Low-distortion Harmonic Signal Quality Testing

Vaclav Papez[1], Stanislava Papezova[2]

[1]*CTU in Prague, Faculty of Electrical Engineering, Technicka 2, 166 27 Prague 6, Czech Republic, phone: +420 224 352 165, fax: +420 224 353 949, papez@feld.cvut.cz*
[2]*CTU in Prague, Faculty of Mechanical Engineering, Technicka 4, 166 07 Prague 6, Czech Republic, phone: +420 224 352 401, fax: +420 224 310 292, stanislava.papezova@fs.cvut.cz*

Abstract- The main problem of the high resolution ADC testing within the frequency range hundreds of kHz to tens MHz is the spectral purity of testing signal. Commercially produced low-distortion generators have the spectral purity sufficient for testing of ADC app. up to 16 bit, analogous to sensitivity of commercial analyzers for measuring of signal quality is enough for check of signal with of signal spectral purity for testing of ADC app. up to 16 bit. There is necessary to use special methods for measuring of special signal sources with extreme high spectral purity that are designed with higher resolution for ADC testing. . These methods make possible to extend dynamic range and to increase sensitivity of signal analyzers, in order to analyze test signal.

I. The signal quality declaration

The quality of the harmonic testing signal is usually described by a ratio of total signal power level (summation of signal, noise and distortion power level) to the power of all disturbing spurious signals (summation of noise and distortion power level) [1]. This ratio is defined by the value of the SINAD (Signal to Noise and Distortion Ratio) and it can be noted as in decibels expressed relation (1).

$$SINAD = 10 \log \frac{P_S + P_N + P_D}{P_N + P_D} \quad (1)$$

where P_S is a power of all signal components
P_N is a power of noise component
P_D is taken as a power of the distortion.

Unmodulated carrier according to (1) is signal for harmonic test signal. With regard to power level it is possible to neglect other components in numerator.
The values of the SINAD signals with low-level distortion, which can be used e.g. for ADC dynamic testing, exceed 100 dB and can reach as much as 150 dB.

II. The signal components measurement

For the real harmonic signal with its typical spectrum (see Figure 1), it is possible to determine the total noise and distortion power directly by adding both values of the power.
The total power of the noise signal is given by the integral of the spectral noise power density in an entire frequency band transferred from the generator. The level of the noise spectral power density is usually the most considerable at the close neighborhood of the carrier, where the noise level, which is determined by the phase noise of the generator, is the highest and is the most difficult to measure. The power of discrete frequency components can be determined as a sum of the power of all these components again in the entire frequency band transferred from generator.

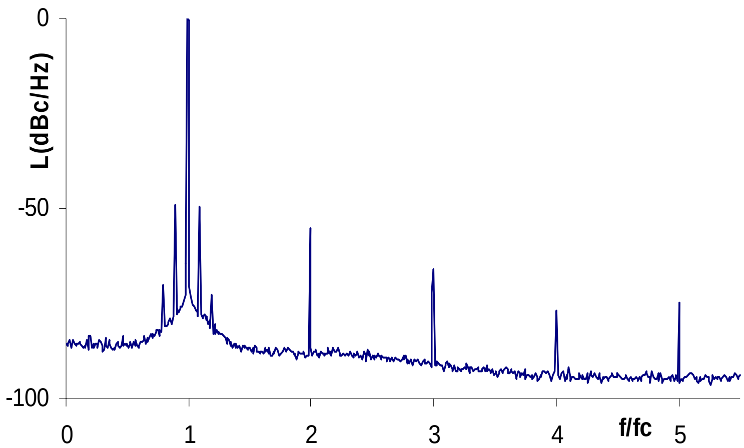

Fig. 1 Typical course of the signal spectrum

To assess a SINAD signal it is necessary:
- to determine the power of carrier,
- to determine the power of all harmonic components of the signal,
- to determine the power of all spurious of the signal,
- to determine the noise broadband background of the signal.
- to determine the signal phase noise.

A. Discret frequency components measurement

Power measuring of the spectrum discrete frequency components is, at the first sight, a simple task feasible again by a direct measuring by a spectrum analyser. Indicated frequency spectrum is similar to Fig 1 and level of particular spectrum components is easily possible to read from it. In the process of measuring, however, an error can sometimes arise. An indicated spurious product should not necessarily rise in the generator; it can be generated by the measuring apparatus. This direct measurement method is not applicable in measuring with the SFDR level higher than 80 dB and with the signals of the level about 30 dBm which are often used.
The most important requirement for checking the linearity of the measuring string is the possibility to set up the attenuator, or at least, the possibility of changing its attenuation. If the measured levels changes differently with the change of the attenuator setting of the indicated level of both the carrier and spurious or harmonic products or unlikely with each other, then the non-linearity of the measuring string affects the measurement.
In case, of non-linearity detection or insufficient sensitivity detection of the measuring string, it is advisable to carry out the measurement by using the circuit according to Fig. 2, in which it is possible to modify the level of the spectra of the signal.

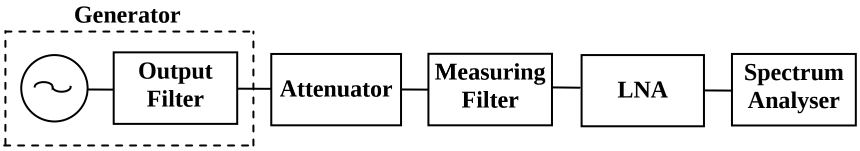

Fig. 2 The measurement of the power of discrete spectrum components

A narrowband notch filter or band-rejection filter is used as a filter harmonized with a frequency of the carrier which transmits required parasitic products with a minimal attenuation. By minimizing of the carrier level, the risk of a rise of spurious products in the analyzer decreases and the measuring is more sensitive then.
Atenuator is connected between tested generator and filter, It ensures acceptable SWR level at the output gate of the generator, alternatively also the set-up of suitable power level at the input of a measuring network. Satisfying of both these conditions is relevant.
Mismatch impedance at the generator output, which would caused directly connected notch filter or band-rejection filter for signal of carrier, would probably affect function of generator and could lead to its damage.
It is convenient to choose the signal power level minimal at the input of measuring network; that is what will be searched spectra components distinguishable in noise at the input of spectral analyzer with. If we choose the

signal power level 0 dBm at the input of measuring network, it is possible to indicate spectrum components about level -150 dBc by use of common spectral analyzer at bandwidth 1 Hz and neglectable filter attenuation. When in use LNA with noise figure 3 dB, it is possible to indicate spectrum components even to level -165 dBc. Less signal level further decreases risk of the rise of spurious or harmonic products in measuring network.
Band-rejection filter is solved as series-shunt network filter with tuned LC circuits. Filter is realized as filter for RF power processing of hundreds of W by using of air-cored coils, high-voltage ceramic capacitors, and adjustable air capacitors. So, in case of use of components with minimal losses and non-linearity, it is possible to achieve stop band transmission less than -100 dB and 3 order intercept point approximate 80 dBm.
Example of frequency characteristic for measuring filter with frequency 4,4 MHz is presented in Fig.3. filter is displayed in Fig. 4.

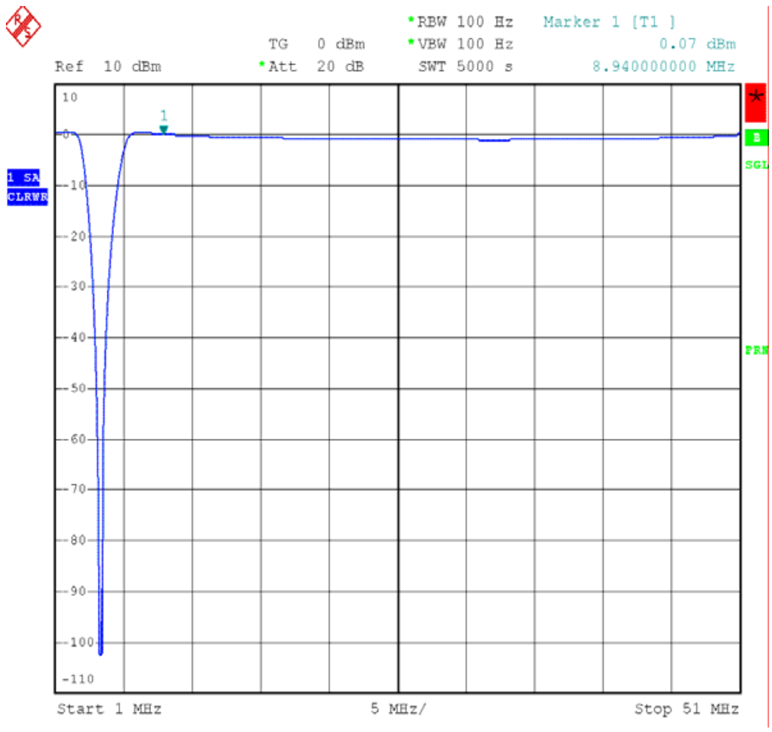

Fig. 3 Frequency characteristic of 4,41 MHz filter

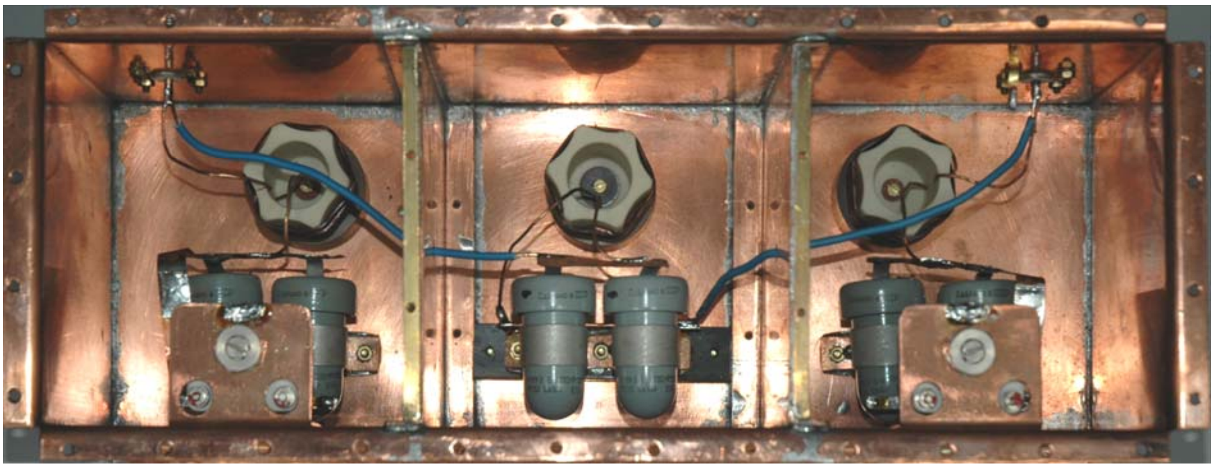

Fig. 4 4,41MHz band-rejection filter

The narrowband notch filter is a crystal filter with a transformer that uses LC resonant circuits. The LC structure matches as band-pass filters with a bandwidth approximately 10 % of the mean frequency [3]. The construction emerges from the structure of capacitive coupled identical parallel-resonant circuits, which are optimised for an

normal approximation near Cebysev. Quartz crystal resonators are connected parallel to the capacitors of the resonant circuits in order to construct a very narrow band notch filter characteristic.
Optimal coupling level is set-up by the autotransformer that is constructed with tap of the coil.
The choice of the coupling between the crystal resonator and the resonant circuit has a decisive effect on the behaviour of the filter. A near coupling ensures high asymmetry of the filter amplitude characteristic in the transmission band due to high changes if the equivalent capacity of a crystal resonator around a serial and especially a parallel resonant frequency. With a loose coupling only slight attenuation is achieved in the attenuation band. Typical in-circuit filter 5 has stop band bandwidth for –10 dB transmission app. 10^{-4} of mean frequency and stopp band transmission less than –110 dB.
Impedance of the attenuator has to correspond with the impedance of connected circuits. It must not produce measurable levels of harmonic products by its non-linearity and to be suitable, it would have an adjustable attenuation in the range 20 to 40 dB. The requirement on minimal non-linearity of the attenuator is its most difficult of realizable requirements here again. Attenuator should not produce harmonic products with level higher than -140 dBc, better -160 dBc, with input signal with power 1W. It matches valuables IP3 100 dBm to 110 dBm for distortion of 3rd order.
A typical dependence of the level of the third harmonic, generated at the input voltage by the attenuating components of 10 dB/50W, is shown in Fig. 5 for various constructions. It is evident that a currently used attenuator constructed by the film technology must be considerably power-over-designed to reach the 3rd harmonic to signal ratio of 120 dB by hundred times, to ensure the 3rd harmonic to signal ratio of 140 dB by thousand times with regard to a nominal power. It is possible to achieve better results only with the attenuators with wire-wound resistors made of special non-magnetic resistive alloys ZERANIN [2], in which, on the contrary, rise problems with regard to their intrinsic inductance.

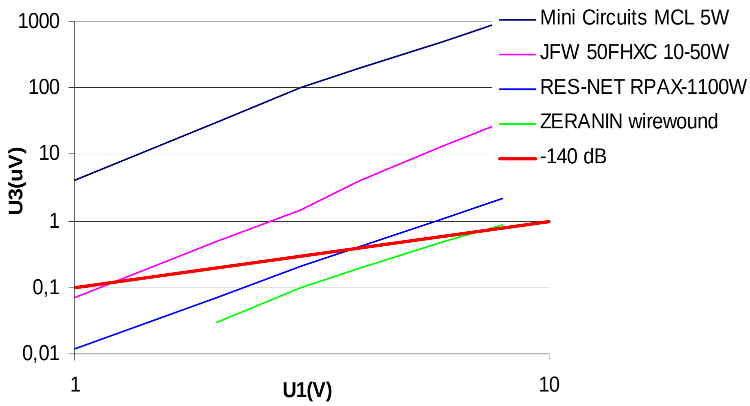

Fig. 5 The level of the 3rd harmonic signal generated by the attenuator

B. The noise background measurement

It is possible to carry out a noise background measurement well with the measuring circuit similar to the one presented in Fig. 2, into which it is possible to add calibrated noise generator with controllable output power at the filter input instead of the attenuator. Measuring is then pursued by the comparison of the noise power of the tested generator with noise power of the calibrated noise generator by setting of the level and attenuator on the same level indicated with spectrum analyzer. This comparison method of the measurement is advantageous, especially due to the fact that the measurement is not taxed with the error caused by inaccuracy in the analysis of the RMS noise spectrum level given by the analyzer.

C. The phase noise measurement

Phase noise is one of the quantities, which affect the quality of test signal in a critical way. It is caused by the fact that the phase noise, which rises in generator together with harmonic signal, is impossible to separate from harmonic signal and it will always acts its distortion.
Normalized single-sideband spectral density L(f) is a measure of the phase noise [4]. It is defined as the ratio of the power in one sideband, in frequency bandwidth 1 Hz to the total signal power at frequency difference f from the carrier (2).

$$L(f) = \frac{P_{ssb}(f_c + f, 1Hz)}{P_c} \tag{2}$$

where $P_{SSB}(f_c+f, 1Hz)$ is single sideband phase noise power on the frequency f_c+f (in the frequency offset f from the carrier frequency f_c), in frequency bandwidth 1 Hz,
P_c is the power of the carrier

The noise power relative to the carrier P_N/P_c is found by integrating the noise spectral density into the band of interest (Δf_1, Δf_2) (3).

$$P_N = \int_{\Delta f_1}^{\Delta f_2} L(\Delta f)\, d\Delta f \tag{3}$$

To determine the single sideband phase noise power P_{SSB} it is possible to use following:

- Direst spectrum analysis
- Carrier suppression
- Two sources and phase detector

Direct spectrum analysis is a technique to determine P_{SSB} directly by the spectrum analysis at the spectrum analyser. But for the measurement it is necessary for the AM noise to be much lower level than the PM noise and a measured level must always be at least by 10dB higher than intrinsic noise of the spectral analyzer.
The second requirement, however, markedly constrains the application of the direct spectra analyses for the signals with a low phase noise, since the level of the signal noise is lower than the noise level of synthesized local oscillator of the spectrum analyzer. To carry out a measurement with an exclusion of the close surroundings of the carrier (in several Hz), it is possible to use a direct measurement by means of a notch filter (described above) to suppress the carrier.

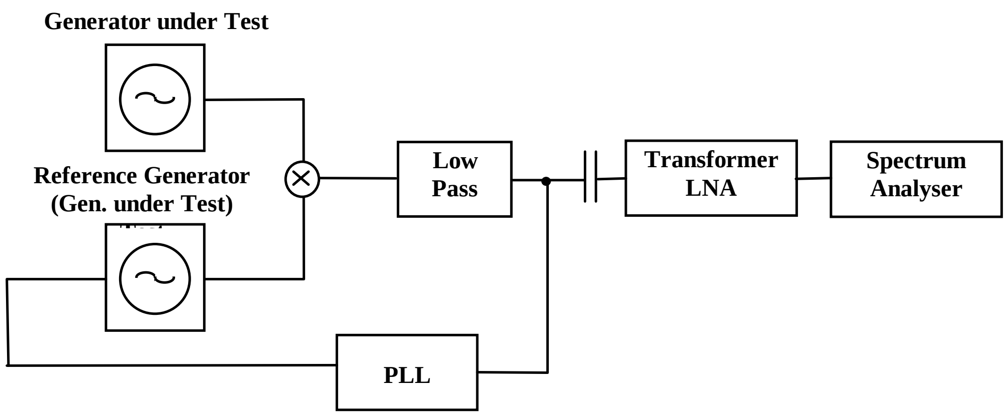

Fig. 6 Two sources phase noise measurement

Two sources and phase detector method, enabling also to measure signals with a noise-to-carrier ratio level less than 160 dB, is a method which compares the noise from two sources, e.g. in the system shown in Fig. 6, where two generators with the phase shift of 90^0 are synchronized in the loop of the phase lock. They generate a phase noise detected by a phase detector and this phase noise is further analysed by a spectral analyzer. The measurement is easy if two conditions are fulfilled. At first, the generators must be stable and a PLL loop bandwidth must be less than low cut-off frequency, on which L(f) should be measured. Secondly, either a referential generator with a phase noise by at least 10 dB less than the analysed generator is available, two equivalent generators are available to analyze, which can be synchronized in the PLL loop. An indicated intrinsic noise level can be reduced by increasing the power of both generators, if the phase detector is able to execute linearly such a high power.
The value of phase noise sideband power L´(f)(dBc/Hz) is possible to determine from voltages or powers indicated at the spectrum analyser (4).

$$L'(f) = 10 \log\left(\frac{U^2_{RMS}(f, 1Hz)}{U^2_{RMS}(B)} Kn\right) = P_N(f) - P_B + 10 \log Kn \tag{4}$$

where $U_{RMS}(f,1Hz)$ is the effective value of phase noise spectrum voltage on the frequency f, in frequency bandwidth 1 Hz
$U_{RMS}(B)$ is the effective value of beat signal voltage (for non-zero beating frequency, if PLL loop does not work)
$P_N(f)$ is the noise level of phase noise on the frequency f, in frequency bandwidth 1 Hz measured in dBm/Hz
P_B is the power level of beating signal in dBm
Kn constant, that qualifies power summation of noise signals, is of value 1/4 if the source has level noise at least 10 dB lower than the generator under test and Kn= 1/8 if both sources are of equal phase noise

A typical course of the sideband phase noise to carrier ratio is presented in Fig. 7.

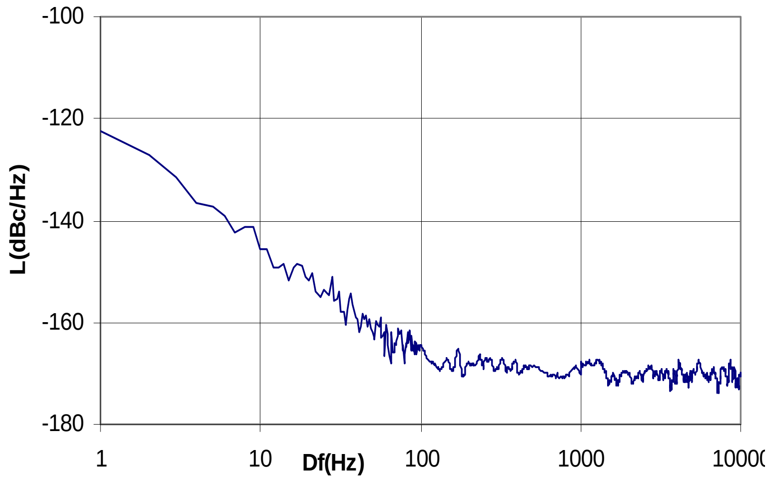

Fig. 7 A typical course of the sideband phase noise to carrier ratio

System for measuring with two sources and phase detector method is delivered by some firms as a commercial measuring apparatus (FSUB from Rohde -Schwarz), or it can be realized as special laboratory preparation.

III. Conclusions

The measuring modes described here in this paper, enable to pursue the quality of the testing signal with the SINAD in the range of 80 up to 140 dB by means of the spectrum analyser which is equipped with the accessories that were realised in the laboratory. The measurements were carried out at individually designed crystal generators with fixed frequencies in the range of 0.441 to 19.507 MHz

Acknowledgement

The research was supported by the research program No. MSM6840770015 "Research of Methods and Systems for Measurement of Physical Quantities and Measured Data Processing " of the CTU in Prague sponsored by the Ministry of Education, Youth and Sports of the Czech Republic.

References

[1] IEEE Standards (2010). IEEE Standard for Terminology and Test Methods for Analog-to-Digital Converters. IEEE Std 1241-2010.
[2] Isabellenhutte Heusler GmbH : Zeranin 30, www.isabellenhuette.de
[3] Papez,V., Papezova,S.: "A Simple Technique for Measuring Signal Source Noise", Proceedings of the 14 th International Symposium on New Technologies in Measurement and Instrumentation and 10 th Workshop on ADC Modelling and Testing, Gdynia/Jurata Poland, 12-15 September 2005, ISBN 83-89786 -37-0, pp 57-60
[4] Lance L., Wendell D., Labaar F.: “Phase Noise and AM Noise Measurements in the Frequency Domain”, Infrafed and Milimeter Waves, vol. 11, pp.239-289, 1984
[5] Smith, M.: Phase Noise Measurement Using the Phase Lock Technique,
www.sysdoc.doors.ch/motorola/AN1639.pdf