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Signal Generator with Minimal Distortion for ADC Testing

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***Abstract*-**The special generator of testing signal was designed for the frequency of 441.171 kHz. The generator consists of the special crystal oscillator and a high power amplifier. The frequency stability of the generator is in order of 10^{-6}/day, the output power 1W, the value of SINAD is close to 120 dB and the total harmonic distortion under - 170 dB by using of linear narrow-band filter.

I. Introduction

The sinusoidal signal is suitable for the ADC dynamic testing especially for the reason that it can be relatively most easily generated with minimum shape distortion, or with high spectral purity, respectively. Therefore the use of this signal is the basis of test methods serving for determination of the ADC key parameters.
In the amplitude frequency spectrum, the ideal sinusoidal signal contains only one spectral component representing the basic harmonic one. A real signal spectrum is more complex; it contains higher harmonic components, inharmonic components and a noise.
The quality of test signal may be characterized with help of SINAD (Signal to Noise and Distortion Ratio) parameter, which is defined as ten logarithms of the ratio of the power of the carrier and the power of all signal components less the power of the direct component less the power of the carrier (1).

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

where P_{All} is power of all signal components,
P_0 power of the direct component,
P_1 power of the carrier.

For error-free measurements, the test signal must have the signal-to-disturbance ratio expressive higher, than the highest achievable dynamic range of the testing equipment, so that the distortion signals could not influence the measurements. In case of ADC, and if we will consider for the maximum achievable dynamic range its signal noise ratio (SNR) at excitation with sinusoidal signal with amplitude corresponding to the maximum input voltage, then the requested value of SINAD of the test signal for n-bit ADC can be expressed with relation (2) [1].

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

where PR is the protection ratio, which is selected, depending on the requested accuracy, in the range from 10 to 20 dB, usually 10 dB.
According to this, for testing of the 14-bit ADC, we need a signal with the value of SINAD = 96 dB, for 16-bit ADC - SINAD = 108 dB and for 20-bit ADC - SINAD = 132 dB.
The typical signal spectrum of commercial generator is shown in Fig. 1. The SINAD value is given by the sum of power harmonic components and of the noise. Because the harmonic components have very different level, the component with peak power level (in Fig.1 the 3rd harmonic one with the level -70 dBc) practically designates the total power. Total output power of the noise signal is defined by the integral of noise spectral power density in whole frequency band, that is transferred of generator into ADC and varies, according to the example in Fig. 1, between -80 and -70 dB. Both components have approximately the same values and it is not possible to improve this state even by use of filter for bandwidth wider than several hundreds Hz. A generator

with such parameters can be used without problems for testing of the 10-bit ADC at maximum.

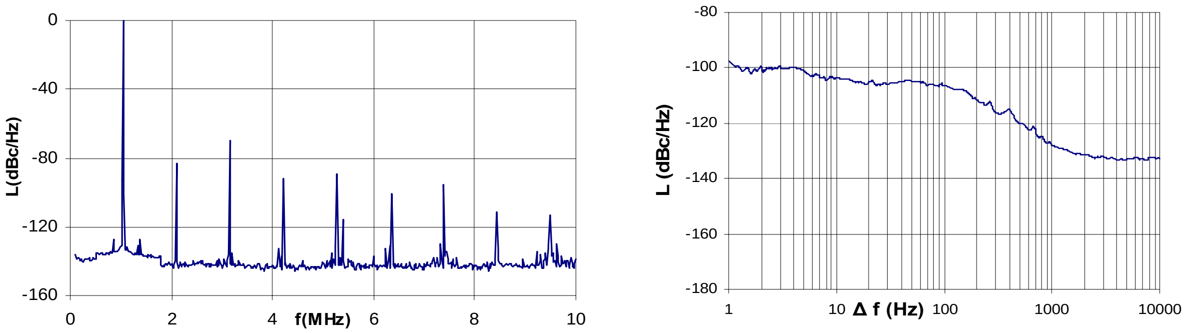

Figure 1. Agilent generator 33120, $f_c = 1.053$ MHz, $P_{out} = 10$ dBm

II. Generators with a high spectral purity

Special generators have been constructed as the sources of testing signals for ADC testing. Generators were designed with a constant frequency, presently in range from 0.4 to 20 MHz, and for an output power of approximately 30 dBm.
A quartz resonator controls a basic oscillator. The design of oscillator is selected especially with regard to the possibility of achievement of the high frequency stability and the fast fall of the phase noise round of carrier at offset frequency growth.
The optimization of the control generator is based on approximation of the oscillator, which shows the noise by means of the perfect oscillator, which is amplitude modulated by the noise signal. The amplitude modulation is converted within the oscillator circuit also to phase modulation and creates the undesirable non-harmonic spectral components round carrier [2].
Based on this analysis, we may determine the basic requirements for structure of the oscillator with the minimal internal noise:

- The oscillator uses the resonator with maximal loaded Q-factor;
- Components used have minimum noise 1/f;
- The oscillator operates with maximum possible power output;
- The signal level of the oscillator is stabilized and controlled;
- Elimination of possible introduction of the noise signal into the oscillator from outside;

The circuit structure of generators is selected simply, as a quartz oscillator with one stage amplifier. The generator was designed based on simple and earlier verified structure of the Gouriet-Clapp generator with amplitude stabilization with non-linear resistor. The circuit was optimized with regard to minimum noise of all components, stability of the RF signal level, loading of crystal with RF power and temperature stability of function. The used active element has to have a low noise figure and high output power for the achievement of a great SNR on the output oscillator. The used high current J–FET has a small noise figure also at low frequencies (3 dB/1MHz) and a high level of intercept point (30 dBm) so that the output power has been approximately 10 dBm chosen with regard to the possible crystal loading. High power amplifier uses a bipolar transistor; the matching is solved by resonant circuits. The amplifier has the gain of 20 dB at the output power 1 W and the bandwidth B3 1/50 to 1/30 of service frequency, approximately. The harmonic suppression is better than 80 dBc for all frequencies in the output; we suppose the use of a linear filter. The noise figure of this power amplifier is 7 dB at its working frequency. The power source with minimal basic noise, with level of the noise voltage up to 1 nV/√Hz or a good accumulator is used for the power supply of the generator. The frequency spectrum of the generator of 1.053 MHz around the carrier is displayed in Fig. 2. It is possible to achieve the level of SINAD 120 dB at the output power 1W.
The design functions very well in frequency band of 1 – 20 MHz, where AT cut crystals are used with ESR of 20 - 50 Ω approximately, which may be loaded with power of 10 mW, approximately.
Totally different situation occurs on lower frequencies, in the band 400 - 500 kHz. Here the DT cut crystals are used with the ESR by one order higher, 300 - 400 Ω, which may be loaded only with considerably lower power. The typical frequency dependence of Y behavior on the driving power for DT cut crystal, 440 kHz, is shown in Fig. 3. The quartz crystal warms due to the Joule loss (it causes its thermal instability and shows itself as a change of resonance frequency and nonlinearity of the crystal), shows its thermal instability by undesirable way,

and also its non-linearity can be exhibited. The diagrams show that the quartz crystal cannot be loaded by input power greater than 100 µW. In case of a higher power the resonant frequency of the crystal varies and its quality factor fall down (in Fig.3 it is indicated by the drop of the peak value of admittance at the crystal resonance).

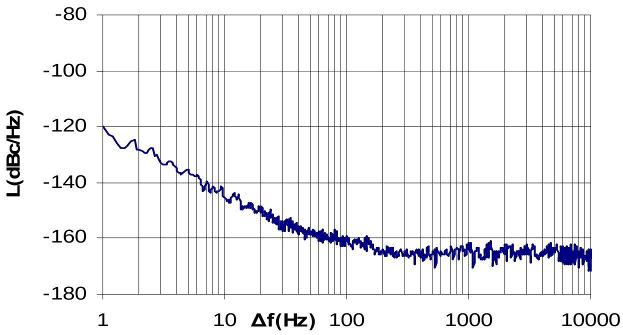

Figure 2. Narrow spectrum of the generator 1.053 MHz

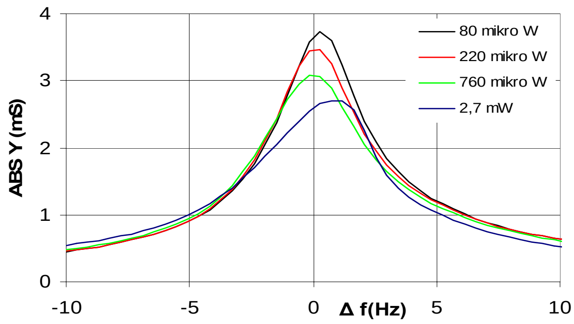

Figure 3. Power dependence of quartz resonant curve

The simple quartz oscillator does not work so that to comply with basic requirements. At crystal power losses of 100 µW, the output power of the oscillator is 1 mW, approximately. At the oscillator it is only very difficult to stabilize the generated signal level and surrounding temperature inadmissibly influences the oscillator function.
Therefore a special bridge symmetric crystal oscillator was developed for use of DT cut crystals in lowest frequency bands. The Wheatstone bridge connected in the feedback loop between input and output of the amplifier [3] represents its basis. The oscillator circuit is solved with regard to minimum distortion of the signal and maximum of the useful signal -to- noise ratio, thoroughly as a symmetric circuit. The oscillator amplifier is a push-pull differential amplifier completed with circuit for control of amplifying for stabilization of level of the generated signal.
The oscillator bridge is wholly symmetric as well; it contains 2 identical crystal resonators and 2 linear resistors. This modification allows to assure, with crystals with small allowed power losses, a high selectivity of the bridge and sufficient power for the amplifier excitation. In comparison with conventional Wheaston bridge with 1 resonator, the symmetric bridge allows approximately double increase of the fictive Q factor of the resonator quality for the same amplification of the amplifier. For achievement of identical output voltage of the bridge and identical fictive Q factor of the resonator quality, there is attached a half voltage on resonators in the bridge with 2 resonators and the resonators are loaded with a quarter loss power [4].
Transfer of the bridge selective circuit and the simple Π-network with crystal (Gouriet-Clapp oscillator) are compared as a Nyquist plot of the whole oscillator, which is shown in Fig. 4. The curves are valid for the crystal with values 1.053 MHz, Q = 2.5 10^5, ESR = 28 Ω, the transfer of the bridge is selected as 0.1, condensators of the Π- network are selected for |Xc| = ESR and they are shown as points with frequency step of 0.5 Hz. It is obvious that the phase characteristic of the bridge is approximately 5-times steeper, than the phase characteristic of the Π-network, which contributes to reduction of the phase noise of the oscillator bridge.
The bridge is connected in the oscillator circuit so that one terminal of its input diagonal is earthed. The output signal on the second diagonal of the bridge is the voltage between its terminals and is processed as a floating voltage against the ground potential with differential inputs of the push-pull amplifier. The amplifier is equipped with the high current J–FET. In symmetric connection is well compensated the nonlinearity of their approximately quadratic transfer characteristic and there is significantly reduced the nonlinear distortion of the signal transferred by the amplifier. This allows to reach a higher frequency stability of signal generated by the oscillator and to reduce the conversion of noise amplitude modulation to phase modulation, which allows to

reach also a higher suppression of the phase noise in the signal spectrum. Simultaneously, a high suppression of transfer of summarized signal is reached with symmetric amplifier as well. The output circuit of the amplifier is realized with a balancing output transformer. The symmetric winding of the transformer is connected to drain electrodes of transistors; the non-symmetric winding is connected to the bridge, from which there is taken the output signal of the generator. The inductivity of the transformer winding is tuned with condensator to working frequency of the oscillator.

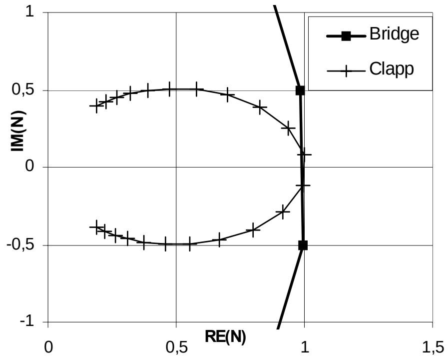

Figure 4. The Nyquist plot of the bridge and Gouriet-Clapp oscillators

The control of the amplifier amplification was made – in simpler case by a non-linear resistor, later by a control loop allowing the control of amplification of active elements.

The control of the amplifier amplification by the non-linear resistor is realized by the resistor having an accurately real impedance, which value depends on attached voltage and simultaneously the flowing current does not show a harmonic distortion (barretter) against the applied voltage. A non-linear resistor is contained in the real controlled amplifier, which resistance increases at increasing level of signal, and which is connected between sources of transistors in symmetric stage so that a direct voltage cannot be applied on it. At increase of voltage on the resistor there occurs an increase of its real component of impedance and a decrease of the amplifier amplification. A non-linear resistor, which resistance decreases at increasing level of signal, can be connected between drain electrodes of transistors in symmetric level so that a direct voltage cannot be applied on it. At increase of voltage on the resistor there occurs a decrease of its real component of impedance, a decrease of the real component of loading impedance of the amplifier and a decrease of the amplifier amplification.

The control of the amplifier amplification by the control loop, which controls the amplification of active elements, can be used at the amplifier with active elements, by a quadratic transfer characteristic, e.g. by used J-FET transistors. By the change of bias current of the transistor there is changed its mutual conductance (it is roughly directly proportional to the bias current), therefore in a symmetric amplifier, it is possible to control in certain limits the amplifier amplification without increase of non-linear distortion of transferred signal. The control signal of the loop is the output signal of the amplifier, which rectifies the sample of the oscillator output signal. The control signal of the loop circuit is further filtrated and amplified and is led to the circuit of setting of the working point of active elements of the amplifier. The increase of output voltage of the amplifier causes the decrease of the bias current of amplifier transistors and consequently also decreases of the amplifier amplification. A fundamental diagram of the oscillator is shown in Fig. 5.

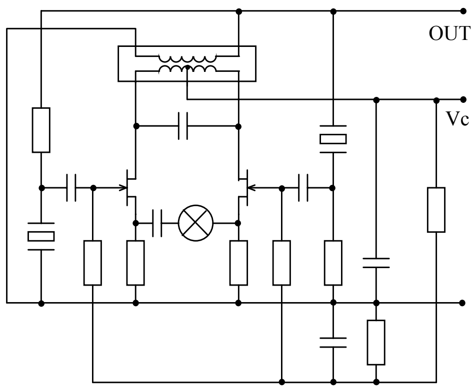

Figure 5. Fundamental diagram of the oscillator

The output signal of the generator is taken from the secondary winding of the balancing transformer. In this case this solution is more advantageous, than taking of signal directly from the crystal circuit [5], because the signal power, which is available on the transformer, is at least by one order higher.
Nevertheless, only a quality separating amplifier can be connected to the oscillator, which have a linear constant and only real input impedance and a neglectable back transfer. A common-gate amplifier with power J-FET e.g. P-8002 is used, with which it is possible to reach the Noise Figure of 2 to 3 dB at current of 30 to 50 mA.
The high power amplifier solution uses a bipolar transistor; the matching is solved on input with a tank circuit, on the amplifier output the matching is solved by a tuned Π network, which works a with high loaded Q with approximate value of 60. Here can be used the power transistor as an active element with parameters of the good AF power transistor, power dissipation of app. 10 W, current transfer ratio of 200, approximately, gain bandwidth product of 100 MHz and also with a low noise figure, mostly of 6-7 dB. Here a problem is met, because the noise figure is not shown at these transistors and it must be measured and tested. From available types there were used the best ones - 2SD669, 2SC4793 above 2SC2238. A fundamental diagram of the amplifier is shown in Fig. 6.

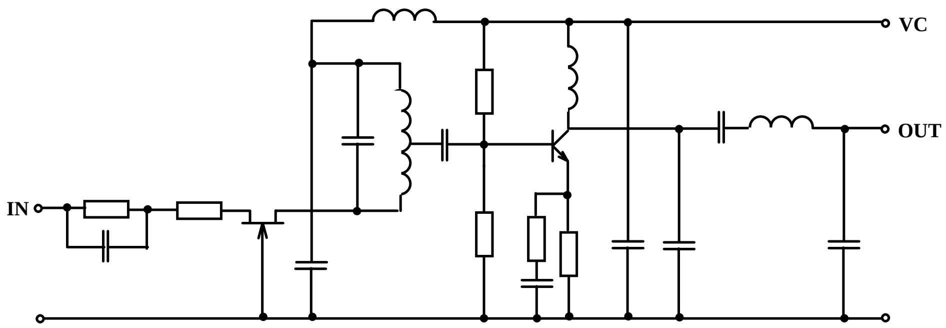

Figure 6. Fundamental diagram of the amplifier

A special highly linear two-circuit band filter can be further inserted to the amplifier output, with which it is possible to reach a suppression of higher harmonic components of generated signal better, than 160 dB.
Filter neither has to generate its own parasitic signals. As well as a linear filter usually makes up a common band-pass filter from the circuit view. But this circuit has to be realized of parts with their own minimal non-linearity. Filters, which are able to process a power of order units W, have to be constructed by a special way, as well as the known filters, which process a power of order kW. [6]. Inductors have to be solved without using ferromagnetic. Air or vacuum capacitors are preferably used. It is possible to use ceramic capacitors only with a low permittivity of dielectric and that, which are dimensioned for the voltage approximately 100 times higher, than which they will be loaded in filter with. But imperfect contact connections, all ferro-magnetic materials used in the construction of the filter or possibly nickel-plated connector can do difficulties too.
The band filter for frequency 441 kHz is shown in Fig. 7. The filter has the bandwidth B_3=8 kHz, the band-pass loss 3 dB, the 2nd harmonic attenuation 87 dB, the 3rd harmonic attenuation 110 dB.

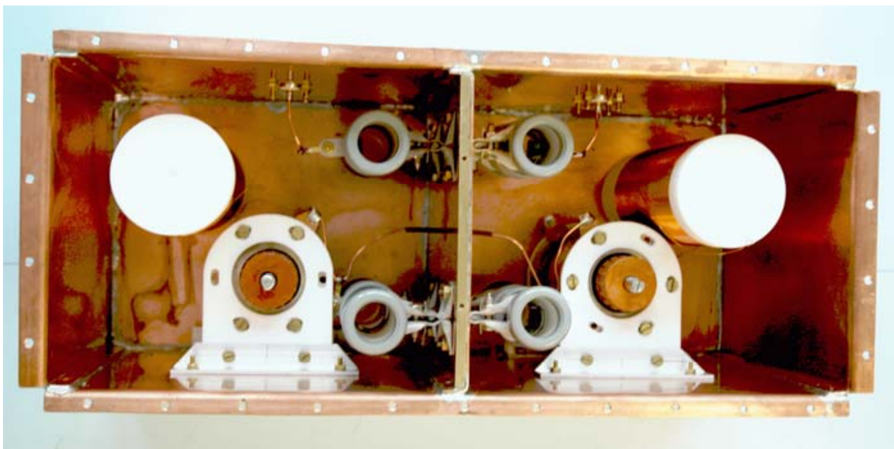

Figure 7. Highly linear band-pass filter for frequency 441 kHz

III. Conclusions

The contribution submits the analysis signal generators from the point of view of spectral purity of their output signal. Further, there is described the construction of special measuring generators in frequency range from 0.4 to 20 MHz. The frequency spectrum of the generator 441.171 kHz is displayed in Fig. 8 and 9 (with the accumulator power supply). All realized generators have similar parameters. It is possible to achieve the level of SINAD of 120 dB at the output power of 1W. The signal quality is adequate for the dynamic testing of 18 bit ADC.

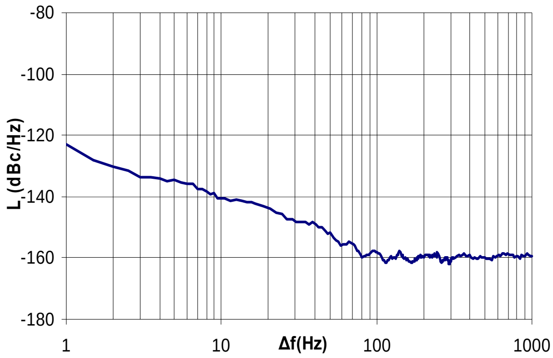

Figure 8.Narrow spectrum of the generator 441.171kHz

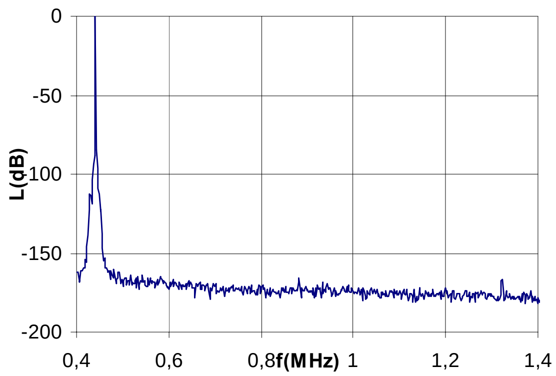

Figure 9. Wide spectrum of the generator 441.171 kHz

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