Simply Adjustable Sinusoidal Oscillator Based on Negative Three-Port Current Conveyors

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Abstract. *The paper deals with sinusoidal oscillator employing two controlled second-generation negative-current conveyors and two capacitors. The proposed oscillator has a simple circuit configuration. Electronic (voltage) adjusting of the oscillation frequency and condition of oscillation are possible. The presented circuit is verified in PSpice utilizing macro models of commercially available negative current conveyors. The circuit is also verified by experimental measurements. Important characteristics and drawbacks of the proposed circuit and influences of real active elements in the designed circuit are discussed in detail.*

Keywords

Current conveyors, electronic adjusting, sinusoidal oscillator.

1. Introduction

Many modern active functional blocks are available for application in analog technology and signal processing in the present time. This fact is discussed in paper [1] where the review and basic theory of the novel blocks are given. First applications of these blocks have been given in the literature, namely DBTA in [2], CFTA in [3] and others. An attention is now focused on the applications in current mode (CM) [4], in particular using the functional blocks with multi current outputs. There are some various modifications of the known circuit elements, namely the current conveyors (CC), the current feedback amplifiers (CFA) and the transconductors (OTA) with new names such as DO-CCCII [5 - 7], MO-CCII [8], CC-CFA [9], MO-OTA [10], or CDTA [11], [12], [13], CDBA [14] etc [1]. Because of their better frequency characteristics and features for electronic controlling, these blocks may be used in wide range of applications in the fields of filters, oscillators, high-speed communication systems, acoustic, measuring, control, sensor, and automotive electronics.

Recently, many circuits and concepts of harmonic oscillators based on CC of second generation (CCII) [15 - 31] and CFA [32 - 37] have been published. Many of these applications are not tunable [12, 13, 19, 22 and 23]. Others can be tuned by a single passive element, namely by a grounded resistor [15-18, 20, 27, 28, 30-32, 34-36, 38] or by a floating resistor [14, 21, 24, 31, 33-35, 37]. The grounded variable resistor can be simply implemented by a JFET [29, 34-35], by an OTA [39] or by a digital potentiometer. However using of the floating element is quite complicated, as you can see for example in a special filter in [40]. In several works [25-27] biasing current (I_b), which drives the resistance R_x of the terminal X of the CC, is used for electronic control. Unfortunately the parameter (I_b or R_x) depends on the IC manufacturing deviations, supply voltage and also obviously on the temperature. Therefore it can cause some problems with precision in this application. Note that the manufacturing tolerances of the R_x can be tens of percent.

Recently published circuits with the conveyors CCII are based on one active block only [21, 24, 31, 33, 36-38], complemented by four or five passive elements. Furthermore circuits with two active blocks, complemented by four or six passive elements [13-14, 17, 19-20, 22, 25-27, 29, 32, 34, 36] and at the most with three CCII and eight passive elements [15-16, 19, 23, 28, 30, 34, 36] have been published. The positive-current conveyors or combination with negative ones are used in publications above. Note that the circuits mentioned above were mostly verified through simulations at audio frequencies only where the use of these new high-speed blocks is not substantiated. In audio band a classical VM approach, the standard operational amplifiers and digital potentiometers for tuning can be fully sufficient. This is not suitable at higher frequencies, where parasitic capacitances and real parameters of the blocks play more significant role. Another weakness of the previous approaches can be inability of direct electronic controlling (except controlling R_x for CCII), complicated implementation (too many blocks and elements), low level of the output signal [24-25] and high THD [26, 34-35, 37].

In this paper very simple oscillator employing two negative conveyors CCII- is presented. Oscillation frequency and condition of oscillation may be driven varying electronically controlled current gains B. A basic variant includes four passive components (two R and two C). Also resistor-less variant with two capacitors only is given. Here, instead of the real resistor, the input resistance R_x of the conveyor terminal X (Fig. 1) is used. Note that the manufacturer guarantees the value of R_x in tolerance of ±20% so this must be taken into account during the design of this simpler variant. The output signal can be taken from two internal nodes. However, to separate the load impedance a voltage follower can be appropriately used.

On the other hand, the disadvantage of this circuit is that one working capacitor is floating and the oscillation frequency may be driven only in a limited range. Despite this, implementation of the proposed circuit is simpler comparing to previous oscillators discussed above. More current outputs are not required and a classical three-port CC is sufficient.

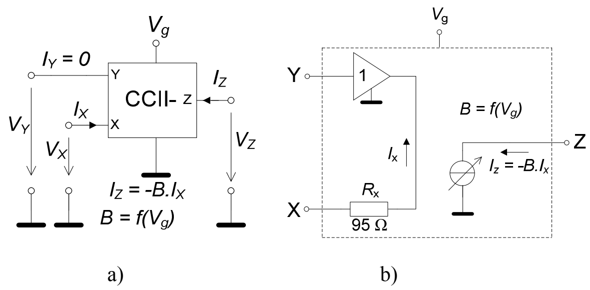

Fig. 1. Principle of adjustable CCII-: a) Symbol, b) model.

2. Three-Port Current Conveyor with Adjustable Current Gain

The principle of this block is clear from Fig. 1. The negative three-port current conveyor CCII- with adjustable current gain has the symbol shown in Fig. 1a, where the port variables are denoted. This block can be described in a classical way [1]. The important relations are written in this figure, too. There is current input X, voltage input Y and current output Z. Compared to common types of the CCII (e.g. AD 844 [41]) this conveyor has the possibility of electronic controlling of the current gain B.

For design and verification, commercially available CCII- (obsolete but sufficient for experiments) was used. There is not a problem for layout designer to create similar element in CMOS or bipolar technology if necessary. This device is commercially available as EL 2082 as two-quadrant current-mode multiplier [42]. The gain control input is calibrated to 1 mA/ mA signal gain (B) for 1 V of control voltage V_g (see [42]), else $B = f(V_g)$ and simplification is valid approximately (example: V_g = 2 V means that exactly B = 1.9). Features of this block are evident from following figures obtained through simulations in PSpice. Magnitude responses of the current gain $B(f)$ are given in Fig. 2. The bandwidth (-3 dB) is 158 MHz for B_0 = 1 = 0 dB. Varying of $B = B(f, V_g)$ by driving voltage V_g is also shown in Fig. 2.

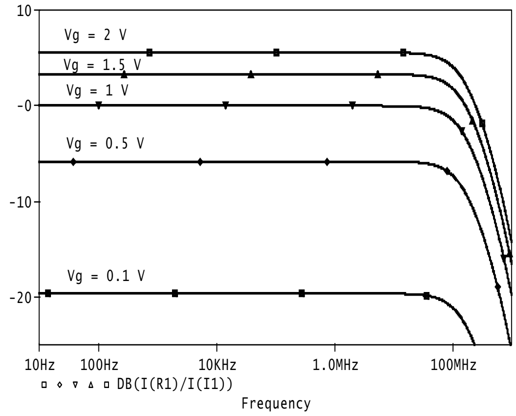

Fig. 2. Magnitude response as a function of driving voltage $B = B(f, V_g)$.

Input-output characteristics for several values of the driving voltage $I_z = f(I_x, V_g)$ are shown in Fig. 3.

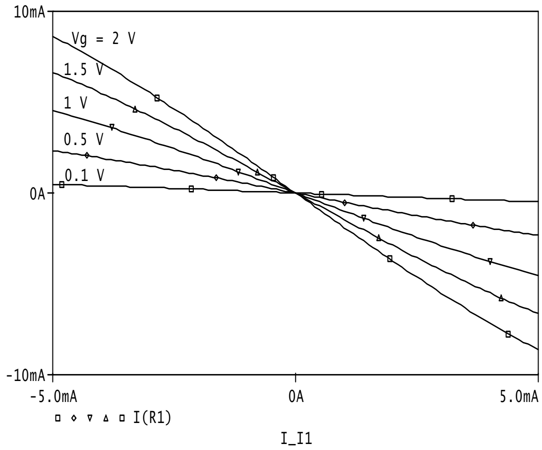

Fig. 3. Input-output current characteristics $I_z = f(I_x, V_g)$.

3. Proposed Oscillator

The proposed tunable oscillator employing two negative conveyors CCII- is shown in Fig. 4. The basic variant (Fig. 4a) has four passive elements, two R and two C. In Fig. 4b, the resistor-less version is shown, using the input X resistance (R_x in Fig. 1) of the real conveyor.

The circuit from Fig. 4 has the characteristic equation of the second-order general form

$$a_2 s^2 + a_1 s + a_0 = 0 . \qquad (1)$$

By symbolical nodal analysis, using the computer tool SNAP and setting of det $\mathbf{Y}$ = 0, the following characteristic equation is obtained

$$s^2 + \frac{C_1R_1 + C_2R_2(1-B_1)}{R_1R_2C_1C_2}s + \frac{1-B_1B_2}{R_1R_2C_1C_2} = 0 \cdot \qquad (2)$$

From the characteristic equation (2) we can determine the oscillation condition in the following form

$$C_1R_1 + C_2R_2 = C_2R_2B_1, \tag{3}$$

$$B_1 \approx V_{g1}, \tag{4}$$

and also the formula for the frequency of oscillations

$$\omega_0 = \sqrt{\frac{1-B_1B_2}{R_1R_2C_1C_2}} \approx \sqrt{\frac{1-V_{g1}V_{g2}}{R_1R_2C_1C_2}}. \tag{5}$$

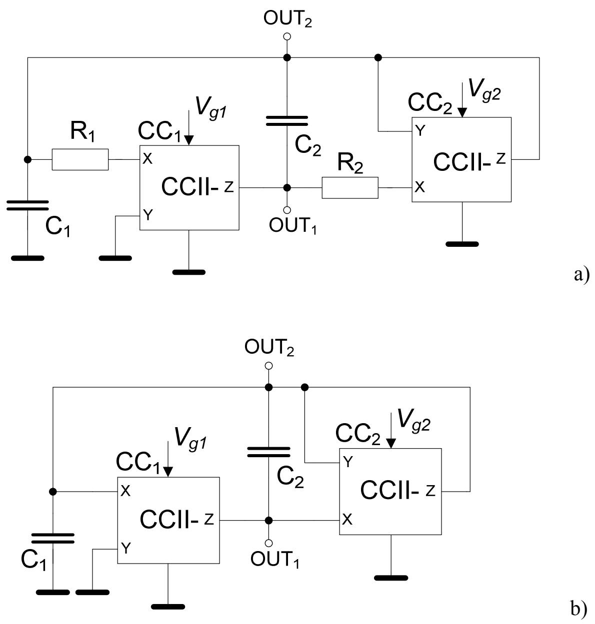

Fig. 4. Adjustable oscillator based on two CCII-: a) basic variant, b) resistor-less variant.

The sensitivities of the oscillation frequency (5) to the passive components and parameters of the CC's were found, namely

$$S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = S_{R_1}^{\omega_0} = S_{R_2}^{\omega_0} = -\frac{1}{2}, \tag{6}$$

$$S_{R_{x1}}^{\omega_0} = S_{R_{x2}}^{\omega_0} = -\frac{1}{2}, \tag{7}$$

$$S_{B_1}^{\omega_0} = S_{B_2}^{\omega_0} = -\frac{1}{2}\frac{B_1B_2}{\left(1-B_1B_2\right)} \approx -\frac{1}{2}\frac{V_{g1}V_{g2}}{\left(1-V_{g1}V_{g2}\right)}. \tag{8}$$

From (3) and (5) it is clear that B_1 is not suitable for ω_0 control because it is also in the condition of oscillation (3). However, B_2 is only in (5) therefore it can be theoretically suitable for ω_0 control. The resistance R_1 in formulas above (also R_2 by analogy) is given by the sum $R_1 = R_{1\text{ext}} + R_{x1}$. External working resistor $R_{1\text{ext}}$ must be added to R_{x1}, which is the input of the current port X. Note that these virtual resistances (R_{x1}, R_{x2}) (without $R_{1\text{ext}}$, $R_{2\text{ ext}}$) are considered only in the resistor-less version (Fig. 4b). However, this utilization can be problematic due to the reason (R_x) discussed in the introductory section. The product B_1B_2 above (respective $V_{g1}V_{g2}$) must be in range $0 \le B_1B_2 < 1$, which is a defining condition for the operation of this circuit as an oscillator. Equation (8) shows that sensitivities of oscillation frequency on parameters of active elements (current gain B) are quite high for $B_1B_2 \rightarrow 1$ (Fig. 5) or $B_2 \rightarrow 0.5$ whereas $B_1 = 2$ respectively (see sections 4 and 5).

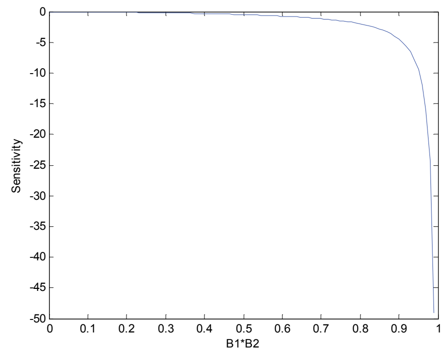

Fig. 5. Detailed analysis of sensitivity (8) of oscillation frequency on product B_1B_2.

4. Design Assumptions

The values of the capacitors are chosen $C_1 = C_2 = 470$ pF, and the external resistors $R_{1\text{ext}} = R_{2\text{ext}} = 100\ \Omega$. Then considering the virtual resistances $R_x = 95\ \Omega$ the total values result in $R_1 = R_2 = 195\ \Omega$. The current gain B_1 is chosen $B_1 = 2$ (then $V_{g1} \approx 2$ V) and B_2 will be changed taking into account the oscillation condition above. The expected value of the oscillation frequency estimated by (5) is $f_0 = 1.737$ MHz ($B_2 = 0$).

5. Experimental Verification

To verify the proposed oscillator the simulations in PSpice using an adequate model of the real CCII- have been carried out. Fig. 6 shows the time waveforms of the output signals in both nodes denoted in circuit diagram (Fig. 4).

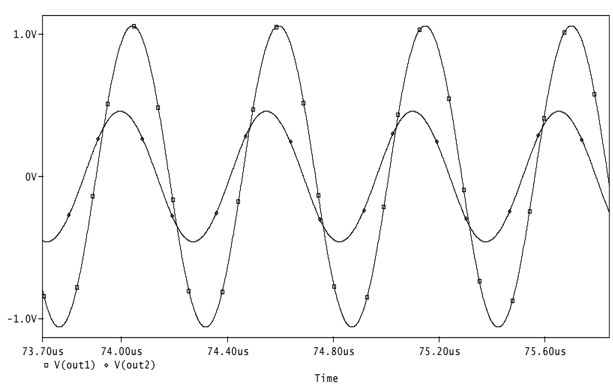

Fig. 6. Time waveforms of the output signals (for $V_{g1} = 2$ V, $V_{g2} = 0$ V), given by simulation (transient analysis in PSpice).

Spectrum of the output signal resulting from the simulation using PSpice is given in Fig. 7.

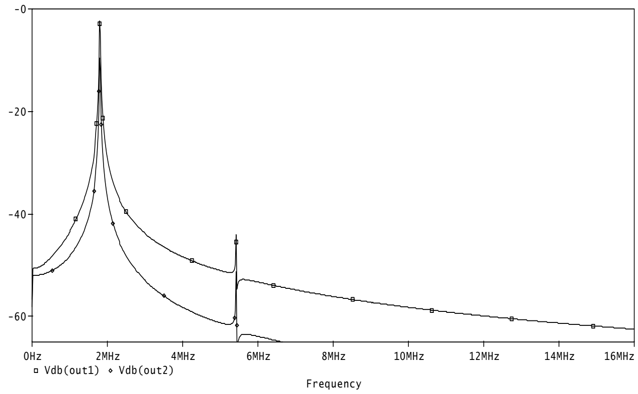

Fig. 7. Spectrum of the output signal.

The simulations were supplemented by adequate laboratory measurements, as shown in Fig. 8 and Fig. 9. These results are confirmation of the theoretical and designed assumptions and also symbolical analysis given above.

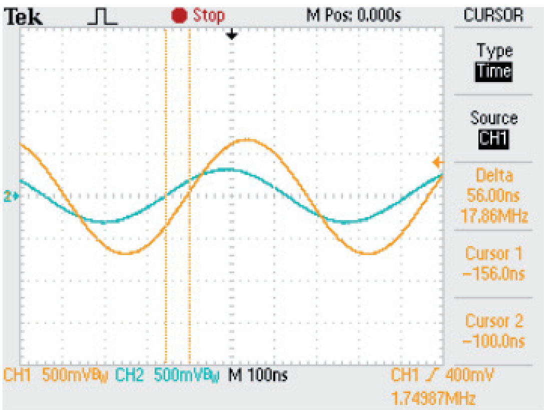

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Fig. 8. Measured output signals (larger is V_{OUT1}, smaller is V_{OUT2} for $V_{g1} = 2$ V, $V_{g2} = 0$ V)

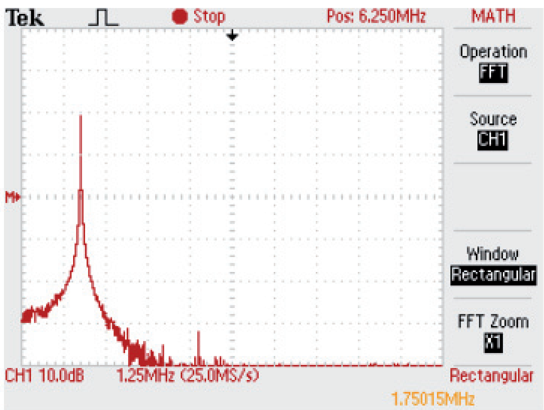

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Fig. 9. Measured spectrum of the output signal.

For start of the oscillations it was necessary to change the value of the R_1 to 67 Ω, which caused changing of the expected theoretical value of the oscillation frequency (f_0) to 1.9 MHz (instead of 1.7 MHz). The parasitic properties of active elements (R_x and their different values given by manufacturing tolerance) causes that condition of oscillation is not fulfilled. Although the influence of parasitic real features is discussed in the next chapter in detail, let's mention, that with regard to the parasitic features of the active blocks, the oscillation frequency is changed to 1.8 MHz, which was confirmed with the simulation by the macro models from [42]. The value of the f_0 measured in laboratory was still about 50 kHz lower (1.75 MHz).

The dependence of the oscillation frequency f_0 on the control voltage V_{g2} is shown in Fig 10, namely ideal theoretical, PSpice simulation, Matlab (version 7.6.0) calculation and measured, too. The measurement of the output voltages (V_{OUT1} and V_{OUT2}) versus the oscillation frequency (f_0) is resulting in the Fig 11. Similarly, the measuring of dependence of the THD on the oscillation frequency f_0 is given in Fig 12.

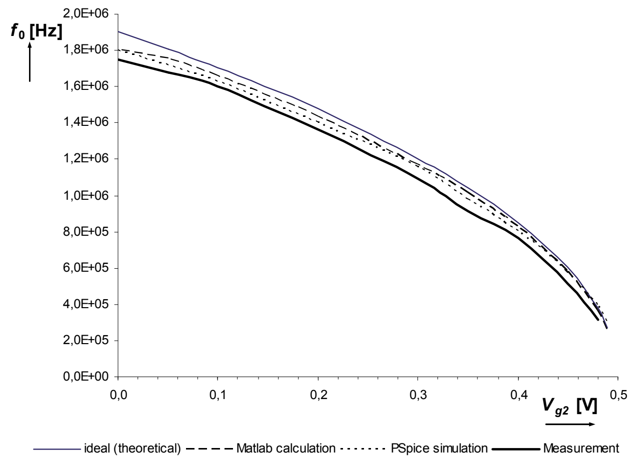

Fig. 10. Oscillation frequency versus control voltage.

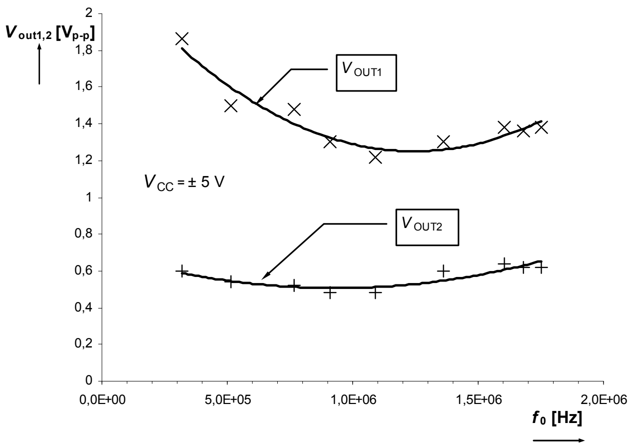

Fig. 11. Output voltages vs. oscillation frequency (measured).

The maximal tunable frequency range is from 0.32 to 1.75 MHz (V_{g2} from 0 to 0.48 V). Nevertheless, we can see (Fig. 11 and Fig. 12) that for the minimal THD it is acceptable to work with the control voltage V_{g2} from 0 to about 0.3 V (THD is below 1%). It reduces tuning to half range (approximately from 1 MHz to 1.75 MHz). There lower THD was achieved due to the internal nonlinearity of used active elements. In a wider range, it is necessary to add a circuit for amplitude stabilization. The first approach contained CC_1 with a fixed gain. Practically, in this case we can obtain an invariable output magnitude in the total range of f_0 but THD is incredible and output waveform even limited. The CC_1 with an adjustable gain is better for direct controlling of the condition of oscillation but it affects a little bit also oscillation frequency (5) and output magnitude. It is appropriate for external amplitude stabilization. For keeping output amplitudes in less invariable level (Fig. 11) it was necessary to set V_{g1} in every measured point (only very small change, see Tab. 1), but THD increased when V_{g2} was above 0.3 V. In other case (V_{g1} was fixed) the amplitudes varied for example from 0.5 to 1 $V_{p\text{-}p}$ (V_{OUT2}) but THD was still under 1%. In the rest of theoretical range (approximately from 0.35 to 0.5 V) it is important to set V_{g1} in each next measured point otherwise THD is very high. These corresponding results are in Tab. 1.

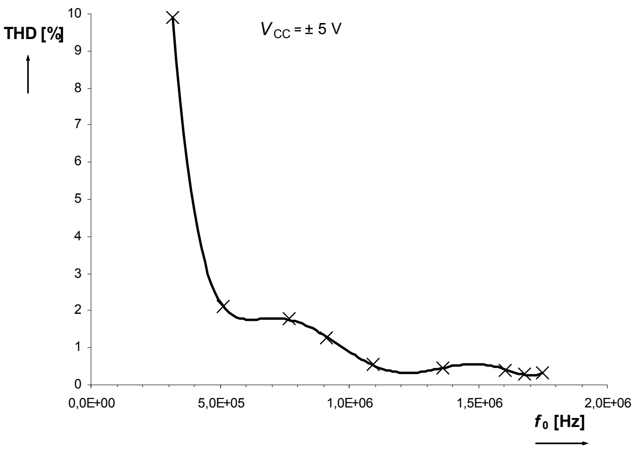

Fig. 12. THD versus oscillation frequency (measured).

f_0 [MHz]	V_{g1} [V]	V_{g2} [V]	Separation of higher harmonics [dB]	THD [%]
0.32	2.06	0.48	20	9.9
0.51	2.05	0.45	30	2.1
0.77	2.02	0.40	35	1.8
0.91	2.01	0.35	38	1.3
1.10	1.98	0.30	45	0.6
1.36	1.97	0.20	47	0.5
1.60	1.95	0.10	48	0.4
1.68	1.94	0.05	51	0.3
1.75	1.93	0	50	0.3

Tab. 1. Values of V_{g1} and V_{g2} and THD for different measured oscillation frequencies.

6. Parasitic Influences

In Fig. 13 the suitable model of the real CCII- which includes the most important parasitic parameters is given. Then using this model (Fig. 13) the circuit diagram from Fig. 4 can be supplemented as shown in Fig. 14 to include all parasitic influences of the practical oscillator. Elements with crosshatch pattern are representing parasitic influences.

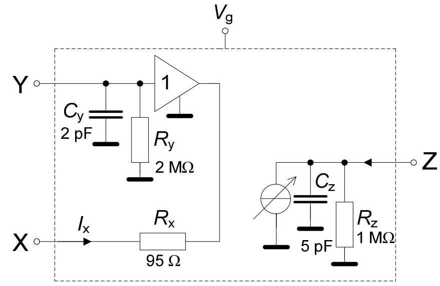

Fig. 13. Important parasitic influences of CCII-.

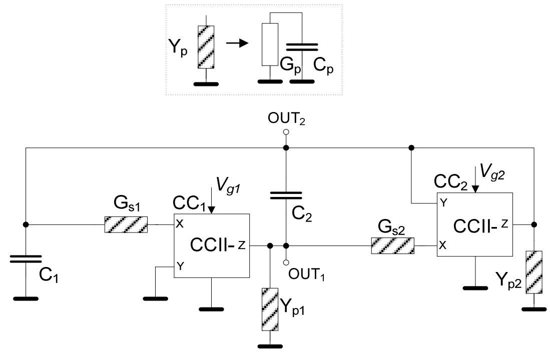

Fig. 14. Important parasitic influences in the proposed oscillator.

This circuit (Fig. 14) has the characteristic equation in the polynomial form (1) with the coefficients in symbolical form as follows:

$$a_2 = 1, \tag{9}$$

$$a_1 = \frac{C_1G_{s2} + G_{s1}C_{p1} + C_2G_{p1}}{C_{p1}C_1 + C_{p1}C_2 + C_{p2}C_2 + C_{p1}C_{p2} + C_1C_2} + \\ + \frac{G_{s2}B_2^*C_{p1} + G_{p2}C_{p1} + G_{s2}C_{p2}}{C_{p1}C_1 + C_{p1}C_2 + C_{p2}C_2 + C_{p1}C_{p2} + C_1C_2} + \\ + \frac{C_1G_{p1} + C_2G_{s1} - B_1^*C_2G_{s1} + C_{p2}G_{p1} + C_{p2}C_2}{C_{p1}C_1 + C_{p1}C_2 + C_{p2}C_2 + C_{p1}C_{p2} + C_1C_2}, \tag{10}$$

$$a_0 = \frac{\left(1 - B_1^*B_2^*\right)G_{s1}G_{s2} + G_{p1}G_{p2} + G_{s2}G_{p2} + G_{s1}G_{p1} + G_{s2}G_{p1}B_2^*}{C_{p1}C_1 + C_{p1}C_2 + C_{p2}C_2 + C_{p1}C_{p2} + C_1C_2} \tag{11}$$

In formulas (10) and (11) the following symbols represent the parasitic influences:

$$R_{s1} = 1/G_{s1} = R_{1ext} + R_{x1} \pm \Delta R_{x1} = R_{1ext} + 95 \pm 20\%\,\Omega, \tag{12}$$

$$R_{s2} = 1/G_{s2} = R_{2ext} + R_{x2} \pm \Delta R_{x2} = R_{2ext} + 95 \pm 20\%\,\Omega, \tag{13}$$

$$G_{p1} = 1/R_{z1}, \tag{14}$$

$$G_{p2} = 1/R_{z2} + 1/R_{y2}, \tag{15}$$

$$C_{p1} = C_{z1}, \tag{16}$$

$$C_{p2} = C_{z2} + C_{y2}, \tag{17}$$

$$B_1^* = \frac{B_1 \omega_T}{s + \omega_T}, \quad B_2^* = \frac{B_2 \omega_T}{s + \omega_T}. \tag{18), (19}$$

Analyzing the equations above, one can see that the influence of the resistance $R_p = 1/G_p$ begins to show symptom in slight increasing of the oscillation frequency f_0 for R_p less than 50 kΩ (but the employed blocks allow to achieve several higher values). Note that the influence of the R_{p1} is only slightly larger than R_{p2}. On the other hand the capacitances C_p play more significant role. Only small change of the capacitance results in a significant change of f_0 (e.g. for both C_p = 5 pF it is over 20 kHz). The influence of the C_{p2} is greater than C_{p1} due to their values, approximately C_{p1} = 5 pF and C_{p2} = 7 pF. This is due to the fact that the parasitic capacitance C_y plays also role but not in CC_1 (port Y is grounded). Furthermore inequality of the input resistances of the current ports $R_{x1} \neq R_{x2}$ plays a significant role, too. Their values are determined by technology and have high production tolerance.

The results obtained by direct analysis of the model (Fig 14) respecting essential parasitic influences in the real oscillator are in a very good accordance with the computer simulations and obtained experimental results. Due to the relatively high tolerance of the resistances R_x, the difference between the theoretically assumed value and the measurement is greater than the difference between the computer simulation and the direct analysis of the model above.

7. Conclusion

In this paper very simple electronically adjustable oscillator employing only two active devices (CCII-) and in the extreme only two passive elements (capacitors) was presented. It allows electronic tuning of the oscillation frequency and condition of oscillation by DC driving voltage. It was practically tested from 320 kHz to 1.75 MHz. Under certain conditions (limited range), the harmonic distortion can be achieved below 1% and the separation of the higher harmonics more then 50 dB. However there are some drawbacks of this solution. The equation for oscillation frequency (5) is not very suitable and therefore tuning is possible only in a limited range. The topic of future work will be focused on removing of this drawback. The circuit was verified without the circuit for amplitude stabilization (only by nonlinear limitation of used active elements). Therefore practically available range of tuning with achievable low THD is restricted. For invariable level of output signal very small changes of B_1 are necessary. The first conception of the oscillator where CC_1 has a fixed gain is not suitable because the control of the condition of oscillation is not possible. Operation of the proposed oscillator was verified through simulations and measurements of the real circuit in the frequency range of units MHz. Also important parasitic effects in this circuit were discussed in detail. The oscillator was analyzed symbolically, tested by computer simulations and by laboratory experiments. This allows a comprehensive view of the behavior of this circuit. The designed circuit will be used for education purposes in courses dealing with electronically adjustable active elements and their applications.

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References

[1] BIOLEK, D., SENANI, R., BIOLKOVA, V., KOLKA, Z. Active elements for analog signal processing: Classification, Review, and New Proposal. *Radioengineering*, 2008, vol. 17, no. 4, pp. 15 – 32.

[2] HERENCSAR, N., VRBA, K., KOTON, J., LATTENBERG, I. The conception of differential-input buffered and transconductance amplifier (DBTA) and its application. *IEICE Electronics Express,* 2009*,* vol. 6, no. 6, pp. 329-334.

[3] HERENCSAR, N., KOTON, J., VRBA, K., MISUREC, J. A novel current-mode SIMO type universal filter using CFTAs. *Contemporary Engineering Sciences*, 2009, vol. 2, no. 2, pp. 59 to 66.

[4] TOUMAZOU, C., LIDGEY, F. J., HAIGH, D. G. *Analogue IC Design: The Current Mode Approach*. London: Peter Peregrinus Ltd., 1990.

[5] TANGSRIRAT, W. Current-tunable current-mode multifunctional filter based on dual-output current-controlled conveyors. *AEU – International Journal of Electronics and Communications,* 2007, vol. 61, no. 8, pp. 528-533.

[6] JAIKLA, W., SIRIPRUCHYANUN, M. Low-component electronically controllable dual-mode universal biquad filter using DO-CCCIIs. In *Proceedings of Asia-Pacific Conference on Communications 2007*, pp. 331-334.

[7] BIOLEK, D., SIRIPRUCHYANUN, M., JAIKLA, W. CCII and OTA based current-mode universal biquadratic filter. In *The Sixth PSU Engineering Conference*, May 2008, pp. 238-241.

[8] WANG. C, ZHAO, Y., ZHANG, Q., DU, S. A new current mode SIMO-type universal biquad employing multi-output current conveyors (MOCCIIs). *Radioengineering*, 2008, vol. 18, no. 1, pp. 83–88.

[9] SIRIPRUCHYANUN, M., CHANAPROMMA, C., SILAPAN, P., JAIKLA, W. BiCMOS current-controlled current feedback amplifier (CC-CFA) and its applications. *WSEAS Transactions on Electronics*, 2008, vol. 5, no. 6, pp. 203-219.

[10] BIOLEK, D., BIOLKOVA, V., KOLKA, Z. Universal current-mode OTA-C KHN biquad. *International Journal of Electronics, Circuits and Systems*, 2007, vol. 1, no. 4, pp. 214-217.

[11] KESKIN, A. U., BIOLEK, D., HANCIOGLU, E., BIOLKOVA, V. Current-mode KHN filter employing current differencing transconductance amplifiers. *Int. J. Electronics and Communications*, 2006, vol. 60, no. 6, pp. 443-446.

[12] BIOLEK, D., BIOLKOVA, V., KESKIN, A. U. Current mode quadrature oscillator using two CDTAs and two capacitors. In *Proceedings of the 5th Int. Conf. on System Science and Simulation in Engineering.* Spain, 2006, pp. 368-370.

[13] LAHIRI, A. New current-mode quadrature oscillators using CDTA. *IEICE Electronics Express*, 2009, vol. 6, no. 3, pp. 135 to 140.

[14] MAHESHWARI, S., KHAN, I. A. Novel single resistor controlled quadrature oscillator using two CDBAs. *Journal of Active and Passive Electronic Devices*, 2007, vol. 2, pp. 137-142.

[15] HORNG, J. W. Current conveyors based allpass filters and quadrature oscillators employing grounded capacitors and resistors. *Computers and Electrical Engineering*, 2005, vol. 31, pp. 81-92.

[16] CHANG, C. M. Novel current-conveyor-based single-resistance-controlled/voltage-controlled oscillator employing grounded resistors and capacitors. *Electronic Letters*, 1994, vol. 30, no. 3, pp. 181-183.

[17] KUMAR, V., PAL, K. Single element controlled sinusoidal oscillators using current conveyors. *Journal of Active and Passive Electronic Devices*, 2009, vol. 8. pp. 197-202.

[18] KUMAR, A., VYAS, A. L. A single resistance controlled eight possible oscillator circuits for analog signal processing applications. *Academic Open Internet Journal*, 2007, vol. 21, pp. 1-7.

[19] TOKER, A., KUNTMAN, H., CICEKOGLU, O., DISCIGIL, M. New oscillator topologies using inverting second-generation current conveyors. *Turk. J. Elec. Engin.*, 2002, vol. 10, no. 1, pp. 119-129.

[20] SHEN-IUAN, LIU. Single-resistance-controlled/voltage controlled oscillator using current conveyors and grounded capacitors. *Electronic Letters*, 1995, vol. 31, no. 5, pp. 337-338.

[21] AGGARWAL, V. Novel canonic current mode DDCC based SRCO synthesized using a genetic algorithm. *Analog Integrated Circuits and Signal Processing*, 2004, vol. 40, pp. 83-85.

[22] SOLIMAN, A. M. Current-mode oscillators using single output current conveyors. *Microelectronics Journal*, 1998, vol. 29, pp. 907-912.

[23] SOLIMAN, A. M. Synthesis of grounded capacitor and grounded resistor oscillators. *Journal of the Franklin Institute*, 1999, vol. 336, pp. 735-746.

[24] LAHIRI, A. Additional realization of single-element-controlled oscillators using single ICCII-. *International Journal of Computer and Electrical Engineering*, 2009, vol. 1, no. 3, pp. 303-306.

[25] PANDEY, N., PAUL, K. A novel electronically tunable sinusoidal oscillator based on CCCII (-IR). *Journal of Active and Passive Electronic Devices*, 2008, vol. 3, pp. 135-141.

[26] HORNG, J. W. A sinusoidal oscillator using current-controlled current conveyors. *Int. Journal of Electronics*, 2001, vol. 88, no. 6, pp. 659-664.

[27] HORNG, J. W., LIN, S., YANG, CH. Sinusoidal oscillators using current conveyors and grounded capacitors. *Journal of Active and Passive Electronic Devices*, 2007, vol. 2, pp. 127-136.

[28] ABUELMAATTI, M. T. New sinusoidal oscillators with fully uncoupled control of oscillation frequency and condition using three CCII+s. *Analog Integrated Circuits and Signal Processing*, 2000, vol. 24, pp. 253-261.

[29] KHAN, A. A., BIMAL, S., DEY, K. K., ROY, S. S. Novel RC sinusoidal oscillator using second-generation current conveyor. *IEEE Transaction on Instrumentation and Measurement*, 2005, vol. 54, no. 6, pp. 2402-2406.

[30] MARTINEZ, P. A., SABADELL, J., ALDEA, C., CELMA, S. Variable frequency sinusoidal oscillators based on CCII+. *IEEE Transaction on Circuits and Systems-I: Fundamental Theory and Applications*, 1999, vol. 46, no. 11, pp. 1386-1390.

[31] KILINC, S., JAIN, V., AGGARWAL, V., CAM, U. Catalogue of variable frequency and single-resistance-controlled oscillators employing a single differential difference complementary current conveyor. *Frequenz*, 2006, vol. 60, no. 7-8, pp. 142-146.

[32] SHEN-IUAN, LIU, JIANN-HORNG, TSAY Single-resistance-controlled sinusoidal oscillator using current-feedback-amplifiers. *Int. Journal of Electronics*, 1996, vol. 80, no. 5, pp. 661-664.

[33] SHEN-IUAN, LIU, CHUNG-SHINN, Shih., DONG-SHIUH, Wu. Sinusoidal oscillators with single element control using a current-feedback amplifier. *Int. Journal of Electronics*, 1994, vol. 77, no. 6, pp. 1007-1013.

[34] GUPTA, S. S., BHASKAR, D. R., SENANI, R. New voltage controlled oscillators using CFOAs. *AEU – Int. J. of Electronics and Communications*, 2009, vol. 63, no. 3, pp. 209-217.

[35] BHASKAR, D. R., SENANI, R. New CFOA-based single-element-controlled sinusoidal oscillators. *IEEE Transaction on Instrumentation and Measurement*, 2006, vol. 55, no. 6, pp. 2014 to 2021.

[36] SOLIMAN, A. M. Current feedback operational amplifier based oscillators. *Analog Integrated Circuits and Signal Processing*, 2000, vol. 23, no. 1, pp. 45-55.

[37] SINGH, V. K., SHARMA, R. K., SINGH, A. K., BHASKAR, D. R., SENANI, R. Two new canonic single-CFOA oscillators with single resistor controls. *IEEE Transaction on Circuits and Systems-II: Express Briefs*, 2005, vol. 52, no. 12, pp. 860-864.

[38] CAM, U., TOKER, A., CICEKOGLU, O., KUNTMAN, H. Current-mode high output impedance sinusoidal oscillator configuration employing single FTFN. *Analog Integrated Circuits and Signal Processing*, 2000, vol. 24, pp. 231-238.

[39] RANDALL, L. G., SANCHEZ-SINENCIO, E. Active filter design using operational transconductance amplifiers: A tutorial. *IEEE Circuits and Devices Magazine*, 1985, vol. 1, pp. 20-32.

[40] DOSTAL, T., AXMAN, V. Biquads based on single negative impedance converter implemented by classical current conveyor. *Radioengineering,* 2007, vol. 16, no. 3, pp. 96-102.

[41] Analog Devices. *Monolithic Op Amp AD 844*, 16 p. [Online] Available at: http://www.analog.com

[42] Intersil (Elantec). *EL 2082CN Current-Mode Multiplier*, 1996, 16 p. [Online] Available at: http://www.intersil.com

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