.

IV. Conclusion

ADC dynamic characteristics such as SINAD can be measured accurately with appropriate input frequency by reducing sidelobe with the flat-top window in the incoherent sampling environment, up-to 12-bit resolution with 4K-point FFT. The test system consists of simple hardware and no additional testing time is required. Also, engineers in industry are familiar with this technology. The limitation of the ADC SINAD measurement accuracy for the relationship between the input and sampling frequencies is obtained by simulations, and even higher resolution than 12-bit may be measured with the same method. Our experimental results support the arguments.

We conclude this paper by remarking that there can be new findings even in mature technology due to never-stopping society demands, and such an anti-technology direction method can be more widely accepted in industry, thanks to its simplicity and reliability.

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