LOW- DISTORTION SINE WAVE SOURCE FOR CALIBRATION OF PRECISION A/D CONVERTERS

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Abstract: *The paper describes construction and technical parameters of the low-distortion Wien type oscillator determined for dynamic testing of high resolution ADCs in frequency range up to 2 MHz.*

Keywords: *dynamic testing, analog-to-digital converter (ADC), total harmonic distortion (THD), oscillator*

1. INTRODUCTION

Basic methods for dynamic testing of ADCs and ADC based devices (e.g. the sine wave curve fit test or FFT test [1], [2]) are based on the application of a sine wave test signal. Requirements to test signal are as follows: good amplitude and frequency stability, low harmonic distortion and low noise level including spurious components.

The spectral purity of this signal expressed by SINAD should be better than SNR (in dB) of an ideal N-bit ADC given by:

$$SNR = 6.02N + 1.76 \tag{1}$$

According to (1), the ADC with 16-bit resolution should be tested using harmonic signal with SINAD better than approximately 100 dB. The best commercially produced sine wave synthesizers fulfil this value in the frequency range only up to 20 kHz (eg. Stanford Research DS360), while recent A/D PCI plug-in boards and VXI modules with resolution of 14 to 16 bits work in the frequency range up to 20 MHz.

Fortunately, it is sufficient to test ADCs on several frequencies only (three or four values in each decade). Thanks to that there are two ways how to handle the generator quality problem. The first one require application of selective band-pass filters at the output of digital synthesized generators, the second one demands set of the precision oscillators with fixed frequencies.

We chosen the second eventuality, and we are developing line of extra-low distortion oscillators. At present time four basic oscillators are assembled, with fundamental frequencies 200kHz, 500kHz, 1MHz and 2MHz and other oscillators (10kHz, 20 kHz, 50kHz, 100 kHz) are under construction.

2. OSCILLATORS DESIGN

The oscillators are the Wien-bridge type (their block scheme shows Fig. 1). A basic idea of the oscillator comes from [3]. The heart of the oscillator are two composite amplifiers CA. Every CA consists of voltage-feedback amplifier (VFA) THS4051 with gain bandwidth (GBW) 70 MHz (see Fig. 2) followed by current-feedback amplifier (CFA) THS3001 with GBW 420 MHz – Fig. 3. CFA – U2 multiplies open-loop gain of U1 by the gain of the amplifier

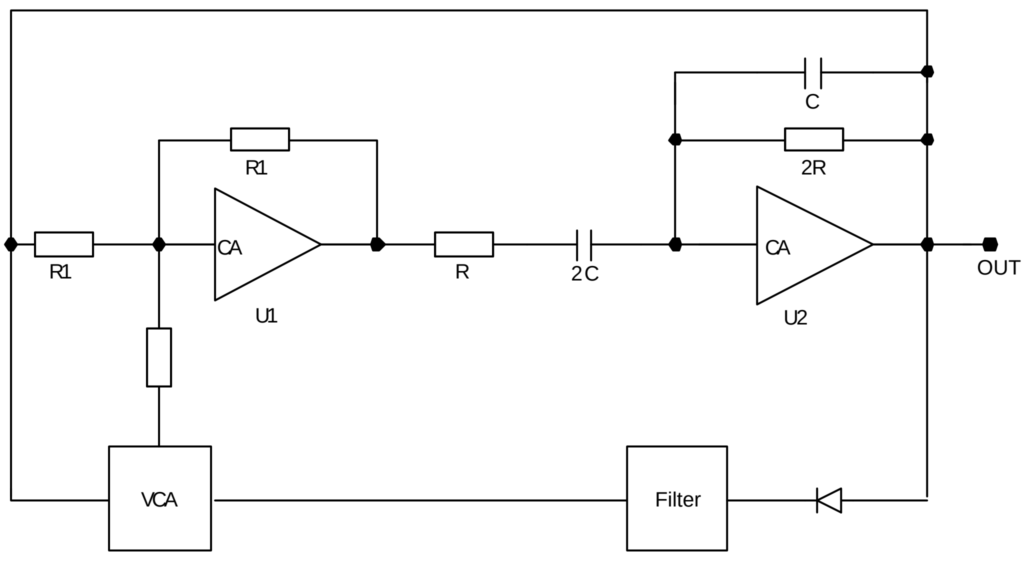

Fig. 1 – Basic structure of the Wien type oscillator.

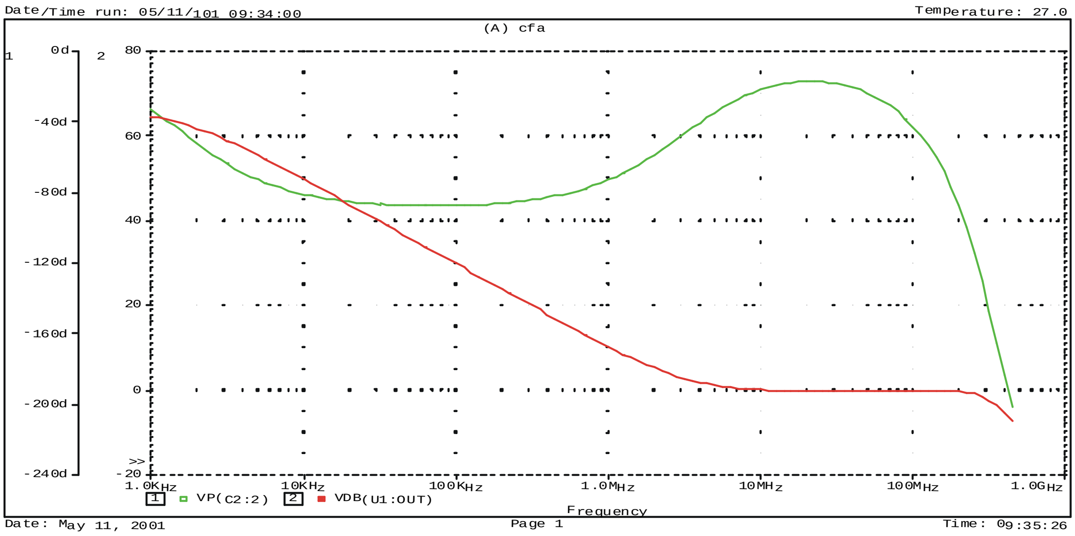

Fig. 2 – Gain/Phase response of the composite amplifier.

$A_v(f)$ so distortion of U1 is significantly reduced. U2 adds no gain at 70 MHz and only a low phase so this composite amplifier is still stable for closed loop gain 1.

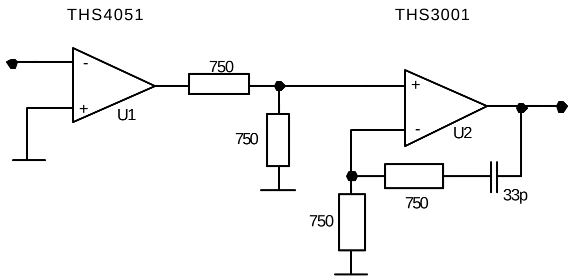

Fig. 3 – Circuitry of the composite amplifier CA.

Oscillators are embedded into boxes in pairs: 200kHz/500kHz and 1MHz/2MHz. Output frequency can be switched between these values. Oscillators can work into both high-impedance and 50Ω termination. Output voltage can be set from $3.8V_{pp}$ to $9.8V_{pp}$ (with high output impedance).

3. MEASUREMENTS

Measurement of spectral parameters of the oscillators is a difficult task. The PC/VXI system described in [4], [5] and [6] was used for this measurement. It consists of VXI mainframe, FireWire controller HP E1421B and digitizer HP E1430A (23-bit resolution, 10MHz sampling frequency).

Measurements with full-scale signal are possible, and thanks to superb characteristics of digitizer are obtained results relevant. However there is a risk, that harmonic components will be affected by distortion of digitizer itself. The fundamental should be rejected by a notch-filter to prevent this. The range of the digitizer can be set lower, and influence of the fundamental is reduced (its magnitude is comparable with magnitude of harmonics).

The active notch filters for all necessary frequencies have been developed for purpose of verification the performance of oscillators. Notch filters are tunable twin-T filters, which are buffered by a two-stage amplifier. Total gain is 40 dB – each stage has 20 dB. This filter rejects the fundamental spectral component by 80-90 dB.

Total harmonic distortion (THD) was chosen as significant spectral characteristic:

$$THD = 20\log\frac{\sqrt{\sum_{i=2}^{n} U_i^2}}{U_1} \qquad (2)$$

where U_i is amplitude of i-th harmonic, U_1 is amplitude of fundamental and n is 5.

In addition of spectral purity measurements, frequency stability and amplitude progress after generators' power-up was measured. Two methods for frequency observation were used. First one uses VXI digitizer HP E1430A and our software, that is able to measure and calculate parameters using sine-wave fit algorithm described in [1], [2] automatically. This method was also used for determination of amplitude. Second method works with precision counter Stanford Research SR620 that allows measure some advanced frequency characteristics of the signal as the standard deviation, or the Allan variance [7]:

$$AVAR = \sqrt{\frac{\sum_{i=1}^{n-1}(x_{i+1} - x_i)^2}{2(n-1)}} \qquad (3)$$

4. RESULTS

Values of THD presented in Table I were obtained for different settings of measurement parameters. First important parameter is the output signal amplitude. From the table, it is obvious, that for lower amplitudes are THD values noticeably better (values of amplitude in Table I are related to 1kΩ load). Second important parameter is the impedance connected to the output of the oscillator. The THD values are markedly worse for 50Ω load than for impedance 1kΩ.

Table I – THD values of presented oscillators

Oscillator	9.8Vpp		3.8Vpp	
	Direct measurement		Direct measurement	
	50Ω	1kΩ	50Ω	1kΩ
200kHz	-80	-88	-84	-97
500kHz	-75	-88	-78	-95
1MHz	-71	-90	-79	-94
2MHz	-72	-80	-78	-87

The following spectra show influence of these circumstances. Fig. 4 shows spectrum of 200kHz oscillator with output amplitude $9.8V_{pp}$, working into 50Ω load, Fig. 5 when output amplitude is set to $3.8V_{pp}$. If we compare these spectra, we see, that level of the 2nd harmonic is slightly lower. When output impedance is changed to 1kΩ, all harmonics lay under noise floor of the oscillator, and the best results are received (Fig. 6).

Situation with other oscillators is similar. Worse results are reached when output amplitude is high and device works into low impedance (50Ω).

Measurements provided with active notch filter showed, that its noise and distortion deforms characteristics of oscillators more than distortion of digitizer HP E1430A when direct measurements are performed. Therefore, results of these measurements were omitted.

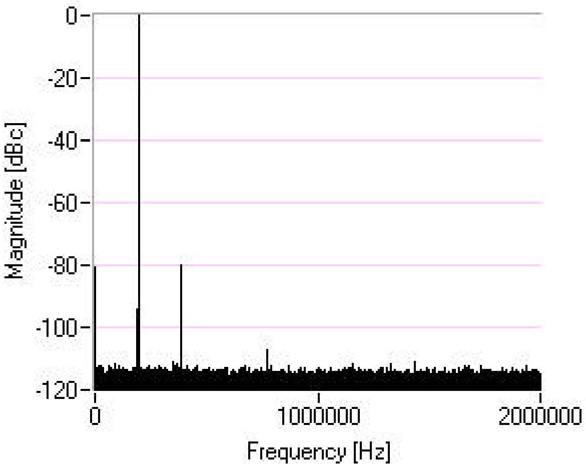

Fig. 4 – 200kHz oscillator, output amplitude $9.8V_{pp}$, output impedance 50Ω.

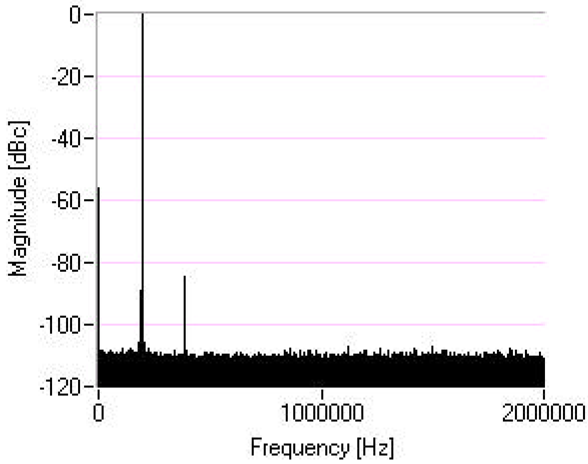

Fig. 5 – 200kHz oscillator, output amplitude $3.8V_{pp}$, output impedance 50Ω.

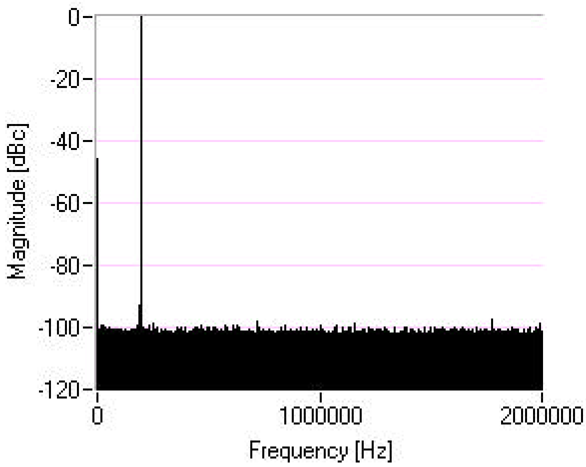

Fig. 6 – 200kHz oscillator, output amplitude $3.8V_{pp}$, output impedance 1kΩ.

The progress of the frequency and the amplitude was measured for 200kHz oscillator. After the power-up there is 2 hours long stabilization period, in which the frequency of the output signal changes in order 10^{-4} and the amplitude up to 10^{-2} (the frequency rises, the amplitude falls). After this interval, the frequency is stabilized. However, temperature dependence of oscillators is very high, and devices should be placed into thermoregulated box for proper function. Unfortunately, temperature dependence was not measured accurately, because of lack of appropriate equipment. Nevertheless frequency changes was identified in range 10^{-4} – 10^{-3}.

The short-term frequency stability measured with counter SR620 was performed with gate time 0.01s, and 500 samples (see [7]). Results are summarized in Table II (values are for longer gate times are comparable).

After necessary stabilization period the frequency stability about 10^{-6} – 10^{-7}. These values are sufficient for standard ADC testing methods, which are working with shorter sample records. Different situation could be with tests, which are using long records (e.g. histogram test). In this case long-term stability must be considered.

Table II – Frequency stability of described oscillators

Oscillator	Frequency [Hz]	Standard deviation [mHz]			Allan deviation [mHz]		
		Typ.	Min.	Max.	Typ.	Min.	Max.
200kHz	193804	12	11	15	9	8	11
500kHz	462565	14	13	26	12	13	17
1MHz	981844	126	115	132	121	107	132
2MHz	2037973	209	187	253	203	180	217

5. SUMMARY

Presented set of oscillators provides very good performance for some tasks of dynamic ADC testing. It offers very good spectral purity, which fits SNR requirements for testing of 14-bit ADCs on frequencies up to 2MHz.

Oscillators have some disadvantages yet. The main problems are appreciable temperature dependence that causes noticeable amplitude and frequency drift, and for oscillators with higher output frequency (1MHz, 2MHz) troubles with start-up, when there is no load at the output.

However, there is very interesting opportunity to build standard set of oscillators embedded in one thermoregulated and shielded box, which would be able to provide defined signal source for wide group of measurement problems. Our goal is to develop such signal standard, verify its parameters and use it for ADC testing standardization at our department.

6. ACKNOWLEDGMENT

This work is part of the project supported by the Grant Agency of the Czech Republic (grant No. 102/99/0775).

7. REFERENCES

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