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SINE WAVE SIGNAL SOURCES FOR TESTING HIGH-SPEED HIGH-RESOLUTION A/D CONVERTERS

Vaclav Papez [1], *Jaroslav Roztocil* [2], *Stanislav Dado* [3]

[1] Czech Technical University, Faculty of Electrical Engineering, Prague, Czech Republic, papez@fel.cvut.cz
[2] roztocil@fel.cvut.cz
[3] dado@fel.cvut.cz

Abstract – The paper deals with conception of a sine wave signal generation for dynamic testing high-speed (1 MSa/s to 100 MSa/s) analog-to-digital converters with high-resolution (14 to 20 bits). An oscillator designed with respect to minimal phase noise is described.

Keywords: ADC testing, phase noise, SINAD, THD

1. INTRODUCTION

Modern analog-to-digital converters (ADCs) have both high resolution and high sampling rate. Typical example is ADC having resolution from 14 to 16 bits and sampling rate of several hundreds of MSa/s. The dynamic testing ADC with such extreme values of parameters represents unusually severe demands to the quality of testing signals. The methods for testing ADCs alone and the digitizers in which ADC are included are practically identical. The methods of testing are prescribed by standards IEEE 1241/2000 and IEEE 1057/2007 (see [1], [2]).

This contribution is oriented towards the practical aspects of sine wave signal, which still remains the most important type of the signal used for testing high resolution ADCs.

2. REQUIREMENTS FOR THE SINE WAVE SIGNAL SUITABLE FOR ADC DYNAMIC TESTING

Sinusoidal waveform with high spectral purity can be generated relatively easily and this is main reason why it forms the base of main testing methods used for the determination of the ADC key parameters (SINAD, ENOB, SNR, SFDR, THD, etc., see [1], [2]).

While ideal sinusoidal waveform contains in one sided amplitude spectrum only one component representing fundamental frequency (1^{st} harmonic), the real output signal from oscillator has substantially complicated spectrum. The spectrum of real signal contains besides the fundamental frequency also higher harmonic and nonharmonic components and a noise. The spectrum of a typical real signal is shown in Fig. 1.

The quality of test signal can be characterized by the parameter SINAD (Signal to Noise and Distortion Ratio), which is defined as the ratio of power of the 1^{st} harmonic to the power of all other components found in spectrum (except the DC component):

$$SINAD = 10 \log \frac{P_1}{P_{All} - P_0 - P_1} \tag{1}$$

where P_{All} is the power of all signal components, P_0 is the power of DC component, P_1 is the power of the 1^{st} harmonic.

The signal suitable for testing should have substantially higher ratio of useful signal to erroneous components than one corresponding to the highest achievable value of dynamic range of the device under the test. The required value of SINAD for testing of n-bits ADC can be expressed by relation:

$$SINAD \geq 6{,}02n + 1{,}76 + PR \tag{2}$$

where PR is protection level, which in dependence on required accuracy of measurement is chosen in the range from 10 to 20 dB. Usually PR = 10 dB, then value of SINAD necessary for testing of 14 bits ADC equals approximately to 96 dB, 108 dB for 16 bits and 132 dB for 20-bit ADC.

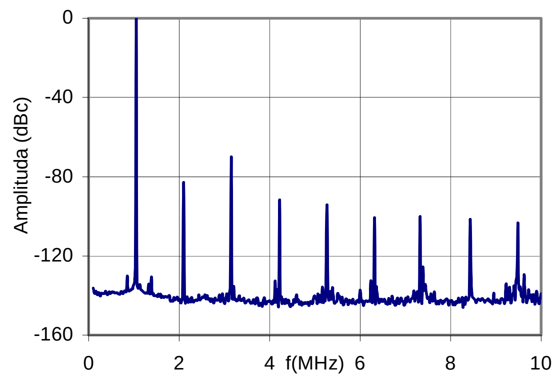

Fig. 1. Spectrum of the output signal from the Agilent 33120A function generator (+10 dBm, 1.053 MHz)

2. GENERATORS WITH SINUSOIDAL WAVEFORM OF OUTPUT SIGNAL

The concept of the commercially available generators of sinusoidal signal is based on the principles of direct (DDS) or undirect (phase locked loop-PLL) digital synthesis. The direct application of the output signals from these generators for the testing ADCs is admissible only in case of low resolution ADCs (maximum 12 bits). The spectral quality of these signals is influenced by levels of higher harmonic components (usually total harmonic distortion THD > -70 dBc), high level of phase noise and the significant level of nonharmonic (spurious) spectral components lying in the vicinity of the fundamental frequency (in the case of DDS based generators).

The spectral analysis of the output signal from the function generator Agilent 333120 can serve as an example. A wideband spectrum of its output signal in the range to 10 MHz at actual frequency 1.053 MHz and output power 10 mW is depicted in Fig. 1. The value SINAD is given by the sum of harmonic components power (particularly of 3rd harmonic) and noise and equals approximately to 67 dB.

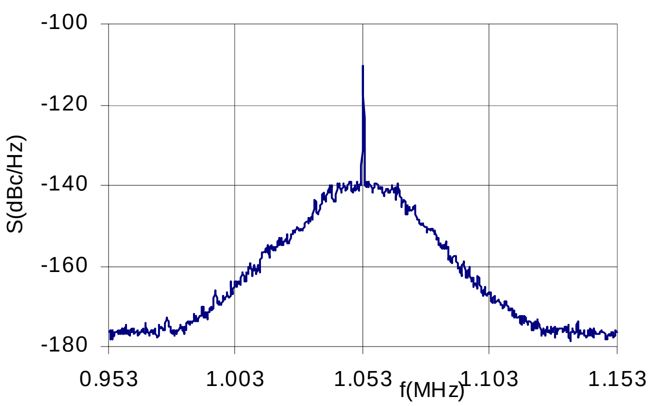

Fig. 2. The phase noise of generator Agilent 33120A in the vicinity of the fundamental frequency (+10 dBm, 1.053 MHz) after narrow band filtering of the output signal.

Inserting the narrow-band filter on the output of generator could attenuate namely the higher harmonic components (under the level of -130 dBc) and wide-band noise. The result of spectral analysis in the vicinity of the fundamental frequency for this case is shown in Fig. 2. At the output power of 10 mW and in the bandwidth of 200 kHz the value of SINAD about 95 dB can be achieved. Naturally the narrow-band filtering of output signal suppresses also the noise and harmonic components lying in the band from 0 to 10 MHz and thus the value of SINAD remains unaffected.

As it can be expected inserting the output filter substantially improves the testing signal parameters. Nevertheless the phase noise cannot be avoided by filtering and its level in the vicinity of the 1^{st} harmonic determines the achievable value of the ratio signal-to-spurious components.

3. GENERATORS WITH HIGH SPECTRAL PURITY

The highest quality commercial generators even with filtering cannot be used for serious testing of ADC having the resolution higher than 16 bits. The higher resolution can be achieved solely by specially designed generators. As an example the set of special generators designed at Faculty of Electrical Engineering of CTU in Prague will be introduced.

The special generators of testing signal were designed for frequencies 1.053 MHz, 2.407 MHz, 4.415 MHz, 9.484 MHz and 19.507 MHz. The attainable output signal of generators was set to 30 dBm so that even the ADC with peak-to-peak amplitude of 20 Vpp can be tested.

The principle diagram of generator is depicted in Fig. 3. The oscillator circuitry of Clapp type is controlled by quartz resonator. This allows to achieve relative frequency stability in order of 10^{-6}/day and leads to the steep drop of phase noise in the vicinity of carrier frequency. In order to reach high SNR (signal to noise ratio) on the output of oscillator, the active element used in oscillator should have low noise figure and high output power.

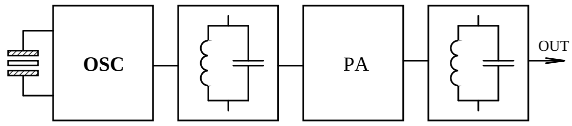

Fig. 3. The block diagram of realized generator

The detailed circuit diagram is shown in Fig. 4. The high current J-FET (T1) with low noise figure even at low frequencies (3dB at 1 MHz) and high value of IP (intercept point) equal to 30 dBm has been used. These parameters allowed to choose output power respecting the possible load of a quartz equal to 10 dBm.

The bipolar transistor (T2) is implemented in the output power amplifier and matching is performed by resonant circuits. The amplifier has gain of 20 dB at the output power of 1 W and bandwidth of about 30 kHz. The attenuation of harmonics is better than -80 dBc for all frequencies; linear band-pass filter can be used on the output (see Fig. 5) to improve THD (total harmonic distortion) up to -160 dB. The noise figure of the power amplifier is equal to 7 dB (at working frequency). The power supply with minimal inherent noise completed with filters or high quality accumulator battery (internal resistance less than 0.1 ohm) were used for feeding the generator.

The value of SINAD is about 130 dB at the output power of 1 W. Consequently the quality of signal is satisfactory for testing of ADC having resolution corresponding to 20 bits or for measurement of the intermodulation distortion with level 160 to 170 dB.

The graph of the phase noise of generator at frequency 1.053 MHz in the vicinity of the fundamental frequency (+/-5 kHz) is shown in Fig. 6.

The similar values were obtained in generators working on frequencies 2.407 MHz, 4.415 MHz, 9.484 MHz and 19.507 MHz. The results of phase noise measurement in the vicinity of the fundamental frequency (+/- 10 kHz) are depicted in Fig. 7 a,b,c,d.

The measurements were based on the principle of 1^{st} harmonic suppression using two types of band stop filtering. The first type is used for wideband measurement, the second one for measurement of phase noise in the vicinity of the fundamental frequency (see [3], [4]).

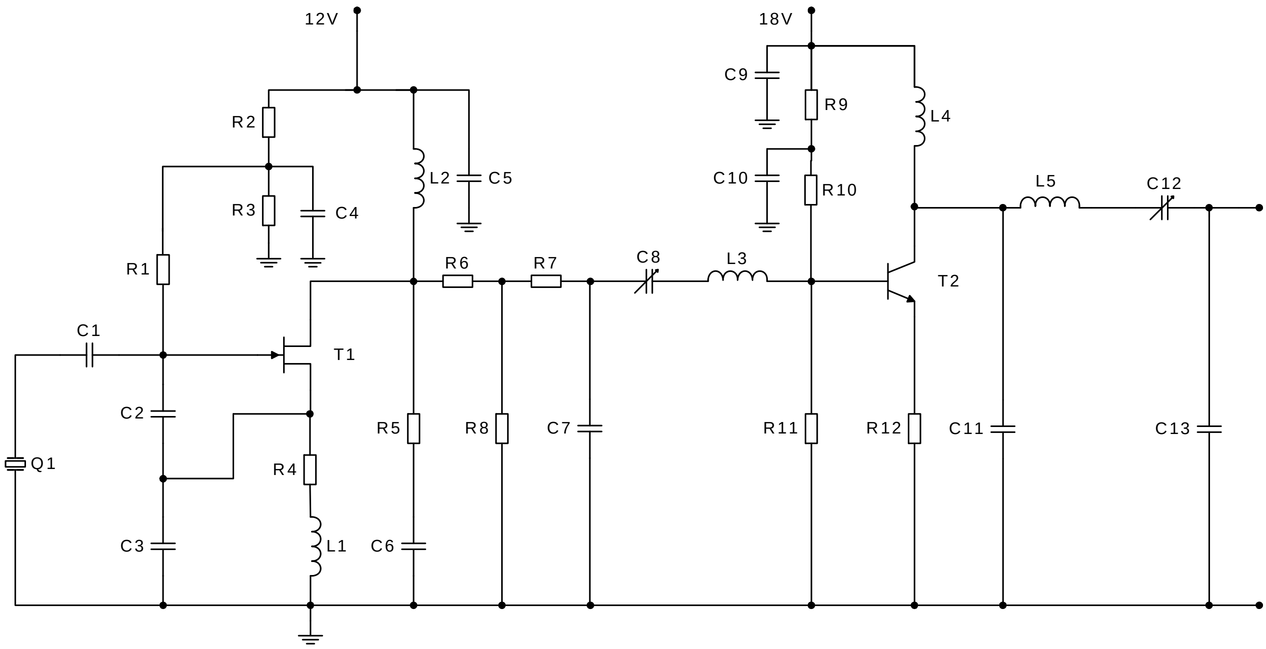

Fig. 4. Circuit diagram of realized generator

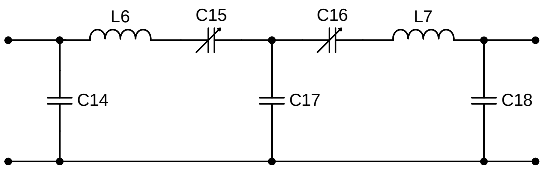

Fig. 5. Circuit diagram of the linear band-pass filter

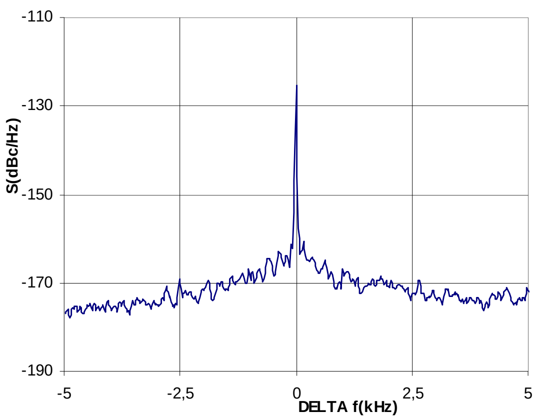

Fig. 6. Phase noise of realized generator at working frequency 1.053 MHz

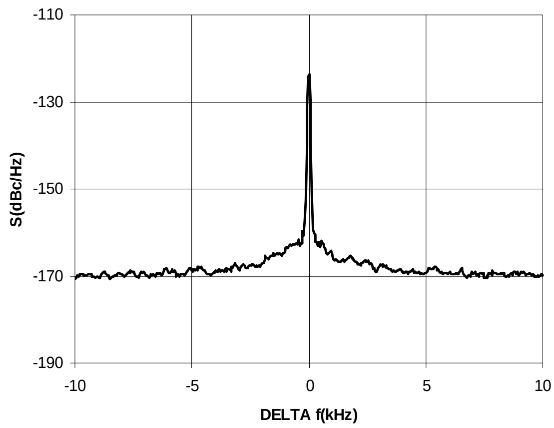

Fig. 7a.

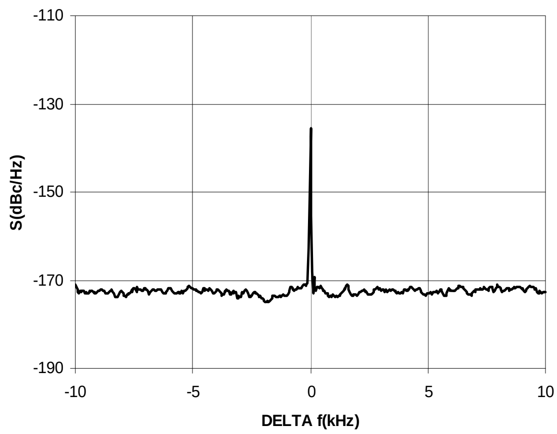

Fig. 7b.

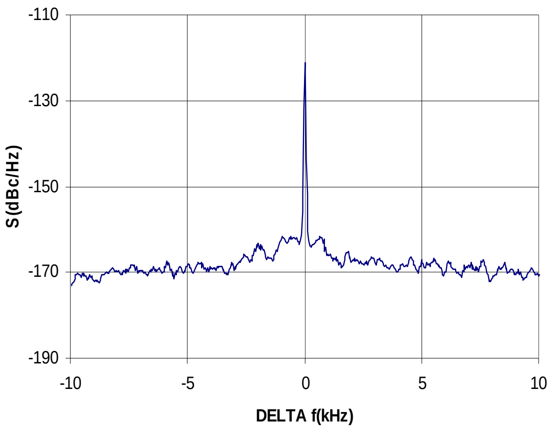

Fig. 7c.

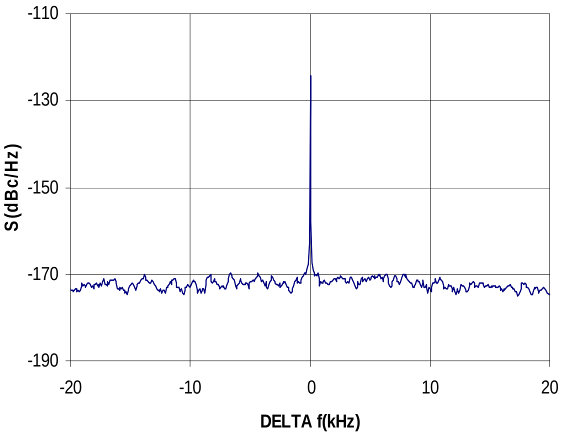

Fig. 7d.

Fig. 7. Phase noise of realized generators at working frequencies a) 2.407 MHz , b) 4.415 MHz, c) 9.484 MHz and d) 19.507 MHz

The filters were realized for the same frequencies as in the case of generators and band pass filters (i.e. 1.053 MHz, 2.407 MHz, 4.415 MHz, 9.484 MHz and 19.507 MHz).

4. CONCLUSIONS

The basic requirements on generators of sinusoidal signals suitable for high resolution ADC testing were described. It is evident, that even the best quality commercially available generators (see [5]) do not produce the signal with quality necessary for direct application for testing ADCs with resolution higher than 12 bits. Thus it is absolutely necessary to implement linear passive band pass filter on the output of generator (see [6]).

Filtering can improve spectral quality of signal increasing the value of SINAD up to 100 dB. The basic condition of successful filters construction is the careful choice of elements having as low as possible nonlinearities.

The further improvement of signal is limited by the level of phase noise of a generator at frequencies near the fundamental frequency. It is very difficult to suppress this noise by band stop filter. The reasonable solution seems to be implementation of free running quartz oscillators with fixed frequency optimized with respect to minimal phase noise. The achievable value of SINAD on the output of combination low noise oscillator - linear band pass filter is about 130 dB.

ACKNOWLEDGMENTS

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