# Highly Pure Sine-Wave Signal Sources for ADC Testing

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*Abstract-* It is necessary to keep at the disposition test signals with a high spectral purity for series measuring e.g. in the area of metrology or electronics. Commercial signal generators do not satisfy higher requirements in this area. Our contribution describes chances of the improvement of their quality while using of suitable filters. There is described the construction of a special generator with a high spectral purity of a signal.

## I. Introduction

The level of spurious components identifies the quality of the test signal. These are harmonic signals, inharmonic spurious signals and noise. A typical spectrum of a sine signal is displayed in Fig. 1. Power of all components, which get to the input of the tested arrangement and will be processed by this arrangement, are determining for quality of the signal.
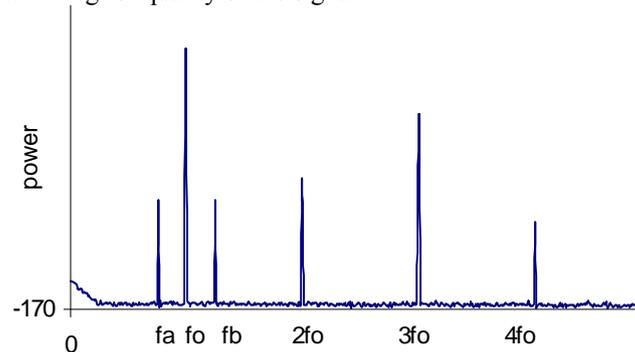


Figure 1. Spectrum of a real harmonic signal

This situation is not much advantageous to ADC converters, which process frequency from DC to a cut off frequency of the anti-aliasing filter. The cut-off frequency can manifold exceeds the frequency of carrier, therefore converters respond on many harmonic and a noise in a wide frequency range.

Quality of the test signal is characterized e.g. by the ratio of the signal (carry) to all disturbance signals, which is given by a value SINAD (Signal it Noise and Distortion Ratio), (1), [1]. ($P_{All}$ is power of all signal components, $P_0$ power direct component, $P_1$ power of the carrier).

$$SINAD = 10 \log \frac{P_1}{P_{All} - P_0 - P_1} \qquad (1)$$

In order that the measuring may always be error free and no-affected by disturbing signals the test signal has to have a signal-to-noise ratio expressive higher than the maximum available dynamic range of the tested arrangement. In case of the ADC we will consider: as a maximal available dynamic range its signal to noise ratio (SNR), exciting sine signal, its amplitude accordant with the maximal input voltage [2], Then it is possible to express the requirement SINAD test signal for n–bit ADC approximately by relation (2)

$$SINAD - PR \geq (6n + 2) \qquad (2)$$

PR is a protection ratio, which we choose in the range 10 to 20 dB depending on the required accuracy of the measurement. SINAD, needed for testing of the 16 bit ADC, is then c. 110 dB, for 24 bit ADC nearly 160 dB.

For a radio engineering arrangement we suppose the dynamic range SFDR (Spurious-Noise-free Dynamic Range) [3] and we receive analogical (3)

$$SINAD - PR \geq \frac{2}{3}(P_{IP} - F - kT_0 10 \log B_N)$$ (3)

$P_{IP}$ is a level (dBm) of the intercept point IP of an arrangement, F is a noise figure (dB), $kT_0$ is thermal noise level related to 1 Hz bandwidth (-174 dBm) and B is equivalent noise bandwidth. SINAD needed for a test of a top-echelon arrangement ($P_{IP}$ = 50 dBm, F = 3 dB) a $B_N$=1 kHz, is then approximately 130 to 140 dB.

## II. Harmonic signal generator

We have to evaluate properties of the concrete test signal depending on its supposed using, especially on the bandwidth of the tested arrangement. Following spectrum evaluation of a functional generator Agilent 33120 may be an example wideband spectrum in range to 10 MHz, at working frequency 1,053 MHz and output power 10 mW is displayed in Fig. 2. The value SINAD is given by the sum of power harmonic components (3. harmonic) and of the noise and varies around –67 dB. The spectrum in a narrow band, which will be decisive for the using in narrowband circuits, is displayed in Fig. 3 for the bandwidth of 200 kHz. There is the value SINAD given by the noise level and reaches a level about -85 dB. It would be even possible to achieve better level by further decrease of the bandwidth. Likewise it is possible to achieve better level SINAD in wide band by a harmonic suppression. The signal spectrum, in case of narrow band-pass filter insertion on the output of the generator, is displayed in Fig. 4.
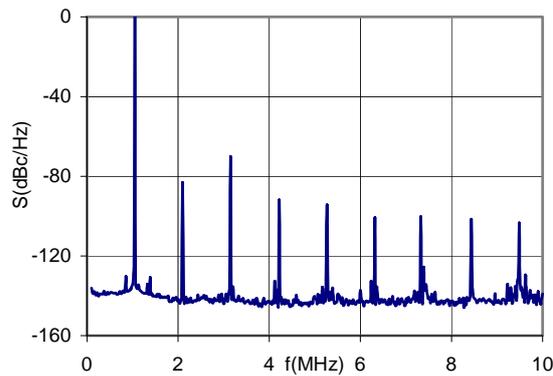


Figure 2. Generator Agilent 33120,
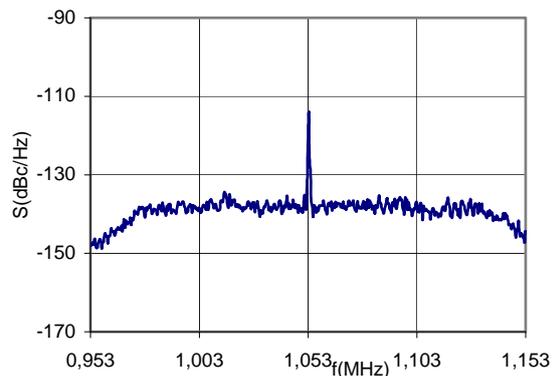$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm,
frequency band 0,1 to 10 MHz



Figure 3. Generator Agilent 33120,
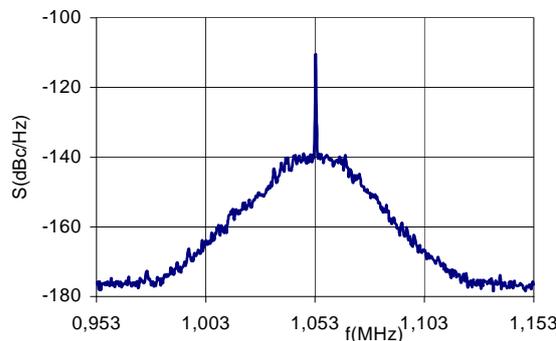$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm



Figure 4. Generator Agilent 33120,
$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm, band-
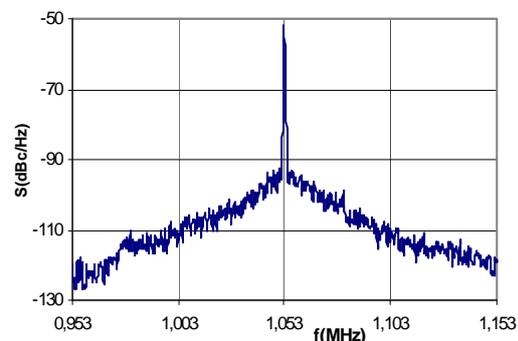pass filter is inserted on the output



Figure 5. Generator ELSY SG2000,
$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm

In the spectrum there is evident, that the filter suppresses the wideband noise signal. A constant level of the thermic noise is noticeable on band margins, where the input noise signal is already suppressed. So

it is possible to achieve SINAD –95 dB in the range 200 kHz at the output power 10 mW. Neither a thermic noise level of the filter no harmonic, which are suppressed on a level better than –160 dBc, already affect the signal-to-noise ratio and SINAD stays the same in the range of wide band to 10 MHz. This signal has markedly better parameters at using of the filter. A noise of the generator in narrow band of the carrier – phase noise – is then dominant for available signal-to-noise ratio. There is impossible to suppress this phase noise by filter.
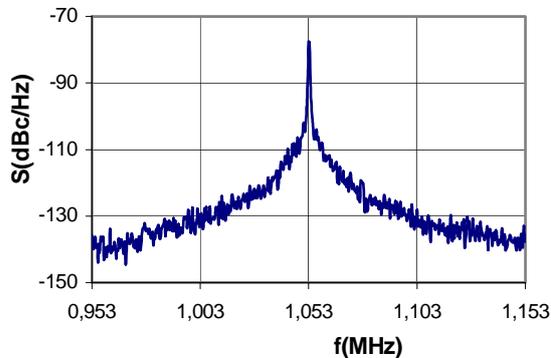


Figure 6. Generator Rohde-Schwarz SMY 01,
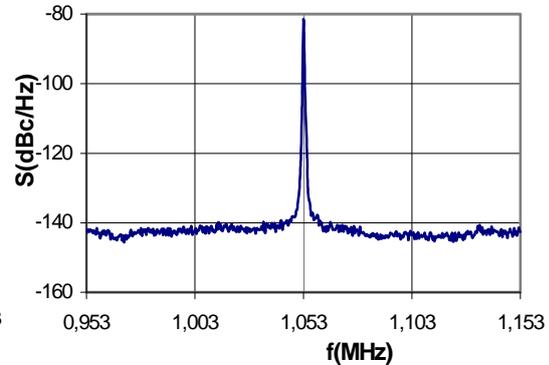$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm

Figure 7. Generator TESLA BM223,
$f_c$ = 1,053 MHz, $P_{out}$ = 10 dBm

Characteristics of typical generators are presented from this aspect in Fig. 5 to 7. The spectrum of a cheap synthetizer ELSY SG2000 is in Fig. 5. The signal-to-noise ratio is minimal and an available value SINAD will be between –60 and –50 dB at the filter using. This generator is applicable only as service generator. The spectrum of Rohde –Schwarz SMY 01 synthetizer is in Fig. 6. That generator is a typical type of marked middle-class instruments. It has been developed for measuring in narrow band radio electronic systems. This generator has better properties than the one previous. It enables to achieve a SINAD level approximately –70 dB at using of the filter. The 40 years old TESLA BM223 generator has been tested for date comparison. This apparatus has a free running tube high power oscillator. Otherwise this generator has no the stability $10^{-6}$ as modern apparatuses, but the spectrum purity of the output signal is better, than at much modern generators. The spectrum is displayed in Fig. 7. It is noticeable, that generator embodies the signal purity in watched range even any better, than Agilent 33120 generator, which has been the best of watched commercial instruments.

## III. Linear filters

Filter with a high spectral purity for signal processing has not only to suppress spurious signals, which come on its input. Filter neither has to generate its own parasitic signals (the harmonics); it has to be linear. Linear 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. [4]. As well as a linear filter usually make up a common band-pass filter or low-pass filter from the circuit view. The filter has been designed with the emphasis on the maximal suppression in stop band, skirt ratio of amplitude characteristic and simplicity. Basic used structures are ladder network T and Π for low-pass filter and a string of coupled resonant circuits for the band-pass filter. Besides the aspects common for the construction of all filters, further aspects resulting from non-linearity of used components have been also accepted in our case.

High wattless power, high working Q factor of resonant circuits contribute to good suppression in the stop band, and to the high rate of decrease of frequency characteristic. But the high voltage and current result in the increase of non-linearity in elements of the filter.

Non-linearity of all components, which are used for realization of the filter, affects the resulting non-linearity of the filter.

**Capacitors** usable in HF range are mostly of a ceramic type. But the ceramic materials with high permittivity, e.g. BaTiO, are ferroelectric and non-linear. Ceramic capacitors are not suitable for the use in circuits with a high linearity. Ceramic capacitors can be used only if they do not contain ferroelectric materials and under condition that there is low field intensity in dielectric. These conditions are met by high voltages RF power capacitors, primarily used for transmitters.

Mica capacitors have low losses, and low temperature and voltage dependency of capacity. However, their non-linearity is usually greater than non-linearity of ceramic capacitors. The reasons are either contact between the silver-plated mica foils and leads, or the impregnation imperfections.

Vacuum capacitors have the best properties. Their price and relative unavailability are their main disadvantages.

Air capacitors are often used as trimming ones. They have small losses; air works as dielectric linear before corona and discharges appear, caused by high intensity of electric field. Mechanical collector of a rotor of a capacitor can also be a source of non-linearity. It is possible to use capacitors without mechanical collector - butterfly capacitors or split-stator capacitors.

Levels of the $3^{rd}$ harmonic to carrier ratios for some types of ceramic and micaceous capacitors measured with CLT 1 apparatus by Radiometer Copenhagen Company are compared. At working voltage 30V are the $U_3/U_1$ ratio for USSR capacitor K15 U- 2200 pF/3 kV –160 dB, for Tesla mica capacitor WK 702 17 3300 pF/4 kV –150 dB, for Tesla ceramic capacitor NPO TK755 750 pF/250 V– 130 dB. The $3^{rd}$ harmonic level was below the apparatus sensitivity threshold for the vacuum capacitor KP 1-8 100 pF/5kV and air capacitor R-920 20 pF, both of USSR production. The $3^{rd}$ harmonic to carrier ratio for all voltages (up to 200 V) was better than 160 dB.

**Inductors** with minimal non-linearity can be realized as air coils without ferro-magnetic core only. The coil construction for frequencies higher than 1 MHz has to be as follows: a single-layer winding, solid circular conductor, winding gaps, coil length preferably less than its diameter. A shielding must be made of a good conducting material; diameter and length of the cylindrical shielding should be approximately 2 times higher than coil dimensions. Levels of the 3rd harmonic to carrier ratio were measured by the system according to [5]. At working current 50mA was the $I_3/I_1$ ratio for coil 2 μH on ferrite toroid Ø 10 mm , $\mu_r$ = 50 –20 dB, coil with ferrite trimming screw core Ø 3,5 mm, l = 8 mm, $\mu_r$ = 50 –50 dB and air coil 12 windings, Ø22 mm, l = 22mm –170 dB.

The linear filter has to be realized of parts with their own minimal non-linearity. The level of generated spurious products (3. harmonic) with regard to processed signal must not exceed -180 to -160 dB at any parts in high-quality filter. Inductors have to be solved without using ferromagnetic. It is preferably to use air or vacuum capacitors. It is possible to use ceramic capacitors only with low permittivity of dielectric that has a low permittivity and 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 amplitude characteristic of used 1053 kHz filter is shown in Fig. 8 The filter has the bandwidth $B_3$=25 kHz, the band-pass loss 2 dB, the 2nd harmonic attenuation 87 dB, the 3rd harmonic attenuation 100 dB.

For the non-linearity measuring uses a notch filter for extension of the dynamic range of the measuring system according to the Fig. 9. The carrier is suppressed by the notch filter, so that signals on the spectral analyzer input have lower level difference.

The notch filter should consist of linear components to avoid the generation of higher harmonic components, [6].
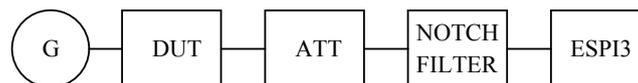


Fig. 9 Block arrangement for the filter measurement

The 3rd harmonic to carrier ratio is better than 150 dB, at the output power 30dBm. The rejection is better than 160 dB for the other harmonic components.

## IV. Generators with a high spectral purity

A special generator has been constructed as the generator with a constant frequency. The frequency of the first specimen has been chosen 1.053 MHz with reference to minimal interferences with clock frequencies of other arrangements. Available output power has been set on 30 dBm in order that it has been possible to test the ADC with possible amplitude of the input voltage 20 $V_{pp}$ too. The block diagram of the generator is displayed in Fig. 10. A quartz resonator controls a basic oscillator. It makes possible to achieve frequency stability of order $10^{-6}$ per day and the fast fall of the phase noise round of carrier at offset frequency growth. 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 possible chosen with regard to the possible crystal loading 10 dBm. High power amplifier uses a bipolar transistor; the matching is solved by resonant circuits. The amplifier has the gain 20 dB at the output power 1 W and the bandwidth B3 approximately 30 kHz. 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
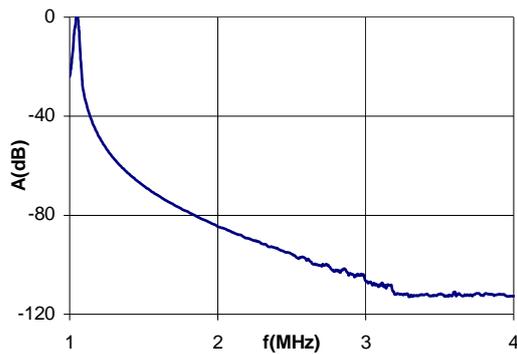
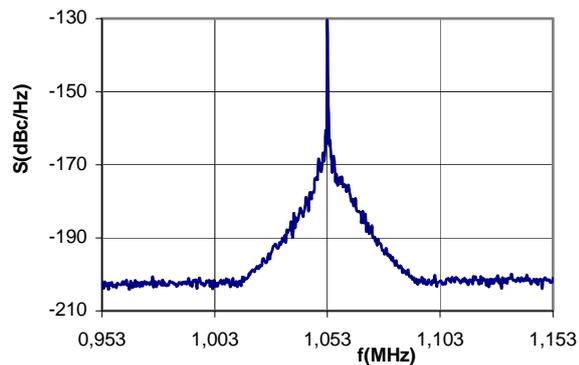Figure 8.  Frequency response of the two resonant circuit band-pass filter



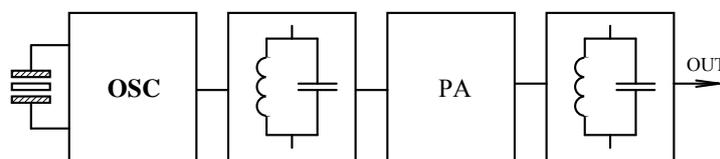Figure 11.  Realised generator,  $f_c$ = 1,053 MHz, $P_{out}$ = 30 dBm



Figure 10. Principle schema of the realized generator

power source with minimal basic noise, completed with a filter or a good accumulator, is used for power supply of the generator. The frequency spectrum of the generator around the carrier is displayed in Fig. 11. It is possible to achieve the level of SINAD 130 dB at the output power 1W. The signal quality is adequate for the measuring of the intermodulation distortion with a gap 160 to 170 dB or for the dynamic testing to 20 bit ADC.

## V. Conclusions

The contribution submitted the evaluation of several signal generators from the aspect of spectral purity of their output signal. It shows the options of the improvement of spectral purity by signal filtering and summarizes demands on the construction of a usable filter. Further there is described the construction of a special measuring generator with a high spectral signal purity.

## VI. Acknowledgments

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