Special Harmonic Signal Generators for ADC Testing

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Abstract- In the recent years, a universal measurement setup for high-resolution ADC testing at the frequency band of 0,5-20MHz was designed and prototyped at the Czech Technical University. Parameters of harmonic signal are analysed in contribution, which is needed for inverters testing and further a construction of a special generator with high spectral purity is described.

I. Measuring signals for high-resolution ADC testing

Requirements on signals for testing of high resolution ADC get out of available parameters of tested converters.
The distortion of testing signal must be markedly higher than the highest reachable dynamic range of the tested equipment, so that the disturbing signals does not affect the measuring. The properties of a concrete testing signal must be monitored with regards to its expected usage.
At ADCs, the SNR (Signal-to-Noise Ratio) is considered to be a maximum obtainable dynamic range related to a quantizing noise. The highest value will be achieved, when an exciting sine signal with the amplitude corresponding to the maximum input voltage and all distortion in system is quantizing noise (1) [1], [2], [3].

$$SNR_{ideal}\,[dB] \cong 6n + 2 \tag{1}$$

where n is the number of ADC bits

Sine signal include, with regard to ideal harmonic course, some distortion and superposed noise. The disortion level 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 a relation in decibels expressed (2)

$$SINAD = 10\log\frac{P_S + P_N + P_D}{P_N + P_D} \tag{2}$$

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.

The measured value of SNR_{msd} is less than actual value of SNR_{ADC} for given ADC. Then it is possible to express the difference ΔS for final value SINAD of the test signal by relation (3). [4]

$$\Delta S = 10\log\left(1 + 10^{\frac{SNR_{ADC} - SINAD}{10}}\right) \tag{3}$$

ΔS difference value is 1 dB for SINAD about 6 dB greater than SNR_{ADC} , is 0,4 dB for SINAD about 10 dB greater and 0,1 dB for SINAD about 16 dB greater. Because the relation $SNR_{ADC} \leq SNR_{ideal}$ is valid and it is mostly possible to expect measuring change less than 0,5 dB, we can determine the valuables SINAD of the test signal according to (4) or (5), if n is replaced with ENOB (Effective Number Of Bits), which is in fact lower than n.

$$SINAD \geq (6n + 2) + 10 \tag{4}$$

$$SINAD \geq (6ENOB + 2) + 10 \tag{5}$$

SINAD according to (4), needed for the 12 bit ADC testing is 84 dB, for 16 bit ADC is then c. 110 dB, for 20 bit ADC nearly 130 dB. But not only quantizing noise limits the dynamic range of the realizable ADCs. At the ADCs with a great number of bits, the thermal noise of the analogue circuits processing the signal obtains the critical effect. The state then can be taken as a state of a radio engineering system having its dynamic range SFDR (Spurious-Noise-free Dynamic Range) (6) and dependently also a new SINAD.

$$SFDR = P_s - F - kT_0 - 10 \log B_N \tag{6}$$

$$SINAD \geq P_s - F - kT_0 - 10 \log B_N + 10 \tag{7}$$

where P_s is a level (dBm) of a radio system input signal

F is a noise figure (dB), kT_0 is a thermal noise level related to 1 Hz bandwidth (-174 dBm)

B_N is an equivalent noise bandwidth.

Typical values of the SINAD according to (7) necessary for the input impedance of 50 Ω, an input voltage $10V_{pp}$, $1V_{pp}$ a 0,2 V_{pp}, B_N 1 to 100 MHz , F=12 and 26 dB are presented in the following table.

SINAD (dB)	F=12 dB			F=26 dB		
	U_s=10V_{pp}	U_s=1V_{pp}	U_s=0,2V_{pp}	U_s=10V_{pp}	U_s=1V_{pp}	U_s=0,2V_{pp}
B=1MHz	136	116	102	122	102	88
B=10MHz	126	106	92	112	92	78
B=100MHz	116	96	82	102	82	68

Thereby considered SINAD values are lower than those in the previous case with regard to a relatively high noise figure of the converters. Nevertheless, the achievement of the SINAD at the test signal exceeding the value of 130 dB, for the ADCs processing a high-level signal with a narrow bandwidth can be necessary anyway.

II. Harmonic signal generators

At present, commercial sine wave generators are generally constructed as frequency synthesizers exploiting a principle of the direct (DDS) or indirect frequency syntheses (PLL). Generators have good frequency stability, currently better than 10^{-6}, but the suppression of the harmonic components of the generated signal, and the generated noise restricts available SINAD values to the values from 60 to 80dB.

Achieving particular improvements is possible relatively easily by the means of the generator output signal filtration using a linear filter. If the filter is really linear and is not a source of harmonic components in itself of a transient signal, it is possible to suppress harmonic components of the generated signal by 80-100 dB by a suitably proposed band-pass filter, and thereby the harmonic components stop influencing the signal parameters. In the same way, the filter also suppresses other unwanted components together with the noise superimposed onto the signal if they have big enough frequency spacing from the carrier (at least several per cent).

The noise of the generator in close surroundings of the carrier – a phase noise- becomes a determining factor for the availability of the signal generator SINAD.

For the commercial branded generators of an average price category HP33120 and BM592 of a frequency of 1053 kHz, typical examples of the spectra of the phase noise in the carrier surroundings are presented in Fig. 1.

With regard to a sharp drop of the signal spectral power density function, along with the increase in frequency spacing of the carrier, the level of the disturbing signals at both generators is determined practically only by the phase noise in the vicinity of the carrier. This phase noise has a relatively very high level occurring in a narrow frequency band. Generator BM 592 is a frequency synthesizer which has a relatively low thermal noise level, but in the vicinity of the carrier, it produces a relatively big amount of a phase noise, which restricts its available SINAD to a level of about 80 dB. The HP33120 is a functional generator which, on one hand, has a higher level of the thermal noise, but, on the other hand, has a lower level of the phase noise in the surroundings of the carrier, that enables it to achieve its SINAD, approximately of 90 dB.

A special generator as a source of a signal suitable for ADC testing has been constructed. The older generators consist of a controlling oscillator and a power amplifier with a maximum output power of 1W.

The controlling oscillator was designed on the basis of a simple verified construction of Clapp oscillator [5]. The circuit was optimized with regards to the minimal noise of all components, RF signal level stability, the RF power crystal loading, and temperature function stability. The controlling oscillator is placed in a small chamber

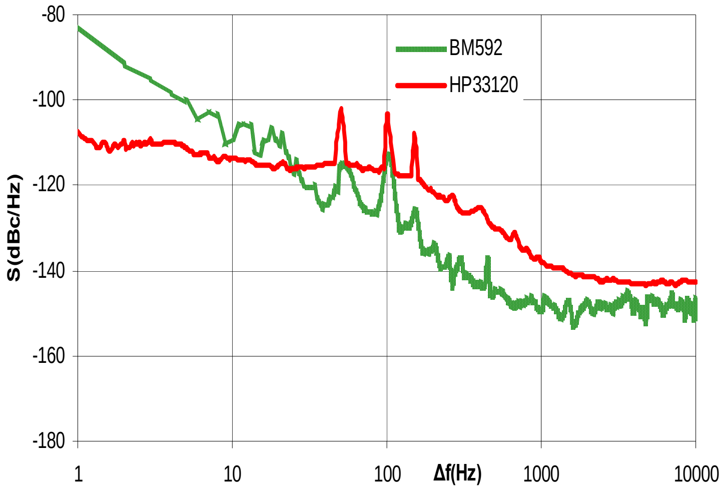

Fig. 1 Generators BM 592 a HP33120

with a constant temperature of 293K. This lower temperature satisfies the used AT cut and all the used components have lower level of intrinsic noise. The exchange of heat between the chamber and its outer environment is ensured by the Peltier thermoelectric module. At higher temperature of the outer environment, the Peltier module cools the chamber below its desired temperature; and heats it up (with current reversing) at lower temperature of the outer environment.

Parallel connection of 2-3 high current J–FETs [6] is used as an active element; non-linear negative feedback represented by a small light bulb is applied at the source outlet. The light bulb is current-carried by RF only. The increase in resistance at the light bulb in the signal level growth causes the drop of total mutual conductance of an active element. The value of IRF is necessary to choose by compromise. For the active element linearity, low loading of the crystal, and low temperature of filament of the bulb, IRF should be low and vice versa for high oscillator SNR signal it should be high. In our samples, IRF was app. 5mA, power dissipation of the crystal was app. 1mW, and the output power at the oscillator 10 mW.

High power amplifier uses a bipolar transistor; the matching is solved by resonant circuits, on the output a linear filter was used.

The simplest circuits with a minimal number of elements generating noise give the best results. The most important thing is the choice of a high-power transistor. To work as an amplifier in A class in a linear mode, it should give the power of app.1W. Therefore, it will be loaded with a power loss of 5W, while at an operational frequency it must have a power gain of 23-26 dB, maximal the reverse transmission of -40 dB at maximum and a noise figure of 3-6 dB at maximum.

The matching of the amplifier input is solved with a tank circuit; the transformer is replaced by a choke coil when connected in the drain of generator transistor. At the output of the amplifier, the matching is solved by the tuned Π network working with the high loaded Q of app.60. For the highest suppression of harmonic components of the generated signal, a special highly linear two circuit band-pass filter is implemented at the output of the amplifier.

Problem of generator and amplifier power supply is neglected too. Any noise incoming together with power supply is modulated onto produced signal and makes its SINAD worse. Only a battery-power supply is a simple and safe solution. But voltage change makes output signal level instability at discharging, otherwise special sources, designed especially with regard to minimal basic noise, are necessary to use for power supply [7].

The frequency spectrum example of the realized generator is introduced in Figure 2 for frequency 1,053 MHz in neighbourhood of the carrier.

Testing generator of latter construction was realized for dynamic testing ADC as sample equipment with its own power supply out of grid or from inbuilt accumulator with output power 1W at the frequency 1053,276 kHz.

The arrangement construction gets out of previously realized low noise stabilizer of DC supply voltage and generator with high spectral purity.

In this case VF generator was modified for using of oven crystal oscillator OCXO6 series, which was produced especially for this object by HC electronics firm Ltd Hradec Králové [8]. The level of generator phase noise is

without further adjustments roughly about 20 dB higher than in case of previously used construction of the Gouriet -Clapp generator with low noise transistor J-FET and with stabilization of the amplitude by use of the nonlinear resistor. The level of the oscillator phase noise is further suppressed by insertion of the crystal filter with minimal bandwidth -B3 ~ 4Hz at the output OCXO and approaches to values reached with Gouriet -Clapp oscillators.
Block diagram of the generator VF part is presented in Fig. 3

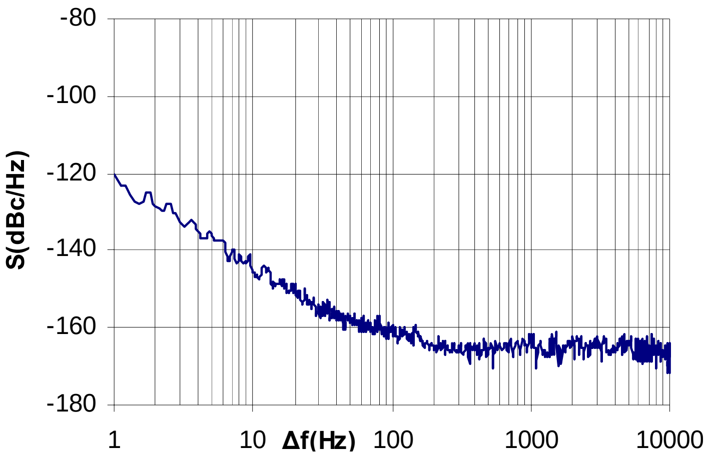

Fig. 2 Frequency spectrum of the generator 1,053 MHz

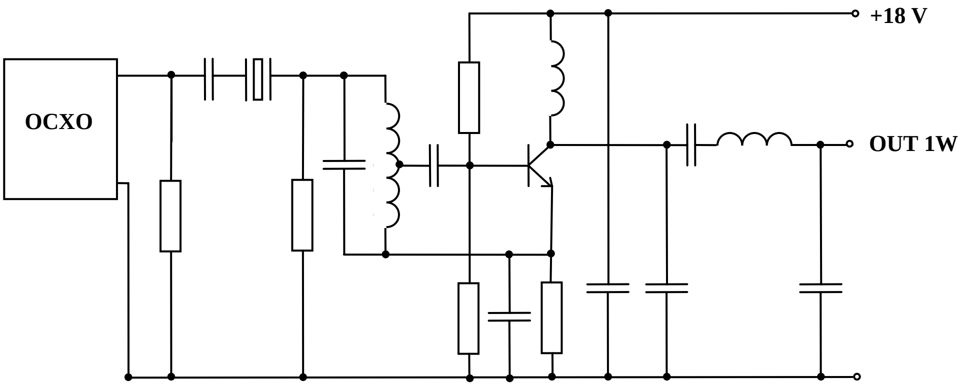

Fig. 3 Block diagram of RF generator

The power supply for HF generator is also solved by the help of a special method. Power source makes it possible to supply the generator out of power network or from an inbuilt accumulator. Mains part of the source is solved by classic technology i. e. by transformer and rectifier, which work at mains frequency and subsequent filtering and DC voltage stabilization. Accumulator allows several-hours apparatus running without power supply from grid. This solution was originally chosen, because the assumed lowest noise level at generator output is only possible to achieve in arrangement running by supplying out of inner accumulator. It is absolutely possible to remove also random disturbing signals propagation out of grid.
The block diagram of the power supply is presented in Fig. 4.

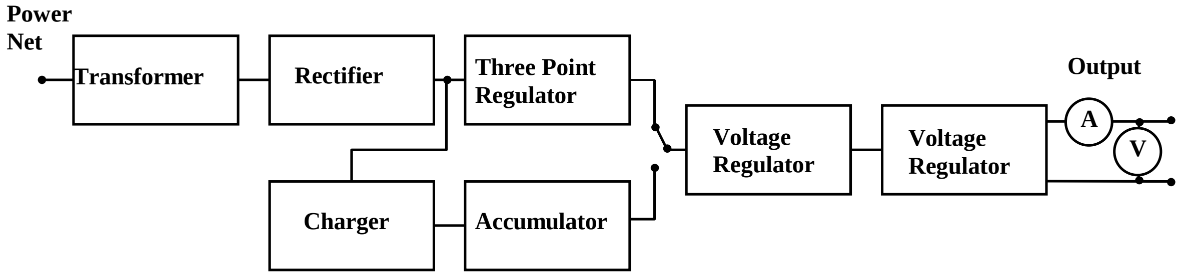

Fig. 4 The block diagram of the power supply

Two stabilizers at the source output are voltage regulators, that are realized according to [7] from discreet components aimed at achieving the minimal level of signal noise, produced by them.
Output voltage of the first one is 18 V and it is used for power amplifier of the generator and for power supply of the second stabilizer with output voltage 12 V, which is used for OCXO. Cascade of two stabilizers achieves stabilization factor better than 120 dB, disturbing signals originating in previous stabilizer match to the level approximately 1 nV and so they are not already identifiable in stabilizer noise.
The spectrum is analogical at the supply running out of grid, but disturbing signals at frequency 50 Hz and its multiple, exceeding level noise about 10 up to 20 dB, come up in addition. Signal noise level is in both cases low enough to affect phase noise of generator notably. The realized source also corresponds in terms of other parameters. Output voltage drift due to accumulator discharging, voltage variation of the grid or apparatus heating is lower than 10 mV. Running out of the inner accumulator is possible during the time of about approximately 8 hours.
Internal arrangement of the instrument is displayed in Fig. 5.

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Fig. 5 Internal arrangement of the instrument

The frequency spectrum at the output generator is presented in Fig. 6.
The generator marked as HC uses, as a controlling oscillator, an oven-stabilized crystal oscillators OCXO6 produced by HC Electronics. The generator HC+F uses an oven-stabilized crystal oscillator OCXO6 as well and, moreover, the crystal filter is implemented between the controlling generator and a power amplifier.

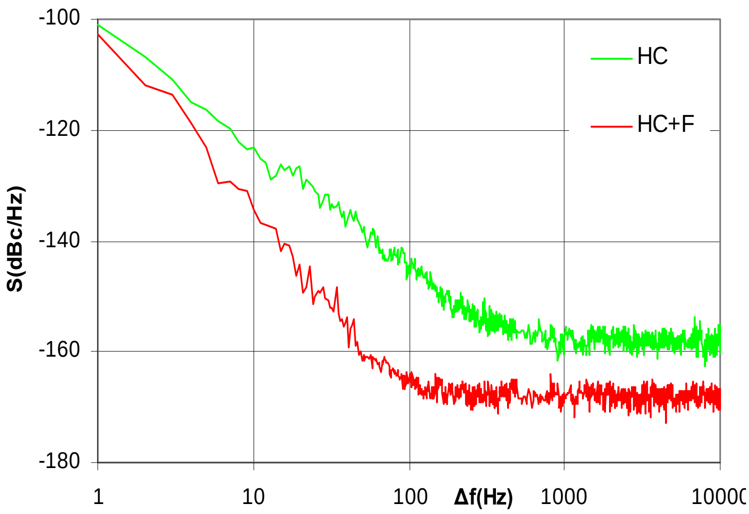

Fig. 6 Frequency spectrum of the generator with OCXO

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III. Conclusions

Commercially used generators enable achieving the SINAD value of approximately 90-100 dB, which is sufficient to the dynamic testing of the ADCs with the ENOB up to 15 bits; at common converters with a noise figure about 20 dB respectively. For testing ADCs of a higher quality, it is possible to develop special testing generators enabling us to achieve the SINAD of 120 -130 dB. It enables testing the ADCs with ENOB up to 20 bits.

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