DESIGN OF FPAA SINEWAVE OSCILLATOR BASED ON VAN DER PAUL EQUATION

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A Field Programmable Analog Array (FPAA) circuit of a low-frequency sinewave oscillator has been proposed and investigated in this paper. For that purpose the typical structure of a sinewave oscillator, based on the modeling of Van der Paul differential equation has been studied. Using the CAD system AnadigmDesigner2 the FPAA circuit of the oscillator has been designed and simulated. It has been practically implemented and experimented by means of Evaluation Board AN221E04 – a product of Anadigm Inc. The obtained results confirm the effectiveness of the proposed solution. The designed sinewave oscillator can be applied in research and educational practice in designing programmable SC circuits and FPAA based systems.

Keywords: Field Programmable Analog Array, FPAA, Sinewave oscillator, Van der Paul equation, Switched capacitor, SC circuits

1. INTRODUCTION

Field Programmable Analog Arrays (FPAAs), produced by Anadigm, are modern programmable integrated circuits for analog and mixed signals processing. They are based on SC circuitry. This technology ensures high precise implementation of time constants and gain factors of the used analog functional blocks [1].

The process of designing of FPAA circuits is assisted by specialized CAD software - AnadigmDesigner2, which uses a library of configurable analog blocks - amplifiers, filters, multipliers, comparators, etc. A programmable sinewave oscillator (OscillatorSin ver.1.2.2) is included in the library, also. It has a programmable amplitude and frequency. Based on a biquadratic filter structure, the circuit oscillates at its own resonant frequency. This oscillator has continuous output that is always valid (full cycle). Oscillation frequency limits are linearly related to the frequency of the sample clock. The absolute limits are from $F_C/100$ to $F_C/5$.

A disadvantage of the built-in oscillator is the high value of the low limit of the generated signal frequency. For instance, at a clock cycle frequency of $F_C = 4$MHz, this limit is 40 kHz. Using lower frequency clock cycle can decrease the limit. For example, if the frequency F_C is 50kHz, the low frequency limit of oscillations decreases to 500Hz. The most important disadvantages of this solution are the increasing the harmonics of the signal (i.e. worsening the signal form) and the decreasing the speed of signal processing in the chip.

Well-known approach for generation of low-frequency sinewave oscillations is the modeling of differential equation by using operation amplifiers. In practice, usually Van der Paul differential equation is modeled [2].

The paper presents the results from design and investigation of FPAA low frequency sinewave oscillator, based on the modeling of Van der Paul differential equation.

For that purpose the base structure for modeling of Van der Paul equation has been examined and formulas for determining and designing the frequency of the generated signal have been discussed. By means of Evalution Board AN221E04, produced by Anadigm, several validation experiments have been made for generating various frequencies.

2. BASIC CIRCUIT

The Van der Paul equation is [2]:

(1) $$\ddot{U}_a + 2\gamma \dot{U}_a + \omega_o^2 U_a = 0$$

According to the analysis, given in [2], steady sinewave oscillations with frequency ω_o originate when $\gamma = 0$. In this case the equation transforms into:

(2) $$\ddot{U}_a + \omega_o^2 U_a = 0$$

The solution of this differential equation can be obtained by structure shown in Fig. 1.

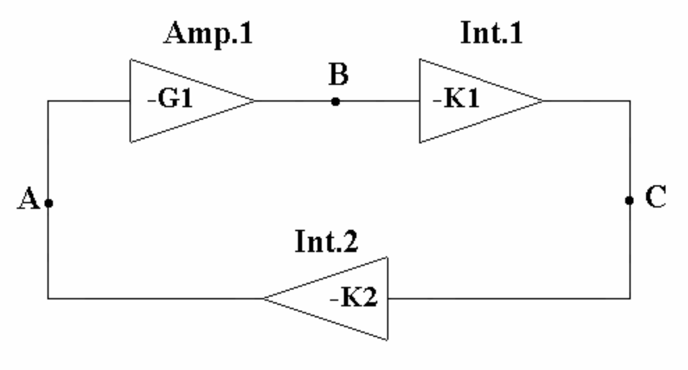

Fig. 1. Functional circuit of a sinewave oscillator, based on Van der Paul equation

The presented structure comprises two inverting integrators (*Int1*, *Int2*) and an inverting amplifier (*Amp.1*).

Let's assume that the signal at point A is:

(3) $$u_A(t) = U_m \sin \omega t .$$

Respectively, the voltages at points B and C on the circuit are:

(4) $$u_B(t) = -G_1 u_A(t) = -G_1 U_m \sin \omega t ,$$

(5) $$u_C(t) = -K_1 \int u_B(t) = -\frac{K_1 G_1 U_m}{\omega} \cos \omega t .$$

The signal at point C is integrated by *Int.2* and in this case the voltage at its output (point A) is:

(6) $$u_A(t) = -K_2 \int u_C(t) = \frac{K_1 K_2 G_1 U_m}{\omega^2} \sin \omega t .$$

According to the structure on Fig. 1, equations (3) and (6) are equivalent, so:

(7) $$U_m \sin \omega t = \frac{K_1 K_2 G_1}{\omega^2} U_m \sin \omega t$$

The equation (7) is true when:

(8) $$\frac{K_1 K_2 G_1}{\omega^2} = 1$$

Consequently, the following expression is received for the frequency of the oscillations:

(9) $$f = \frac{\sqrt{K_1 K_2 G_1}}{2\pi}.$$

The analysis of (9) shows that the frequency of the generated signal can be programmed either by changing the constants of integration K_1 and K_2, or by changing the gain G_1 of the inverting amplifier.

3. FPAA Implementation

Fig. 2 shows the implementation of the generator by using the chip AN221E04, produced by Anadigm Inc. AnadigmDesigner2 program has been used, which ensures the drawing, editing and simulating the circuit.

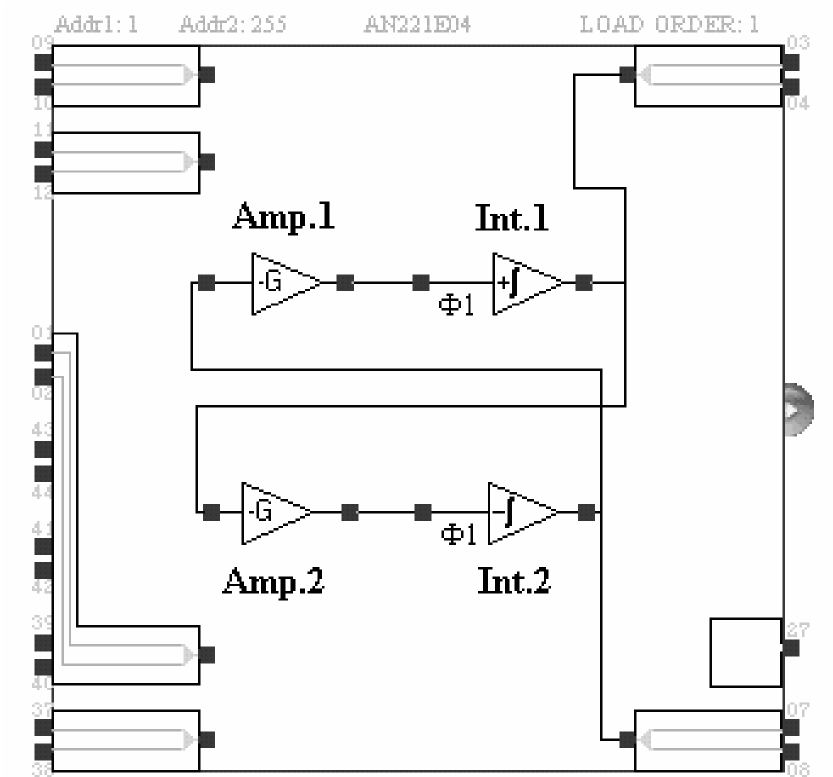

Fig. 2. FPAA implementation of a sinewave oscillator

The structure is similar with the one shown in Fig. 1. Standard elements from the library have been used - amplifiers $(-G)$ as well as an inverting $(-\int)$ and a non-inverting ($+\int$) integrators. Adding the second inverting amplifier protects from undesired saturation at the output of *Int.2*, which can be caused by the relatively high values of voltage at the output of *Int.1*. For that purpose the gain factors G_1 and G_2 should be less than 1. In order to keep the fulfillment of the phase condition for generation, it is necessary that the integrator *Int.1* should be non-inverting. By analogy with equation (9) the following expression is received for the frequency of oscillations in case of the structure in Fig. 2:

$$(10) \quad f = \frac{\sqrt{K_1 K_2 G_1 G_2}}{2\pi}.$$

Since the case $K_1 = K_2 = K$ и $G_1 = G_2 = G$ is most commonly used, formula (10) obtains the form:

$$(11) \quad f = \frac{KG}{2\pi}.$$

4. EXPERIMENTAL RESULTS

The circuit has been examined by using AN221K04 AnadigmVortex Development Board. At first, several experiments were made to check the frequency of oscillations. Using formula (11) it was calculated that $KG = 0.314159$ should be ensured for a frequency of $F = 50KHz$. Consequently, when the value of K is $K = K_1 = K_2 = 0.5$, the gain of amplifiers should be $G = G_1 = G_2 = 0.6283$. In practice, when the values $K_1 = K_2 = 0.5$ and $G_1 = G_2 = 0.628$ have been programmed into the array, a frequency of F_{meas} = 49.972 kHz ($delta = 0.06\%$) was measured at the output of the generator. Using the possibility of programming the amplifiers' and the integrators' parameters, the frequency of the generated signal can be adjusted most precisely. For example, if changing $G_1 = 0.629$, we receive for output frequency F_{meas} = 49.994 kHz ($delta = 0.01\%$).

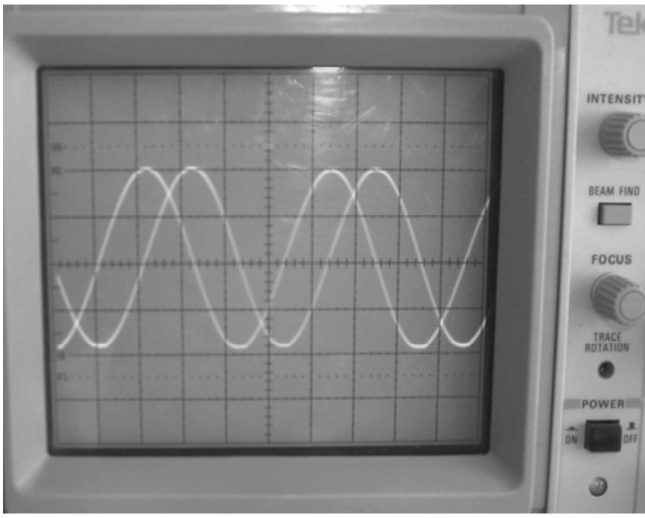

Fig. 3. Signals at the outputs of the integrators

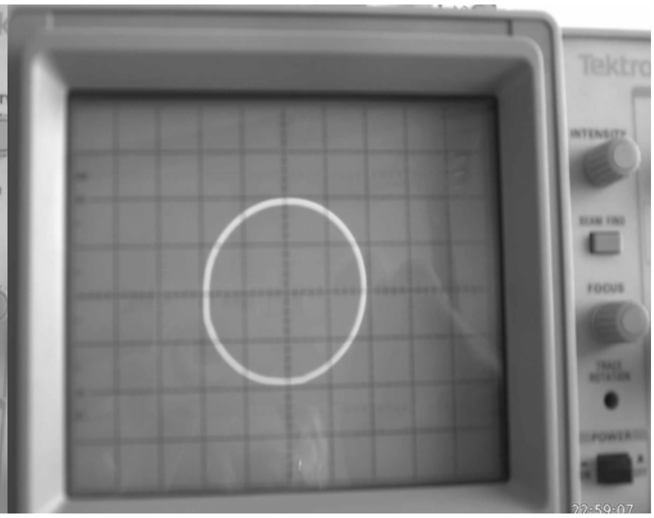
Fig. 4. Phase portrait of the generated signal

A photo of the generated signals at the outputs of the integrators is shown in Fig. 3. Fig. 4 represents the phase portrait, which has been received by using the same signals.

Tabl. 1 shows the results of the experimental investigation of the implemented generator. The first column presents the desired frequency of generation, the second column – the product KG, necessary for achieving the desired frequency (when $K_1 = K_2$, $G_1 = G_2$). The third column shows the chosen values of $K_1 = K_2$, and the fourth one – the values of $G_1 = G_2$, necessary for achieving the desired frequency of generation. The fifth column presents the achieved result $Fmeas$, and the relative error $Delta$ has been calculated in the sixth column.

Tabl. 1. Results from examination of FPAA sinewave oscillator

F, Hz	**k.G**	**K1=K2, [1/us]**	**G1=G2**	**Fmeas, Hz**	**Delta, %**
200	0.001257	0.0400	0.0314	201	-0.60%
500	0.003142	0.0800	0.0392	505	-1.00%
1000	0.006283	0.0800	0.0785	1006	-0.60%
2000	0.012566	0.0800	0.1571	2014	-0.70%
5000	0.031416	0.1000	0.3142	5032	-0.63%
10000	0.062832	0.1000	0.6283	10097	-0.97%
20000	0.125664	0.2000	0.6283	20097	-0.49%
50000	0.314159	0.5000	0.6283	49972	0.06%
100000	0.628319	1.0000	0.6283	99703	0.30%
200000	1.256637	3.0000	0.4189	200003	0.00%
250000	1.570796	4.0000	0.3927	252012	-0.80%

Fig. 5 shows the relationship between the experimentally measured $Fmeas, Hz$ and the desired frequency of generation F, Hz. Fig. 6 demonstrates the relative error $Delta$, % vs. the frequency of the signal F, Hz.

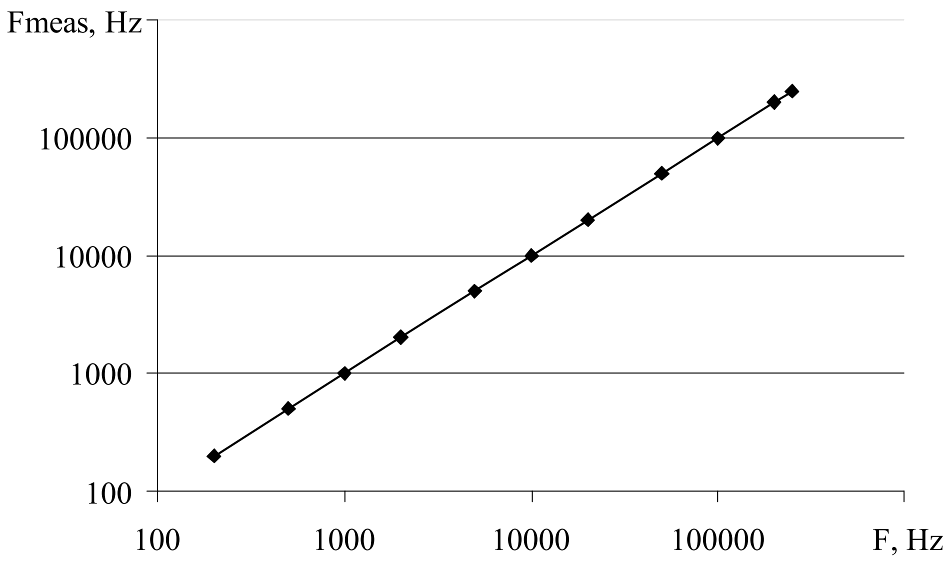

Fig. 5. Graphic of measured vs. desired values of frequency

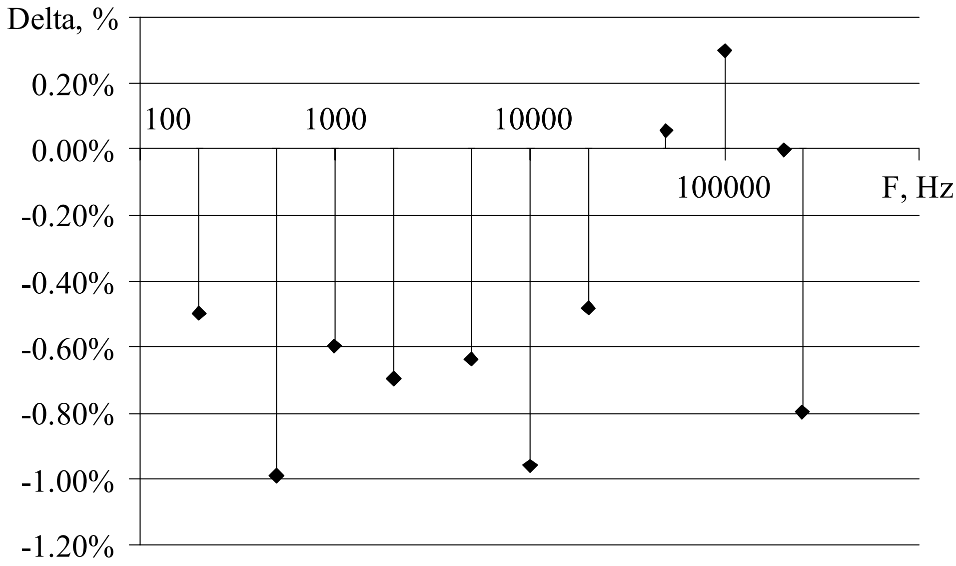

Fig. 6. The error Delta, % vs. the frequency of the generated signal

5. Conclusions

The paper represents an approach for implementing a low-frequency FPAA sinewave oscillator.

For that purpose the structure of a sinewave signal generator (Fig. 1), based on Van der Paul equation has been studied. Using an FPAA, produced by Anadigm, a low-frequency sinusoid generator has been implemented (Fig. 2) and practically examined.

The achieved results show that in the range of 200Hz ÷ 250kHz the proposed structure generates signals with relative error of frequency less than or equal to 1% (Tabl. 1).

The possibility of fine adjustment of the frequency of the generated signal by means of precise changing of the gain and the constant of integration of the used FPAA units is an additional advantage of the proposed circuit.

The presented generator can be applied in constructing SC circuits and FPAA based electronic systems.

6. References

[1] www.anadigm.com *Technical documentation*. Anadigm Inc.
[2] Tietze U., Ch. Schenk. *Halbleiter-schaltungstechnik*. Springer-Verlag.1999.