Current Gain Controlled CCTA and its Application in Quadrature Oscillator and Direct Frequency Modulator

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Abstract. *A modified conception of adjustable current conveyor transconductance amplifier (CCTA) and its interesting application in simple quadrature oscillator expandable for direct frequency modulation purposes, employing only four grounded passive elements is presented in this paper. It is quite simple solution for modern communication subsystem components. An electronic adjusting of the oscillation frequency is easily possible and control of condition of the oscillation is realized via only one grounded resistor. The characteristic equation, condition of oscillation and major parasitic influences of real active part are discussed. The verification includes PSpice simulation and measurement with the CCTA block formed by commercially available active elements.*

Keywords

Electronic adjusting, quadrature oscillator, controllable active element, CCTA.

1. Introduction

1.1 Current Gain Controlled CCTA Element

Nowadays many suitable active elements for the electronic adjusting in the signal processing (high-speed data communication systems, regulation and measurement techniques, electro acoustics, etc.) are available [1]. We can introduce novel elements such as differentially buffered transconductance amplifier (DBTA) [2] or current differencing transconductance amplifier (CDTA) [3], for instance. Unfortunately many of them are not commercially available.

The current conveyor transconductance amplifier (CCTA) is a quite new active element [4-8] that has internal structure based on the third-generation current conveyor (CCIII) and multiple-output transconductance amplifier. One of the modifications [9], [10] supposes that current conveyor is of the second-generation type (CCII) like in our case (Fig. 1). Principle of the internal structure is shown in Fig. 1c. It allows the use of the voltage input and the design of applications working in the voltage and current mode.

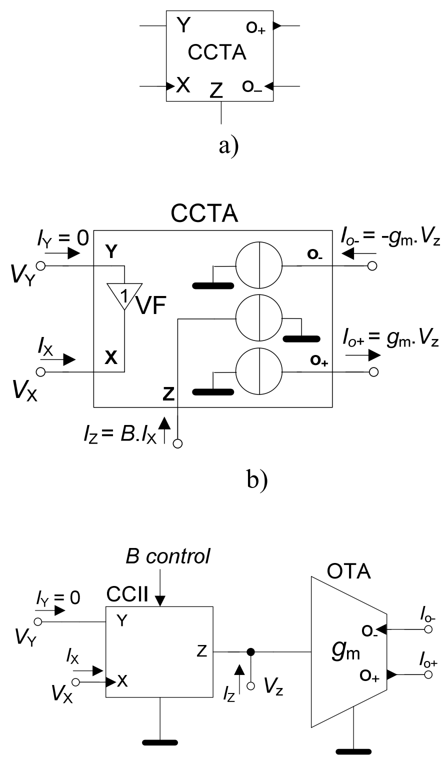


Fig. 1. General and modified CCTA active element. a) Schematic symbol , b) behavioral model, c) basic principle.

The modification of basic CCTA can be referred as CGCCCTA (current gain controlled current conveyor transconductance amplifier). The element is described by the following equations

$$V_Y = V_X,\ \ I_Y = 0,\ \ I_Z = B \cdot I_X, \quad (1), (2), (3)$$

$$I_{o+} = -I_{o-} = g_m V_Z. \quad (4)$$

The conception of this active element for experimental purposes built from commercially available devices is shown in Fig. 2. There is the controllable current conveyor (CCII-) EL 2082 [11] and two diamond transistors (DT) OPA 860 [12] in the topology. Electronic control of the current transfer is easily possible. Note that the manufactured CCTA [8] does not provide this feature. It is necessary to have two positive current outputs for the proposed oscillator circuit.

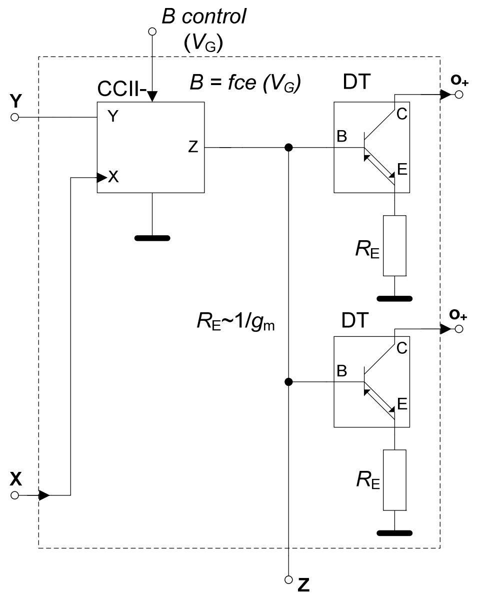


Fig. 2. Conception of CG-CCCTA element for experimental purposes based on commercially available components.

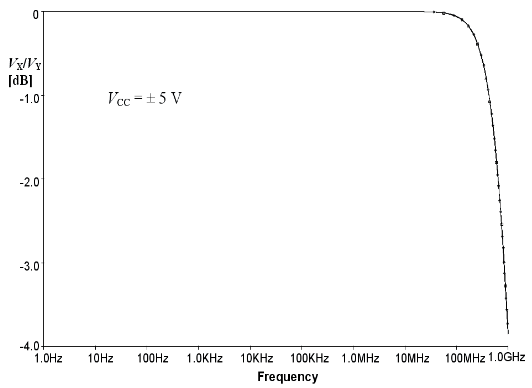


Fig. 3. Voltage transfer between Y and X ports of CCTA in Fig. 2.

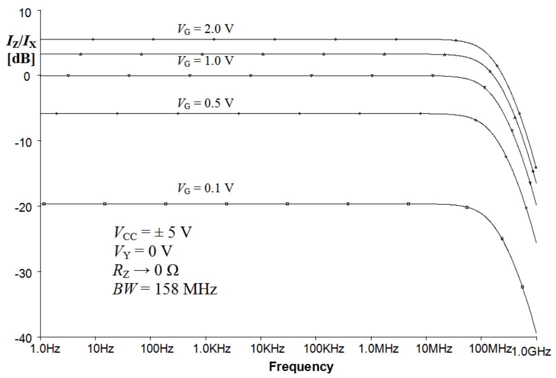


Fig. 4. Current transfers between X and Z ports of CCTA in Fig. 2.

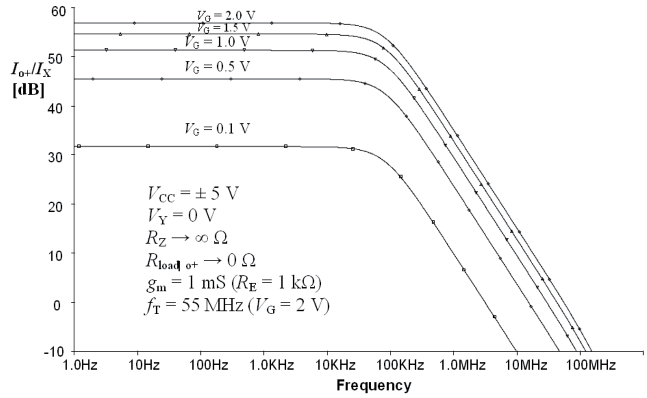


Fig. 5. Adjustable transfer between X and o ports of CCTA in Fig. 2.

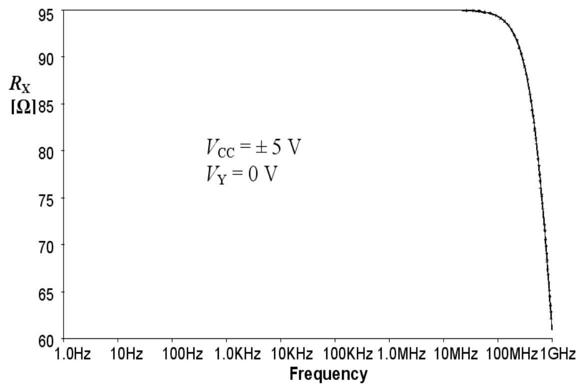


Fig. 6. Frequency dependence of R_X of CCTA in Fig. 2.

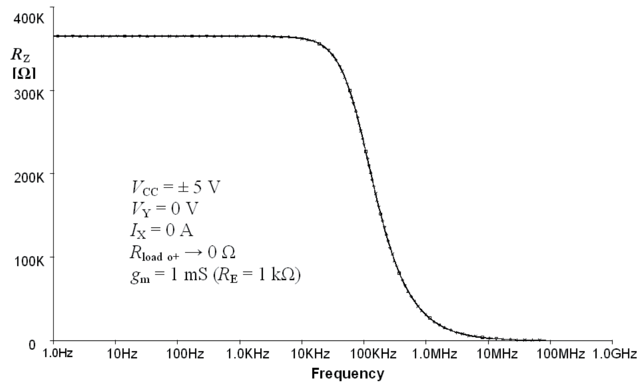


Fig. 7. Frequency dependence of R_Z of CCTA in Fig. 2.

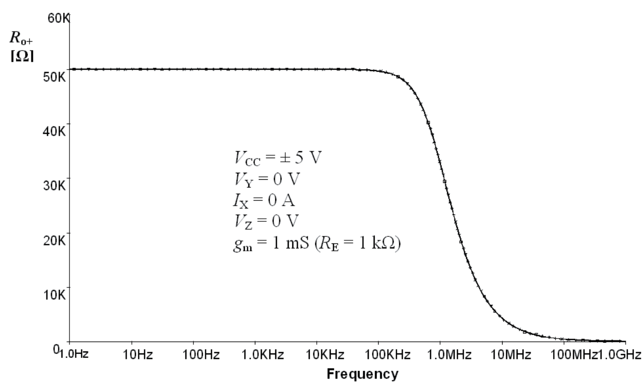


Fig. 8. Frequency dependence of R_{x+} of CCTA in Fig. 2.

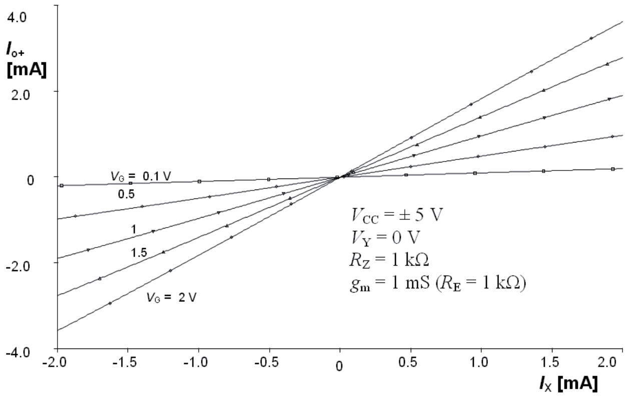


Fig. 9. Dependence of output current I_{x+} on input current of CCTA in Fig. 2.

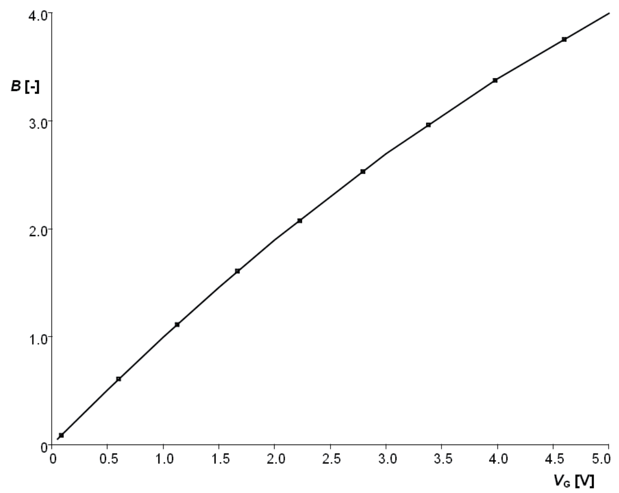


Fig. 10. Dependence of current gain B on DC control voltage V_G.

The principles and novel electronically (voltage) controlled current conveyors which can be suitable for theoretical bases for on chip design of modified CCTA were introduced in some recent works [13], [14]. Graphs in Fig. 3 to Fig. 10 show the main features obtained by simulations of CGCCCTA element showed in Fig. 2. The provided parameters are both important internal transfers in CGCCCTA element and important small signal parameters like impedance of current input X, impedance of auxiliary port Z and impedance of OTA output R_{o+}. You can see that frequency and dynamic features are better than in some low-voltage integrated technology but higher power consumption is a cost for these advantages. GBW of the proposed CGCCCTA is about 55 MHz. Small signal parameters have quite good values. However, R_X (input resistance of current input) is quite high and therefore not negligible.

1.2 Recent Progress in Oscillators Design

Many works focused on quadrature oscillators with novel modern active elements [1] were published. However, there is still some space for improvements and another approach to the problem. For example, some solutions are adjusted via floating or grounded passive elements [15-20]. Oscillation-frequency adjusting resistor is there replaced by FET transistor and it causes additional complications. There can also be problems in low power IC technologies especially in high frequency applications and low level of the output signal (for example several tens of μA in current mode) [21-25]. Recently published quadrature oscillators contain one [25-28, 31], two [19, 22, 29, 32, 34] or three [21, 33] active elements. In our opinion, realizations with one active element are more favorable. The electronic adjustability of oscillation frequency is not verified in many works [10, 22, 26, 28, 29], somewhere it is difficult [15, 19, 30]. The adjustment of active element parameters is possible by the internal biasing current that controls the resistance of current input (R_x) and transconductance (g_m) [10, 15, 21, 24-27]. Instead of the mentioned solutions the controllable current gain is used for the control of the oscillation frequency in our solution. Some of the proposed solutions are based also on commercially available devices [9, 10, 23]. Recent published solutions have quite high THD [10, 15, 17, 26, 31]. In some cases [33] THD is really terrible. Non-precise and inaccurate setting of the condition of oscillation is probable reason of such high THD. Due to the precise and smooth setting of the oscillation condition it is possible to obtain quite low THD.

The conception based on commercially available elements has better dynamic and frequency features but it requires higher supply voltage and it has higher power consumption. All previous works with the feature of controllable oscillation frequency are based on biasing control of g_m or/and R_x. There is another way how to control the oscillation frequency. The method is not so common and it is based on current gain adjusted by the voltage in formed active element. There are also some other generally favorable features like grounded passive elements, simple circuit structure and quite high output signal level. Recently published CCTA-based oscillator solutions require two or more negative and positive current outputs (I_{o-}, I_{o+}) but only two positive outputs are mandatory in our solution, which simplifies internal CCTA conception.

In comparison with our first work [34] focused on voltage controllable oscillator based on two controllable current conveyors, the presented solution provides improved form of the characteristic equation and formulas for oscillation frequency and independent oscillation condition. Conception proposed in [34] has unsuitable expression in oscillation frequency formula that allows only limited values of current transfer (B) and therefore also a limited tuning range. Only capacitors are grounded in [34]. In this work, all passive elements are grounded and the range of current gain (B) for control of oscillation frequency is not limited from principle of design (equation for oscillation frequency). Constrains are given by a limited range of adjustable current gain and by real properties of the used active element.

Recently published solutions of CCTA-based oscillators are compared in the following text. Almost each type of oscillator with modern active elements published lately is based on integrators (lossy or lossless) in one or more loops. It is fundamental for design approach, therefore in case of circuit complexity, recent solutions and the presented circuit are similar in basic concept and in number of used passive elements.

Jaikla et al. [10] proposed conception based on one CCTA that was built from commercially available elements and 3 passive elements. Oscillation frequency was set on 70 kHz (adjustable by g_m). Features of the oscillator were also experimentally verified. The quadrature output cannot be obtained and THD of 5.7 % is achieved. The solution proposed by Pisutthipong et al. [15] is based on two CCTAs designed in bipolar technology and two passive elements (capacitors). The oscillation frequency was set to 380 kHz. The circuit was verified by PSpice simulation and has the possibility of quadrature output. The achieved distortion is 2.5 %. Research described by Lahiri in [25] introduces a structure that consists of one active unit (designed again in the bipolar technology) and four passive elements. The quadrature oscillator is tunable from 20 kHz to 700 kHz. Simulation results are not focused on THD analysis. Conception shown in [25] is quite similar to the presented oscillator circuit. Solution in [25] uses CCTA element with three Z auxiliary ports (for mixed mode solution) and current outputs of OTA section are in both polarities (positive and negative). Conception of ports of modified CCTA (CGCCCTA) presented in this paper for application in adjustable oscillator is simpler. Only one Z port is required and sufficient in presented CGCCCTA and output current of OTA section is of one polarity which simplifies final realization. Feedback system of solution presented in [25] connects three high impedance ports (Y, Z and o) together and uses also four grounded passive elements. The presented solution has simpler feedback (connected Z and o port). Characteristic equations of both solutions are different. Condition of oscillation is based on equality of two resistors in [25], while but on product of resistor and transconductance (g_m) of OTA section in our solution. In [25], tunability depends on g_m. Our solution is tunable directly by adjustable current transfer B or by one resistor. Siripruchyanun et al. [26] introduced the oscillator based on just one CCTA (again in the bipolar technology, one current output of OTA section) and two passive elements. There are no quadrature outputs and THD is 3 %. Oscillation frequency control is based on g_m (I_b) control (not verified) and condition of oscillation is given by equality of both capacitors. Lahiri also proposed the quadrature oscillator [27] employing one modified CCTA - DVCCTA (differential voltage CCTA designed in the bipolar technology) and four passive elements. Configuration of feedbacks is similar to the presented solution but in [27] there is only one OTA output and two voltage inputs Y. Tuning is possible by g_m and condition of oscillation is based on equality of two resistors. The oscillation frequency is tunable by g_m (I_b) from 80 kHz to 800 kHz with switching of working capacitors. THD of 4.7 % is achieved. The solution introduced by Siripruchyanun et al. [28] contains one CCTA (CMOS technology simulations) and two passive elements (similar [26]). The oscillation frequency is 500 kHz and output waveform has THD 1 %. There are no quadrature outputs. Bumronghoke et al. [31] uses one CCTA with two auxiliary Z ports (again designed in the bipolar technology) and two passive elements on oscillation frequency of 264 kHz without quadrature outputs and with THD 2.5 %. Their oscillator uses electronically controllable current input resistances and g_m (two separated OTA sections with the same polarity of current outputs) is tunable perhaps from 30 kHz to 3 MHz with switching of working capacitors. Electronically tunable oscillation frequency is given by the difference of both g_m of OTA sections.

All the solutions mentioned above use bias current (I_B) control of R_x or g_m to adjust the oscillation frequency or oscillation condition if it is possible in principle (some solutions have not capabilities for electronic adjusting or it was not verified). Our solution of quadrature oscillator employs one CCTA with current outputs (OTA section) of one polarity and four grounded passive elements. Electronic adjusting of the oscillation frequency is based on voltage controlled current gain and verified also experimentally from 200 kHz to 1.1 MHz. Achievable THD varies from 0.6 to 4 % in the mentioned range of oscillation frequencies. Benefits of the presented oscillator solution are mainly in simplification of the used active element (less auxiliary ports and outputs). The main aim of this work is to prove, observe and evaluate another possible easy way to electronic (voltage) control of oscillation frequency without g_m (I_b) control and/or without replacing of any passive element by its electronic adjustable equivalent. The modified CCTA element (adjustable current gain between X and Z port) has lot of possible applications, oscillator or modulator and mixers for example, as presented in this paper.

2. Oscillator Based on one CGCCCTA and Grounded Elements

The proposed circuit is shown in Fig. 11. The oscillator is based on lossless and lossy current-mode integrators connected in the loop. Integrators are created by internal CCTA components (CCII and OTA) and passive elements. Output responses are obtained on adequate grounded element that converts current to voltage. Practical output responses are available on high-impedance nodes therefore additional voltage buffers are required. Fortunately, our CCTA solution based on commercially available elements contains also voltage buffer inside OPA 860 chip.

The characteristic equation has the following form

$$a_2 s^2 + a_1 s + a_0 = s^2 + \frac{g_m R_2 - 1}{R_2 C_2} s + \frac{g_m B}{R_1 C_1 C_2} = 0 \,. \quad (5)$$

Conditions of oscillation and oscillation frequency are

$$g_m R_2 = 1, \tag{6}$$

$$\omega_0 = \sqrt{\frac{g_m B}{R_1 C_1 C_2}}. \tag{7}$$

Relative sensitivities are

$$S_{g_m}^{\omega_0} = S_B^{\omega_0} = -S_{R_1}^{\omega_0} = -S_{C_1}^{\omega_0} = -S_{C_2}^{\omega_0} = 0.5, \tag{8}$$

$$S_{R_2}^{\omega_0} = 0. \tag{9}$$

Oscillation frequency can be electronically adjusted by the current transfer B. It is clear from (6) and (7) that R_2 can be used to control the oscillation condition without disturbing the oscillation frequency and with easily implemented automatic gain control circuit (AGC).

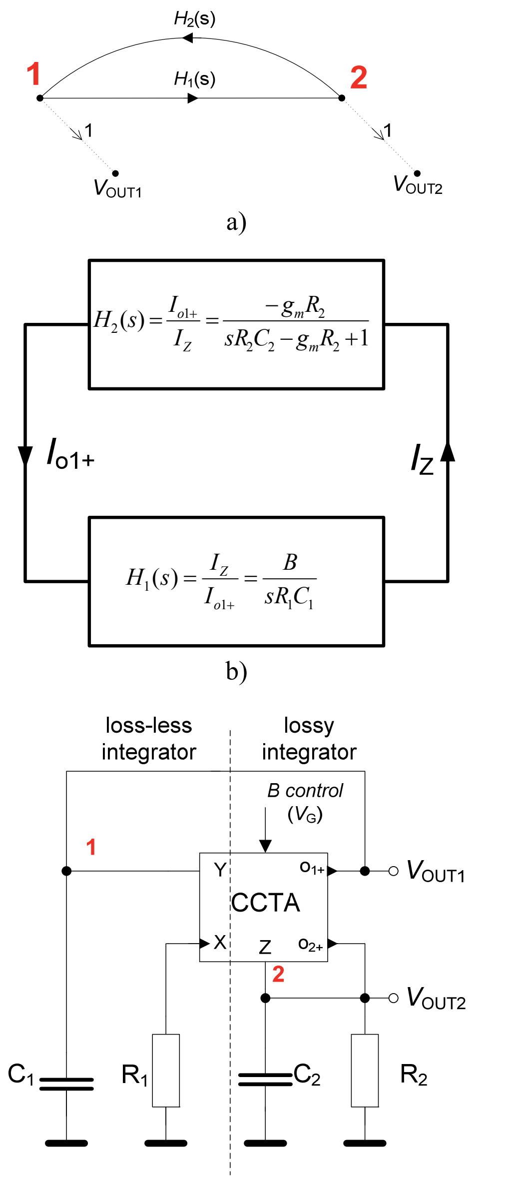


Fig. 11. The proposed quadrature oscillator principle: a) Basic signal-flow graph, b) block diagram, c) the proposed circuit.

From (6) and (7) it is clear that also R_1 can be used for electronic adjusting of the oscillation frequency. We can replace it by a digital potentiometer or a digital to analog converter. Practically, there are problems with unfavorable frequency features and quite high parasitic capacitances of used replacements in some cases. However, the direct electronic control of the oscillation frequency by B is easier than switching of a resistor array and also profitable for its simplicity and low cost. It is better for continuous frequency changes because switching of R_1 allows only discrete changes of f_0. Using of the B in this conception allows (very easily) some additional advantages of the mentioned oscillator that are discussed in section 3.

3. Simulation and Experimental Results

Passive elements are selected as $R_1 = R_2 = R = 1$ kΩ, $C_1 = C_2 = C = 220$ pF. Parameters of the active element are $g_m = 1$ mS ($R_E = 1$ kΩ) and the current transfer $B = f(V_G)$ is well-adjustable by V_G from 0.1 to 4 V. The supply voltage was $V_{CC} = \pm 5$ V. The measured output responses in time domain are in Fig. 12. In Fig. 13 there is the FFT spectrum.

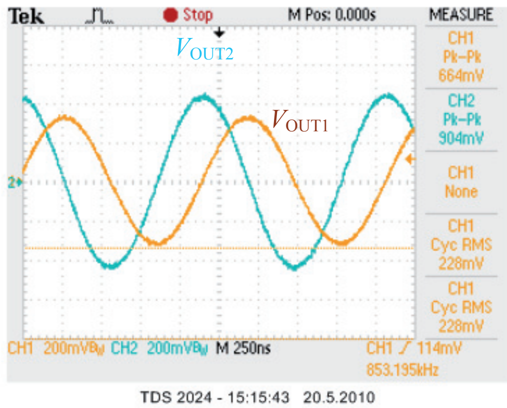


Fig. 12. Generated output quadrature waveforms.

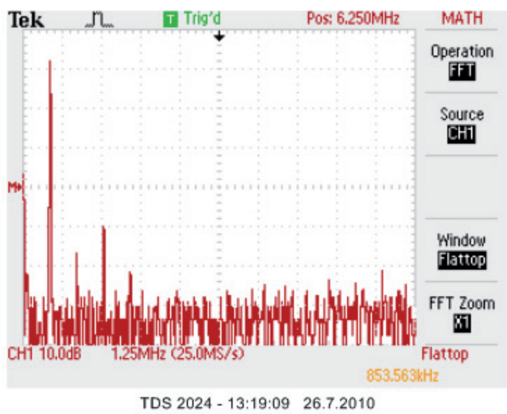


Fig. 13. Output FFT spectrum in wider range.

R_2 has to be of a slightly higher value (1.1 kΩ) to start the oscillation. The control voltage V_G was set to 2 V (that corresponds to the real current transfer B ~ 1.89) and the theoretical oscillation frequency is f_0 = 0.938 MHz. We achieved f_0 = 0.922 MHz in the Matlab simulation (parasitic non-ideal properties of the used CCTA were included), 0.886 MHz was obtained from the PSpice simulation with available models and finally, the value of 0.853 MHz was gained from the measurement. The suppression of higher harmonics components is about 45 dB (THD approximately 0.6 %) at the given oscillation frequency without AGC (only non-linear sections of input-output characteristic of the active element). The dependence of the oscillation frequency on V_G is depicted in Fig. 14. The dependence of THD on the oscillation frequency is shown in Fig. 15.

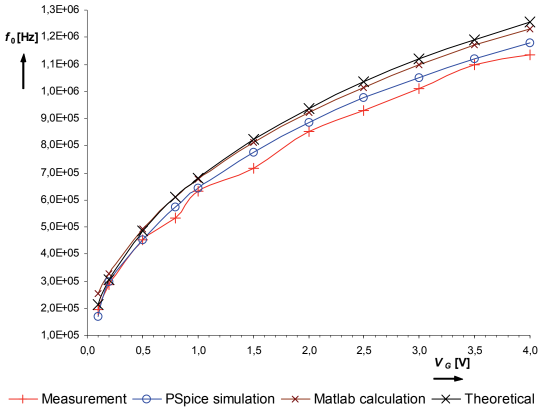


Fig. 14. Dependence of the oscillation frequency on the control voltage.

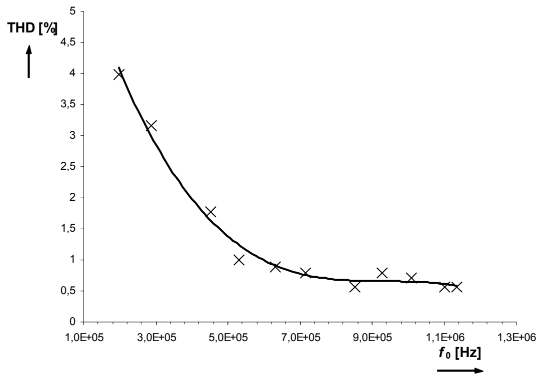
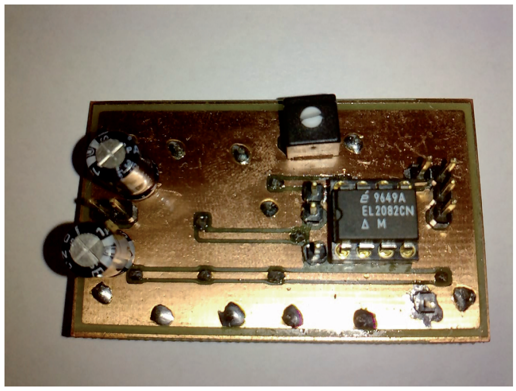


Fig. 15. The dependence of THD on the oscillation frequency.

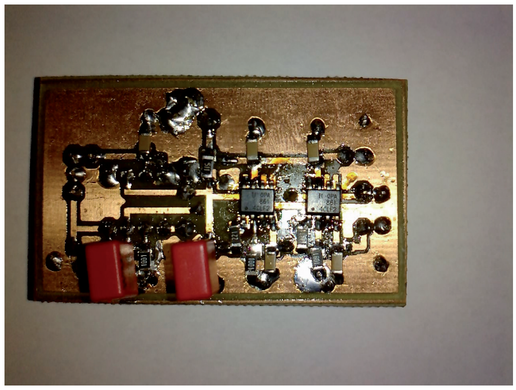
Fig. 14 and Fig. 15 are supported by the detailed values summarized in Tab. 1. The amplitude of output oscillation is limited to 3 V in case that the oscillation condition is more than fulfilled ($g_mR_2 > 1$) and THD is terrible in case of maximal amplitude. In the presented case (setting of g_mR_2 ~ 1) the amplitude is lower (about 0.5 V, see Fig. 12) but it is still quite a high value in comparison with several other works where output level is only few tens of mV or μA (in current mode realizations). Very small changes of R_2 value (tens of Ω) are necessary in each of the measured point in order to preserve the low THD when AGC circuit is not present in the circuit. Low THDs were achieved (under 1%) in half of the range. Of course, there were fluctuations of output signal level in the whole range of adjusting when AGC circuit was not present.

V_G [V]	B [-]	f_0 ideal [MHz]	f_0 Matlab [MHz]	f_0 PSpice [MHz]	f_0 measured [MHz]	Suppression of the higher harmonics [dB]	THD [%]
0.1	0.1	0.215	0.253	0.171	0.197	28	4.0
0.2	0.2	0.304	0.328	0.299	0.287	30	3.2
0.5	0.51	0.487	0.494	0.454	0.452	35	1.8
0.8	0.8	0.610	0.610	0.575	0.532	40	1.0
1.0	0.99	0.681	0.676	0.642	0.631	41	0.9
1.5	1.46	0.822	0.812	0.777	0.716	42	0.8
2.0	1.89	0.938	0.922	0.886	0.853	45	0.6
2.5	2.31	1.040	1.020	0.977	0.929	43	0.7
3.0	2.69	1.120	1.100	1.050	1.010	43	0.7
3.5	3.05	1.190	1.170	1.120	1.100	45	0.6
4.0	3.39	1.260	1.230	1.180	1.130	45	0.6

Tab. 1. Simulation and experimental results.



a)



b)

Fig. 16. The measured prototype: a) Top side, b) bottom side.

Influences of real properties of the active element on oscillation frequency are caused by the parasitic properties (capacitances and mainly R_X) of the CCTA structure built from commercially available devices. On chip realization of this active element should have better properties than our experimental testing device. A detailed study of non-idealities can be found in the next section. The measured prototype is shown in Fig. 16.

Due to the possibilities of voltage control of B, the presented solution has some non-standard features which are not so obvious. Fig. 17 demonstrates the possible configuration of this voltage controlled oscillator as a frequency modulator.

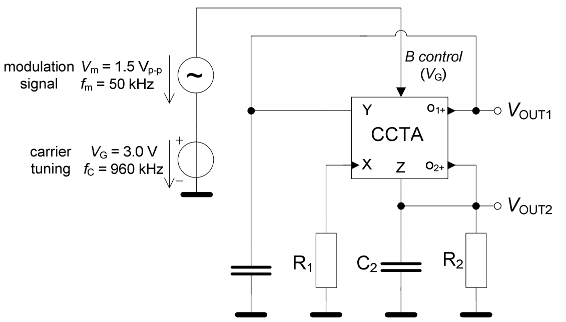


Fig. 17. Demonstration of the possible application of the proposed oscillator with direct *B* control as the frequency modulator.

The main advantage of this solution is direct and immediate control of the carrier frequency (f_C) by the DC voltage (V_G) and frequency modulation by a superposed AC signal (sine waveform). Measurement results of the frequency modulator with sine modulation signal are in Fig. 18. The carrier frequency is 960 kHz. Other parameters of modulation (V_m, f_m) and carrier signal (V_C, f_C) are included in the figure.

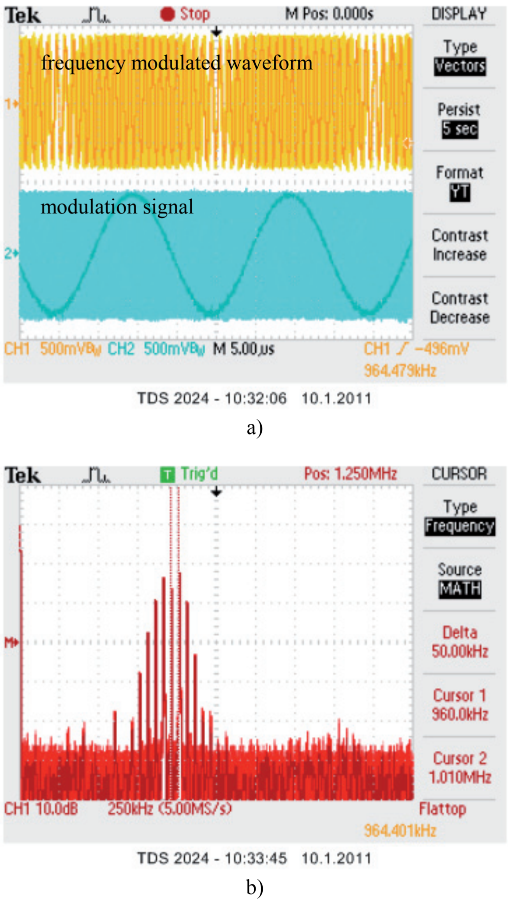


Fig. 18. Measurement results of the application of the oscillator as the frequency modulator:
a) Time domain, b) frequency spectrum.

We can describe function of oscillator as frequency modulator by the following equations and approximate dependences. The oscillator produces the output voltage

$$v_{out}(t) = V_C \cos(\omega_C t) \tag{10}$$

where ω_C is given by

$$\omega_C = \sqrt{\frac{g_m B}{R_1 C_1 C_2}}\,. \tag{11}$$

The oscillator produces only the carrier frequency in case without a modulation signal that is given by the DC control voltage

$$B \approx V_G\,. \tag{12}$$

In case with a modulation signal

$$B \approx V_G + v_m(t)\,, \tag{13}$$

where

$$v_m(t) = V_m \cos(\omega_m t)\,. \tag{14}$$

V_m is the amplitude of the modulation voltage and ω_m is the angular frequency of the same voltage.

Another feature of the proposed circuit is using of *B* controlled oscillator for frequency shift keying (FSK), see Fig. 19. The modulation signal is now the square waveform with amplitude V_m = 1.5 V and frequency f_m = 10 kHz, DC offset is 2 V. Simulation results both in time and frequency domain are shown in Fig. 20.

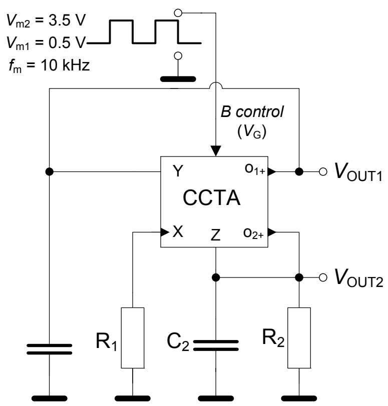
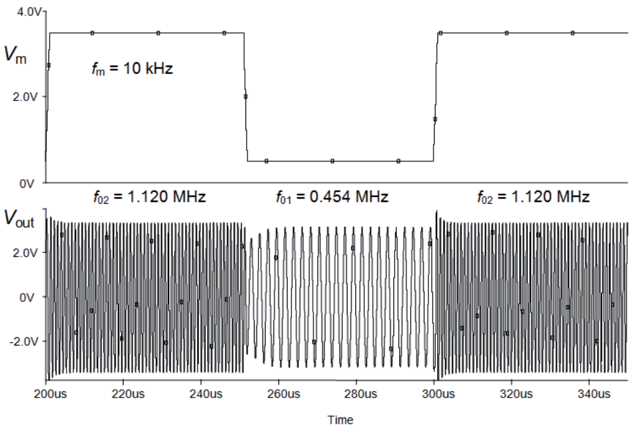
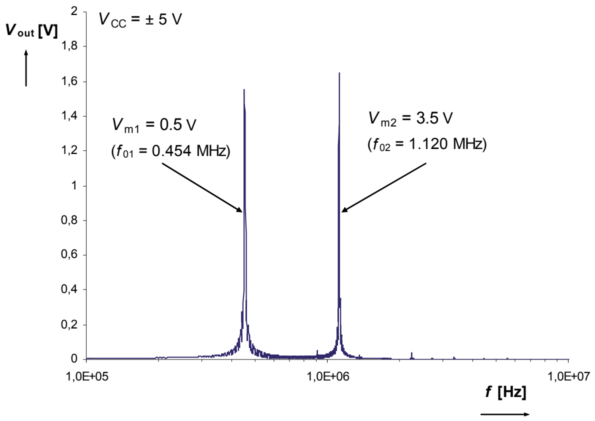


Fig. 19. Demonstration of the possible application of the proposed oscillator with the direct *B* control as the FSK modulator.

However, there are very important frequency limitations of the auxiliary control voltage V_G (used for *B* adjusting). This port is designed mainly for DC control. Practically, a modulation signal can have frequency up to several kHz for EL 2082 used in CGCCCTA block. Due to the missing AGC circuit, parasitic amplitude modulation appears (see Fig. 18 and 20) mainly for higher modulation frequencies (tens of kHz). This problem can be minimized by good amplitude stabilization. The mentioned problem is given by conception of the used CGCCCTA element that is overall sufficient for confirmation of theoretical assumptions, but may be insufficient for very precise practical application as modulator where strict specifications are given. Practically, a similar device designed on chip should achieve better features.



a)



b)

Fig. 20. Simulation results of the application of the oscillator as the FSK modulator: a) Time domain, b) frequency spectrum.

4. Influences of Real Active Element

Parasitic elements influence functionality by the real input and output properties (R_X, R_Y, R_Z, R_{o1+}, R_{o2+}, C_Y, C_Z, C_{o1+}, C_{o2+}) of the used CCTA (Fig. 21). They are depicted as Z_{p1} and Z_{p2} in Fig. 22 and focused to two important circuit nodes. We can determine [11], [12] that in the non-ideal model (Fig. 21) it applies: $R_Y \sim 2$ MΩ, $R_X \sim 95$ Ω, $R_Z \sim 0.36$ MΩ, $R_{o1+} = R_{o2+} \sim 50$ kΩ, $C_Y \sim 2$ pF, $C_Z \sim 7$ pF, $C_{o1+} = C_{o2+} \sim 2$ pF. Frequency dependences of these parameters are evident from the introductory section. According to the simulation, the DT input resistance is dependent also on the value of the degradation resistor R_E (therefore also on g_m). For example if $R_E = 1$ kΩ then $R_{B\_DT} \sim 1.1$ MΩ and if $R_E = 50$ Ω then $R_{B\_DT} \sim 260$ kΩ. It impacts mainly the R_Z but also significantly influences oscillator function if R_Z value is lower than several tens of kΩ. For parasitic elements in Fig. 22 it applies $Y_{p1} = 1/Z_{p1}$, $Y_{p2} = 1/Z_{p2}$, $C_{p1} = C_Y + C_{o1+}$, $G_{p1} = 1/R_{p1} = G_Y + G_{o1+} = 1/R_Y + 1/R_{o1+}$, $C_{p2} = C_Z + C_{o2+}$ and $G_{p2} = 1/R_{p2} = G_Z + G_{o2+} = 1/R_Z + 1/R_{o2+}$, $B^* = B\omega_T/(s+\omega_T)$.

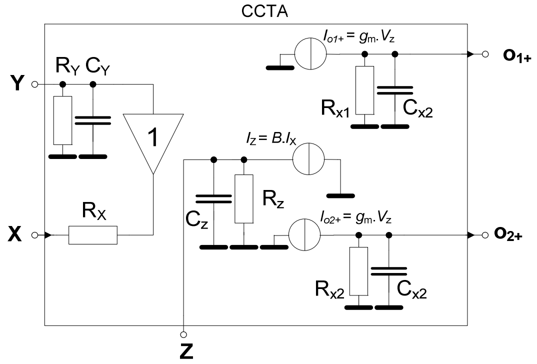


Fig. 21. Non-ideal model of CCTA.

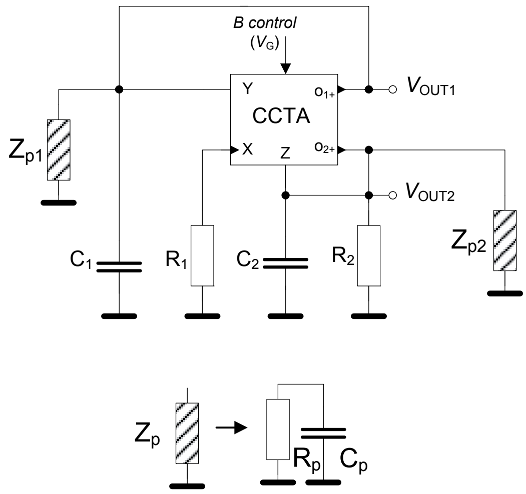


Fig. 22. Important parasitic influences in the proposed oscillator circuit.

Also $R_1^* = 1/G_1^* = R_1 + R_X$ has to be considered because the real resistance of the current input X causes variation between the real and ideal oscillation frequencies. We cannot omit it because its value is indispensable (95 Ω). The obtained coefficients of the real characteristic equation are

$$a_2 = 1, \tag{15}$$

$$a_1 = \frac{g_m(C_{p1}+C_1) - C_1G_2 + C_2G_{p1}}{C_1C_2 + C_{p1}C_{p2} + C_1C_{p2} + C_2C_{p1}} + \frac{C_{p1}G_2 + C_1G_{p2} + C_{p1}G_{p2} + G_{p1}C_{p2}}{C_1C_2 + C_{p1}C_{p2} + C_1C_{p2} + C_2C_{p1}}, \tag{16}$$

$$a_0 = \frac{g_m B^* G_1^* + g_m G_{p1} + G_{p1}G_2 + G_{p1}G_{p2}}{C_1C_2 + C_{p1}C_{p2} + C_1C_{p2} + C_2C_{p1}}. \tag{17}$$

The condition of oscillation and the characteristic equation are now

$$g_m(C_{p1}+C_1) + C_2G_{p1} + C_{p1}G_2 + C_1G_{p2} + C_{p1}G_{p2} + G_{p1}C_{p2} = C_1G_2, \tag{18}$$

$$\omega_0 = \sqrt{\frac{g_m B^* G_1^* + g_m G_{p1} + G_{p1}G_2 + G_{p1}G_{p2}}{C_1C_2 + C_{p1}C_{p2} + C_1C_{p2} + C_2C_{p1}}}. \tag{19}$$

The impact is clearly evident from Tab. 1 in variations between real and expected oscillation frequencies.

5. Conclusion

Modification of current conveyor transconductance amplifier (CCTA) was used in order to propose an oscillator. The active element was constructed from commercially available devices for experimental purposes. Simple construction of the quadrature oscillator with one electronically adjustable active element CCTA and four grounded passive elements has been proposed. In comparison with some previous solutions all passive elements are grounded and it is necessary to have both CCTA outputs of positive orientation. Independent adjusting of the oscillation frequency and the condition of oscillation is possible. The range of f_0 control was tested approximately from 0.2 MHz to 1.1 MHz. THD is quite low (under 1 %) in half of the frequency range, without AGC system, in case the oscillation frequency is preset constantly. AGC system is necessary especially for the precise tunable application without fluctuation of output amplitude but its implementation (grounded resistor) is simple. Due to the current gain (B) controlled by an external force (voltage) the proposed oscillator can be used for modulation purposes. There are not many disadvantages of this solution: necessity of voltage buffers on outputs, quite low and limited range of the current transfer B and non-accurate relation between B and control voltage which is given by one of the used active elements (EL 2082). Also R_X value of the proposed CCTA experimental circuit is not excellent. The listed disadvantages are not caused by the conception of the proposed oscillator, but by the construction of the CCTA from the commercially available elements and by their real features. Theoretical assumptions were confirmed by the simulation and measurement results.

Acknowledgements

The authors are thankful to the editors and reviewers for their constructive recommendations, which helped to improve this paper. Research described in the paper was supported by the Czech Ministry of Education under research program MSM 0021630513 and by the Czech Science Foundation projects under No. 102/08/H027 and No. 102/09/1681. Research described in the paper is a part of the COST Action IC0803 RF/Microwave communication subsystems for emerging wireless technologies, financed by the Czech Ministry of Education by the grant No. OC09016.

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, p. 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, p. 329-334.

[3] 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, p. 443-446.

[4] PROKOP, R., MUSIL, V. New modular current devices for true current mode signal processing. *Electronics,* 2007, vol. 16, no. 4, p. 36-42.

[5] PROKOP, R., MUSIL, V. CCTA: a new modern circuit block and its internal realization. In *Electronic Devices and Systems IMAPS CZ International Conf.* Brno (Czech Republic), 2005, p. 89-93.

[6] PROKOP, R., MUSIL, V. New modern circuit block CCTA and some its applications. In *The 14th Int. Scientific and Applied Science Conf. Electronics ET'2005, Book 5.* Sofia (Bulgaria), 2005, p. 93-98.

[7] PROKOP, R., MUSIL, V. Modular approach to design of modern circuit blocks for current signal processing and new device CCTA. In *Proceedings of the 7th IASTED International Conference on Signal and Image Processing.* Anaheim (USA), 2005, p. 494-499.

[8] PROKOP, R. Modular approach to design of modern analog devices in CMOS technology. *Doctoral (Ph.D.) Thesis.* Dept. of Microelectronics FEEC BUT Brno, Czech Republic, 2009, p. 1-98.

[9] HERENCSAR, N., KOTON, J., VRBA, K. Single CCTA-based universal biquadratic filters employing minimum components. *Int. J. on Computer and Electrical Engineering*, 2009, vol. 1, no. 3.

[10] JAIKLA, W., SILAPAN, P., CHANAPROMMA, C., SIRIPRUCHYANUN, M. Practical implementation of CCTA based on commercial CCII and OTA. In *International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS 2008).* Thailand, 2008, p. 1-4.

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

[12] Texas Instruments. Wide bandwidth operational transconductance amplifier and buffer OPA 860, 2005, 29 p. [Online] Available at: www: http://www.ti.com

[13] MINAEI, S., SAYIN, O. K., KUNTMAN, H. A new CMOS electronically tunable current conveyor and its application to current-mode filters. *IEEE Transaction on Circuits and Systems I - Regular papers*, 2006, vol. 53, no. 7, p. 1448-1457.

[14] MARCELLIS, A., FERRI, G., GUERRINI, N. C., SCOTTI, G., STORNELLI, V., TRIFILETTI, A. The VGC-CCII: a novel building block and its application to capacitance multiplication. *Analog Integrated Circuits and Signal Processing*, 2009, vol. 58, no. 1, p. 55-59.

[15] PISUTTHIPONG, N., SILAPAN, P., SIRIPRUCHYANUN, M. CC-CCTA-based current-mode quadrature oscillator. In *The Seventh PSU Conference*. 2009, p. 302-305.

[16] SENANI, R., GUPTA, S. S. New single resistance controlled oscillators employing a reduced number of unity-gain cells. *IEICE Electronics Express,* 2004, vol. 1, no. 16, p. 507-512.

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

[18] TANGSRIRAT, W., PRASERTSOM, D., PIYATAT, T., SURAKAMPONTORN, W. Single-resistance-controlled quadrature oscillator using current differencing buffered amplifiers. *Int. Journal of Electronics*, 2008, vol. 95, no. 11, p. 1119-1126.

[19] KESKIN, A. U., BIOLEK, D. Current mode quadrature oscillator using current differencing transconductance amplifiers (CDTA). *Circuits, Devices and Systems*, 2006, vol. 153, no. 3, p. 214-217.

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

[21] TANGSRIRAT, W., TANJAROEN, W. Current-mode sinusoidal quadrature oscillator with independent control of oscillation frequency and condition using CDTAs. *Indian Journal of Pure and Applied Physics*, 2010, vol. 45, no. May 2010, p. 363-366.

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

[23] LAHIRI, A. Resistor-less mixed-mode quadrature sinusoidal oscillator. *International Journal of Computer and Electrical Engineering*, 2010, vol. 2, no. 1, p. 63-66.

[24] LAHIRI, A., MISRA, A., GUPTA, K. Novel current-mode quadrature oscillator with explicit-current-outputs using CCCDTA. In *Proceedings of the Nineteeth International Conference Radioelektronika* 2009. Bratislava (Slovak Republic), 2009, p. 47 to 50.

[25] LAHIRI, A. Explicit-current-output quadrature oscillator using second-generation current conveyor transconductance amplifier. *Radioengineering,* 2009, vol. 18, no. 4, p. 522-526.

[26] SIRIPRUCHYANUN, M., JAIKLA, W. Current controlled current conveyor transconductance amplifier (CCCCTA): a building block for analog signal processing. *Electrical Engineering Springer,* 2008, vol. 90, no. 6, p. 443-453.

[27] LAHIRI, A., JAIKLA, W., SIRIPRUCHYANUN, M. Voltage-mode quadrature sinusoidal oscillator with current tunable properties. *Analog Integrated Circuits and Signal Processing*, 2010, vol. 65, no. 2, p. 321-325.

[28] SIRIPRUCHYANUN, M. SILAPAN, P., JAIKLA, W. Realization of CMOS Current Controlled Current Conveyor Transconductance amplifier (CCCCTA) and its applications. *Journal of Active and Passive Electronic Devices,* 2009, vol. 4, p. 35-53.

[29] LAHIRI, A. Novel voltage/current-mode quadrature oscillator using current differencing transconductance amplifier. *Analog Integrated Circuits and Signal Processing*, 2009, vol. 61, no. 2, p. 199-203.

[30] JAIKLA, W., SIRIPRUCHYANUN, M., BAJER, J., BIOLEK, D. A simple current-mode quadrature oscillator using single CDTA. *Radioengineering*, 2008, vol. 17, no. 4, p. 33-40.

[31] BUMRONGHOKE, T., JAIKLA, W., SIRIPRUCHYANUN, M. An electronic controllable, simple current-mode oscillator using single MO-CCCCTA and grounded capacitors. In *Proceedings of the 1st International Conference on Technical Education (ICTE2009).* Thailand, 2010, p. 217-220.

[32] SOTNER, R., JERABEK, J., PETRZELA, J., DOSTAL, T., VRBA, K. Electronically tunable simple oscillator based on single-output and multiple-output transconductor. *IEICE Electronics Express*, 2009, vol. 6, no. 20, p. 1476-1482.

[33] HORNG, J., LEE, H., WU, J. Electronically tunable third-order quadrature oscillator using CDTAs. *Radioengineering*, 2010, vol. 19, no. 2, p. 326-330.

[34] SOTNER, R., HRUBOS, Z., SLEZAK, J., DOSTAL, T. Simply adjustable sinusoidal oscillator based on negative three-port current conveyors. *Radioengineering*, 2010, vol. 19, no. 3, p. 446 to 453.

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