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SINE-WAVE SIGNAL SOURCES FOR DYNAMIC TESTING HIGH-RESOLUTION HIGH-SPEED ADCs

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Abstract: The paper deals with methods of a sine-wave signal generation for dynamic testing high-speed (1 MSa/s to 100 MSa/s) ADCs with high resolution (14 to 20 bits). The techniques of noise and distortion measurement of spectrally-pure sine-wave signals are also discussed.

Keywords: sine-wave signal distortion measurement, dynamic ADC testing.

1. INTRODUCTION

The methods for dynamic ADC testing based on the harmonic signal [1] require spectrally-pure testing signal on the ADC input. In the real world, the generated sine-wave signal always contains noise and distortion, which therefore increase the uncertainty of the ADC dynamic parameters determination.

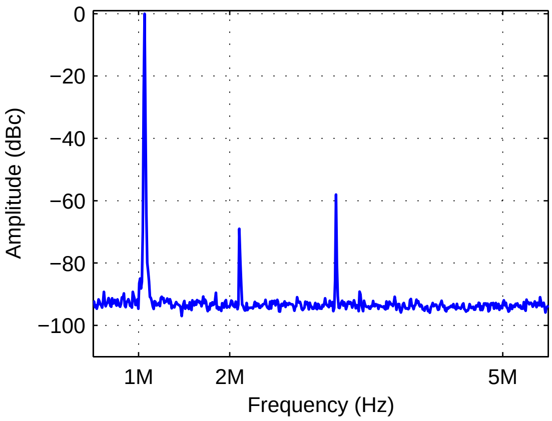

Fig. 1. Frequency spectrum on the output of the generator Agilent 33250A (+10 dBm, 1053 kHz); measured by the spectrum analyzer Agilent ESA-E series E4402B (RBW 1 kHz).

2. SINE-WAVE SIGNAL GENERATORS

The generator applied to ADC testing should have low noise and distortion. Important parameters of the generated signal are as follows:
- phase noise;
- level of spurious components especially occurring close to the carrier;
- level of harmonic components.

Commonly produced signal generators can be used only for testing purposes when low-resolution (10 bits at maximum) ADCs are under test. Typical THD values are worse than –60 dB in the frequency range 1–20 MHz. The frequency power spectrum of such a generator (Agilent 33250) is shown in Fig.1.

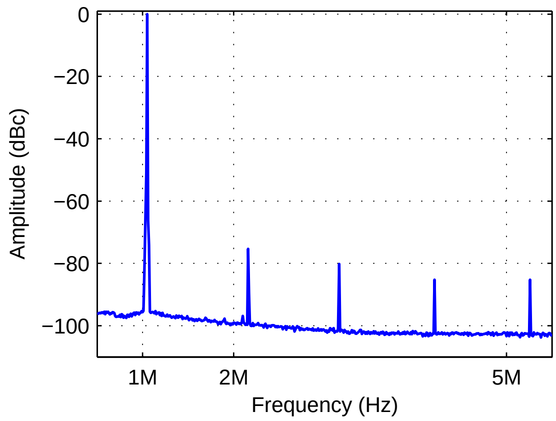

Fig. 2. Frequency spectrum on a free-running quartz oscillator (+10 dBm, 1053 kHz); measured by the spectrum analyzer R&S (RBW 1 kHz).

Direct application of common laboratory generators is quite inappropriate for ADC testing with high resolution (14–20 bits). Better parameters can be reached by one-purpose sine-wave generators with free-running oscillators (quartz or RC oscillators).

These generators usually have very low amplitudes of spurious components and can be optimized either to low harmonic distortion or phase noise and short-term stability. An example of a frequency spectrum of a quartz oscillator is shown in Fig. 2. Such generators can be applied to testing ADCs of 12 bits at maximum.

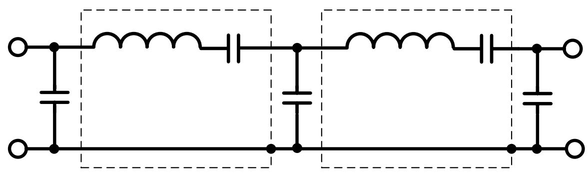

Fig. 3. Circuit diagram of 4th order band-pass filter

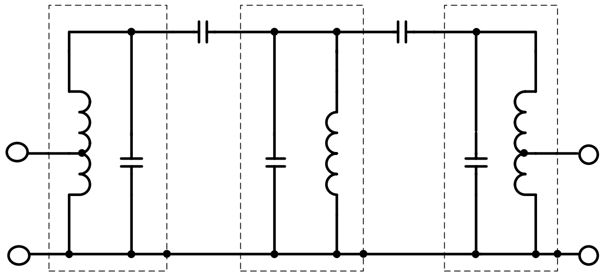

Fig. 4. Circuit diagram of 6th order band-pass filter

Testing ADCs with resolution higher than 14 bits can be performed only if the signal from the above mentioned generators is improved.

3. SINE-WAVE SIGNAL QUALITY IMPROVEMENT

The low-noise low-distortion testing signal can be obtained by using a narrow-band band-pass filter that suppresses undesired harmonic/non-harmonic components.

This band-pass filter is usually designed as an active filter or passive LC filter with coils on ferromagnetic cores. This concept of the filter design brings about non-linear components.

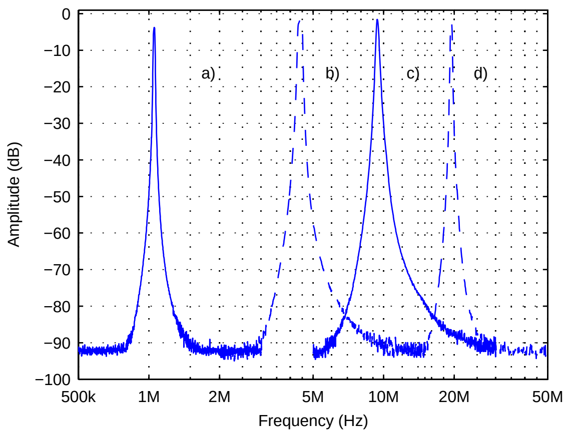

Fig. 5. Frequency responses of 6th order band-pass filters: a) 1053 kHz, b) 4415 kHz, c) 9484 kHz, d) 19507 kHz

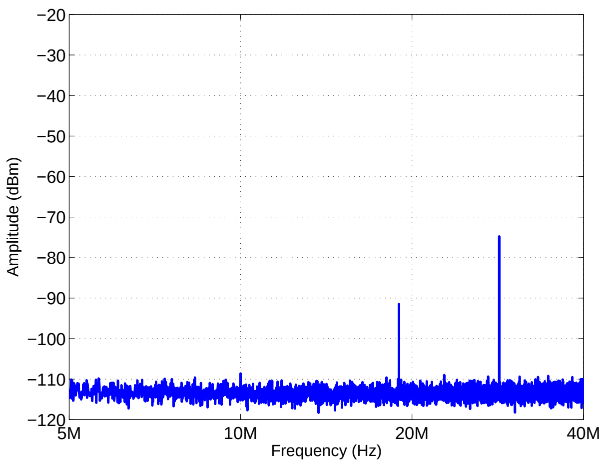

Fig. 6. Frequency spectrum of a sine-wave signal (9484 kHz, +24 dBm, Agilent 33220A) filtered by a common band-pass filter, measured by the spectrum analyzer Agilent ESA-E series E4402B (RBW 1 kHz) with a suppressed carrier.

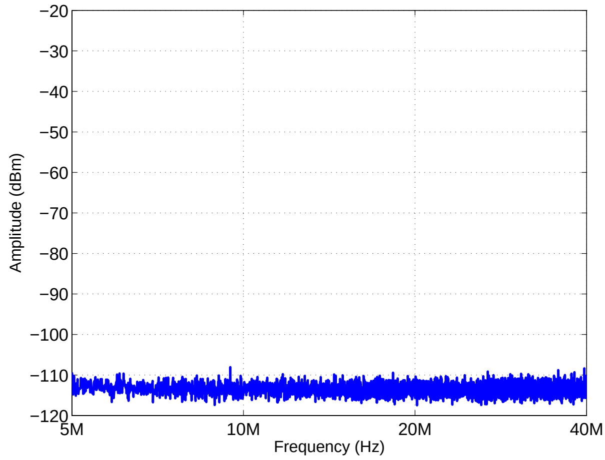

Fig. 7. Frequency spectrum of a sine-wave signal (9484 kHz, +24 dBm, Agilent 33220A) filtered by a high-quality band-pass filter, measured by a spectrum analyzer Agilent ESA-E series E4402B (RBW 1 kHz) with a suppressed carrier.

The filter can be designed either as a 4th order band pass filter with capacitive coupled serial resonators (Fig. 3) or as a 6th order band pass filter with capacitive coupled parallel resonators (Fig. 4). Frequency responses of band-pass filters are shown in Fig. 5.

The non-harmonic components are efficiently suppressed, but some harmonic components still remain in the spectrum of the output signal. These components are produced by the filter's non-linearity as shown in Fig. 6.

To avoid the additional generation of harmonic components, the band-pass filter has to be strictly designed with linear components (vacuum capacitors, air coils, etc.). In such a case, it is possible to achieve SFDR better than 135 dBc and THD better than –130 dB in the frequency range from 1–50 MHz on the filter output (Fig. 7).

This signal can be used for testing ADC converters with resolution up to 20 bits, see [5].

4. NOISE AND DISTORTION MEASUREMENT

To evaluate the uncertainty of dynamic ADC parameters determination, it is necessary to measure the level of noise and distortion presented in the testing signal.

Common measurement instruments do not have such a dynamic range (usually 60 to 80 dB only) to accommodate spectrally very pure signal. Therefore, they can not be directly used to measure the levels of non-harmonic and harmonic spectrum components of the signal produced by the method described in a previous paragraph.

4.1. Carrier suppression method

To be able to use common measurement instruments (spectrum analyzer, lock-in amplifier, etc.) it is necessary to decrease the dynamic range of the measured signal on the instrument input. A notch (band-stop) filter (Fig. 2) can be used to sufficient reduction of the carrier level.

The notch filter should be assembled from linear components, to avoid the generation of higher harmonics, see [5].

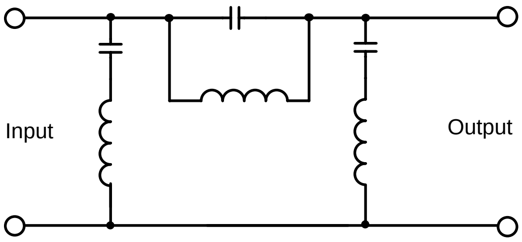

Fig. 8. Circuit diagram of 6th order notch-filter

A general disadvantage of the notch filter is the fact that a notch filter with an extremely narrow band-stop area cannot be designed applying standard LC design rules. This type of the filter also suppresses a non-harmonic components and/or phase noise in a close-to-carrier area, and thus they can not be measured.

4.2. Close-to-carrier noise and distortion measurement

A specially designed extremely narrow band-stop (notch) filter – based on the serial resonance of a quartz resonator (see Fig. 10) – could be used if the phase noise and/or close-to-carrier distortion measurement is demanded.

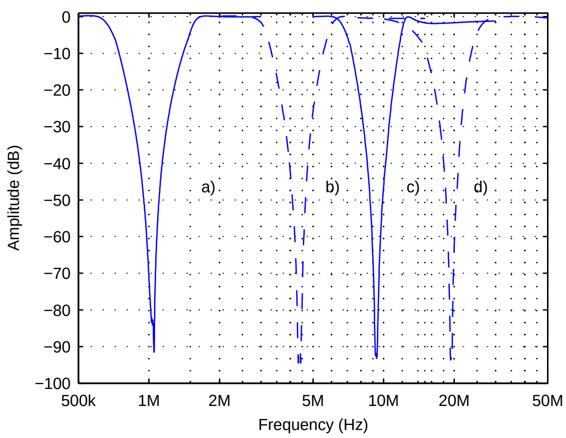

Fig. 9. Frequency responses of 6th order band-stop filters: a) 1053 kHz, b) 4415 kHz, c) 9484 kHz, d) 19507 kHz

Only close-to-carrier frequencies are passed through by the notch filter. The frequency response of the prototyped extremely narrow band-stop filter is shown in Fig. 11 and the detailed view of the band-stop area is shown in Fig. 12.

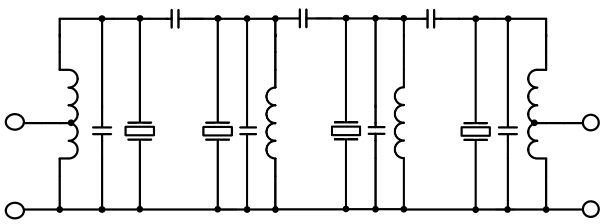

Fig. 10. Circuit diagram of the four-quartz resonators filter

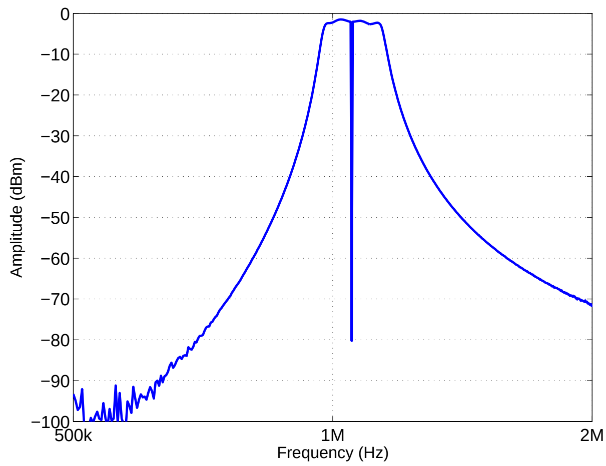

Fig. 11. Frequency response of the four-quartz resonator filter

This type of the filter in the combination with the previously mentioned (paragraph 3) band-stop filter enables to observe the whole spectrum (either the distortion or noise in the close-to-carrier area or the harmonic and non-harmonic components farther from the carrier).

Spectra on the output of three generators measured by means of the prototyped extremely narrow band-stop filter are shown in Figs. 13–15.

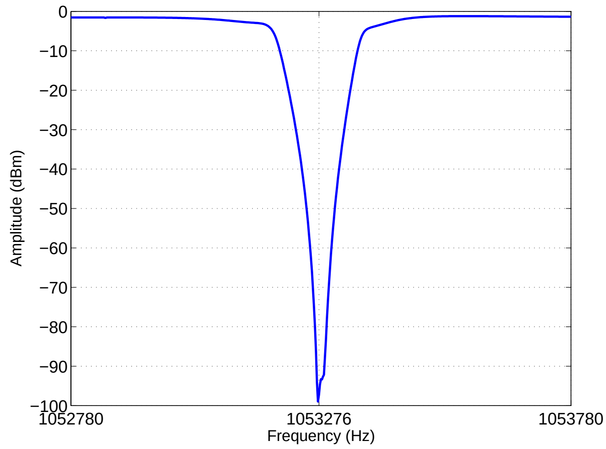

Fig. 12. Frequency response of four-quartz resonator filter; detailed view on the band stop area

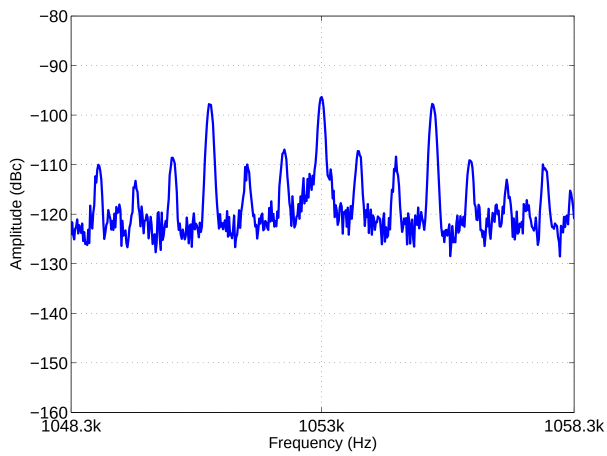

Fig. 13. Spectrum of a close-to-carrier area of a common generator HP33120A; RBW 100Hz

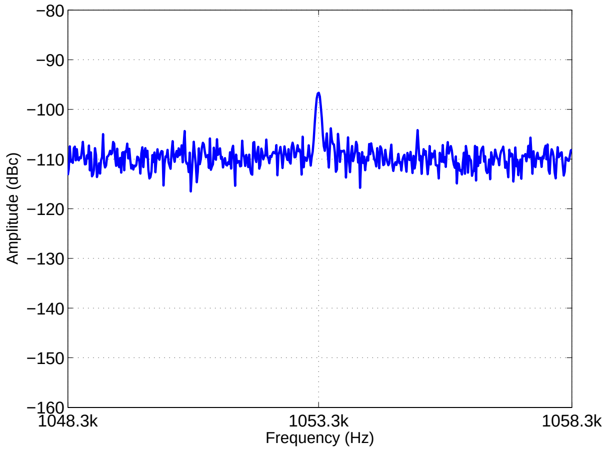

Fig. 14. Spectrum of a close-to-carrier area of free-running quartz oscillator designed to long-term frequency stability; RBW 100 Hz

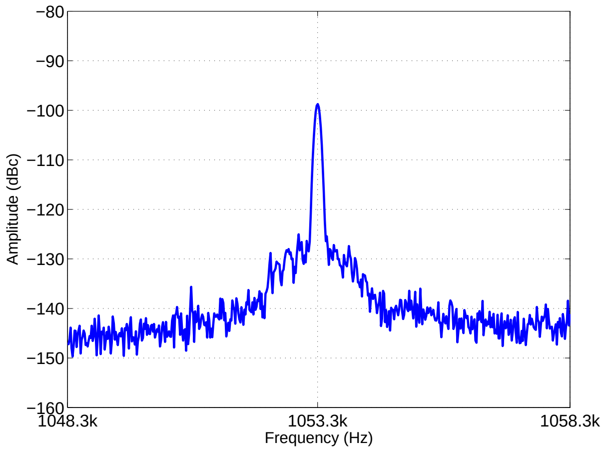

Fig. 15. Spectrum of a close-to-carrier area of free-running quartz oscillator designed to low phase noise; RBW 100 Hz

The close-to-carrier phase noise and spurious distortion of a common generator based on DDS can be observed in Fig. 13. The appearing spurious distortion components are very important and must be considered. They have different characteristic than a typical phase noise of a free-running oscillator. The level of this spurious distortion can rise to –100 dBc. The amplitude and frequency of these components depend on the generated carrier frequency, see [4]. The signal from a common DDS generator filtered by the band-pass filter has sufficiently suppressed harmonic and spurious components in the band-stop area of the band-pass filter, but the close-to-carrier distortion components still remain in the filtered signal. For this reason, a common DDS generator is not an optimal source for high-resolution ADC testing.

The spectra of the close-to-carrier area of the free-running quartz oscillators optimized for short-time frequency stability are shown in Fig. 14, and for low phase noise in Fig. 15. The achievable phase noise with this oscillator at the frequency offset 10 kHz is lower than -160 dBc/Hz.

5. CONCLUSION

This paper describes method improving quality of the signal produced by sine-wave generators. This technique enables to achieve a sine-wave signal with SFDR better than 135 dBc and THD better than –130 dB.

The sine-wave signal distortion measurement by reducing the signal dynamic range by a selective attenuation of the carrier is also described.

The method can be used for the close-to-carrier noise measurement of the signal sources, as well as for the noise and distortion measurement in the whole spectrum. The method is based on the use of a commonly used spectrum analyzer and a specially designed set of filters.

ACKNOWLEDGMENTS

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