LETTER IEICE Electronics Express, Vol.12, No.19, 1–7

Design of the simple oscillator with linear tuning and pi/4 phase shift based on emulator of the modified current differencing unit

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Abstract: This paper presents a simple oscillator with 45 degrees phase shift between output signals. A Modified Current Differencing Unit (MCDU) was used for its design. The MCDU offers controllability of input resistances of current inputs and controllability of current gains. These features are not available together in the standard current differencing unit and it limits usability in some applications. The proposed oscillator allows linear electronic control of oscillation frequency and independent control of condition of oscillation with simple implementation of amplitude stabilization. The PSpice simulations and measurements in laboratory with manufactured behavioral emulator of the MCDU confirmed the expected features of the solution.

Keywords: electronic control, behavioral model/emulator, oscillator, modified current differencing unit

Classification: Electron devices, circuits, and systems

References

[1] H. O. Elwan and A. M. Soliman: Analog Integr. Circuits Signal Process. **11** (1996) 35. DOI:10.1007/BF00174237

[2] N. Herencsar, R. Sotner, B. Metin, J. Koton and K. Vrba: 8th International Conference on Electrical and Electronics Engineering (ELECO) (2013) 17. DOI:10.1109/ELECO.2013.6713927

[3] B. Metin, N. Herencsar and K. Vrba: Radioengineering **21** [2] (2012) 718.

[4] J. Vavra and D. Biolek: Int. Conf. on Electronic Devices and Systems (EDS IMPAPS) (2008) 7.

[5] J. Vavra and J. Bajer: Analog Integr. Circuits Signal Process. **74** (2013) 121. DOI:10.1007/s10470-012-9906-8

[6] D. Biolek, R. Senani, V. Biolkova and Z. Kolka: Radioengineering **17** [4] (2008) 15.

[7] C. Acar and S. Ozoguz: Microelectron. J. **30** (1999) 157. DOI:10.1016/S0026-2692(98)00102-5

[8] A. Toker, S. Ozoguz, O. Cicekoglu and C. Acar: IEEE Trans. Circuits Syst. II, Analog Digit. Signal Process. **47** (2000) 949. DOI:10.1109/82.868465

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
Publicized September 4, 2015
Copyedited October 10, 2015

[9] D. Biolek: Euro. Conf. on Circuit Theory and Design (ECCTD) (2003) 397.
[10] M. Siripruchyanun and W. Jaikla: Circuits Syst. Signal Process. **27** (2008) 113. DOI:10.1007/s00034-008-9014-2
[11] R. Sotner, J. Jerabek, N. Herencsar, T. Zak, W. Jaikla and K. Vrba: Adv. Electr. Comp. Eng. **15** (2015) 3. DOI:10.4316/AECE.2015.01001
[12] Ch. Sakul, W. Jaikla and K. Dejhan: Radioengineering. **20** [4] (2011) 890.
[13] W. Jaikla and A. Lahiri: AEU, Int. J. Electron. Commun. **66** (2012) 214. DOI:10.1016/j.aeue.2011.07.001
[14] S.-H. Tu, Y.-S. Hwang, J.-J. Chen, A. M. Soliman and C.-M. Chang: IEEE Trans. Instrum. Meas. **61** (2012) 2305. DOI:10.1109/TIM.2012.2184958
[15] R. Sotner, J. Jerabek, J. Petrzela, N. Herencsar, R. Prokop and K. Vrba: Elektronika Ir Elektrotechnika **20** (2014) 13. DOI:10.5755/j01.eee.20.9.8709
[16] R. Sotner, J. Jerabek, N. Herencsar, J. W. Horng and K. Vrba: 37th Int. Conf. on Telecommunications and Signal Processing (TSP) (2014) 396.
[17] R. Sotner, J. Jerabek, N. Herencsar, K. Vrba and T. Dostal: AEU, Int. J. Electron. Commun. **69** (2015) 814. DOI:10.1016/j.aeue.2015.01.012
[18] W. Surakampontorn and W. Thitimajshima: IEE Proc. G **135** (1988) 71. DOI:10.1049/ip-g-1.1988.0010
[19] A. Fabre and N. Mimeche: Electron. Lett. **30** (1994) 1267. DOI:10.1049/el:19940878
[20] S. Minaei, O. K. Sayin and H. Kuntman: IEEE Trans. Circuits Syst. I, Reg. Papers **53** (2006) 1448. DOI:10.1109/TCSI.2006.875184
[21] R. Sotner, A. Kartci, J. Jerabek, N. Herencsar, T. Dostal and K. Vrba: Meas. Sci. Rev. **12** (2012) 255. DOI:10.2478/v10048-012-0035-4

1 Introduction

Development of active devices based on current difference starts with differential current conveyor (DCCII) [1]. A detailed discussion of history of active elements utilizing current difference is provided for example in [2] and [3]. These devices contain so-called current differencing unit (CDU). CDU was studied as an independent building part by Vavra et al. [4] and introduced as a suitable active device for synthesis of applications in [5, 6]. The very-well known active devices utilizing CDU part are so-called a current differencing buffered amplifier (CDBA) [6, 7, 8] and a current differencing transconductance amplifier (CDTA) [6, 9]. There were some attempts to extend the features of control in the frame of the CDU part. For example Siripruchyanun et al. [10] presented modification of the CDTA where the input resistances of both inputs of the CDU part are controllable. However, this extent of control is insufficient for some applications. Therefore, modified current differencing unit (MCDU) was introduced in [11] where the applications in reconfigurable reconnection-less filters were discussed. Except electronic control of the resistances of the input terminals (p and n), the MCDU supposes existence of additional control of current gains in both ways (from p and n) before current subtraction. This extension allows synthesis of the interesting applications especially oscillators.

The oscillators producing output signals with phase shift are required subsystems in communication and measurement. The electronically controllable oscilla-

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
Publicized September 4, 2015
Copyedited October 10, 2015

tors utilizing current difference based devices are designed as quadrature (phase shift equal to 90 degrees), for example [12, 13]. However, simple circuits producing different phase shifts than 90 degrees have not been studied enough. Oscillators with pi/4 phase shift can be used for special modulation purposes. Except multi-phase solutions (sophisticated chains of lossy blocks, for example [14]), where multiples of basic minimal integer phase shift are available, there were not many simple structures reported in the past where 45 degrees phase shift is available. There are some simpler electronically controllable solutions than multiphase chains of blocks, where such phase shift is available. The papers [15, 16, 17] present structures where phase shift 45 deg. and linear electronic control is available. However, the circuit solutions [15, 16, 17] are more complex than presented in this paper (additional passive elements [15] or additional controllable voltage amplifier [16] are required, or more than 2 active devices are necessary for construction and some of them have multiple-outputs [17]), see Table I. Our solution here allows to utilize each of the MCDU parameter (namely: input resistances - R_p, R_n, and current gains - B_1, B_2) in simple single active device based electronically controllable oscillator where two output amplitudes (unchangeable during the tuning process) with 45 deg. phase distance are available.

Table I. Comparison of simple linearly electronically controllable oscillators providing independent FO and CO generating output voltage amplitudes with $\pi/4$ phase distance.

Reference	Type of active elements	No. of passive elements	No of active elements
[15]	ZC-CG-VDCC	4	1
[16]	ZC-VCCFDITA, VA	2	2
[17]	OTA, CA	2	3
proposed	MCDU	2	1

CA current amplifier; MCDU modified current differencing unit; OTA operational transconductance amplifier; VA voltage amplifier; ZC-CG-VDCC z-copy controlled gain voltage differencing current conveyor; ZC-VCCFDITA z-copy voltage controlled current follower differential input transconductance amplifier.

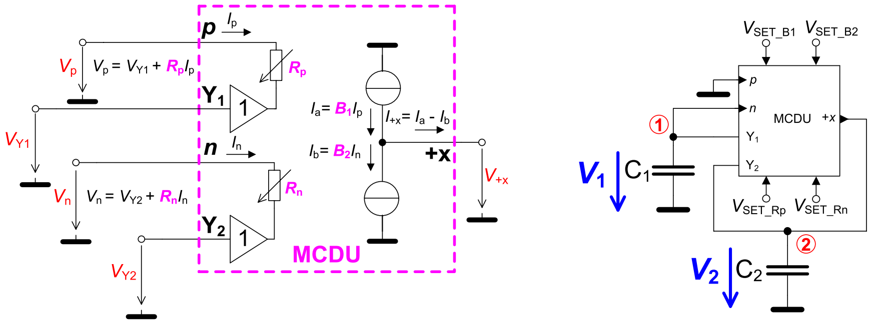
2 Proposed MCDU-based oscillator

The definition of the MCDU was given in [11]. The basic principle of CDU was clearly explained in [4, 5, 6]. The principle of the MCDU is given in Fig. 1(a) where ideal small-signal model is shown. Presence of two independent Y terminals together with controllable gains B_1 and B_2 in the active device are the new features in comparison to standard CDU. All inter-terminal relations are marked directly in the Fig. 1(a).

We focused our design on special type of the oscillator where constant phase shift $\pi/4$ is available and stays unchanged during the tuning of the frequency of oscillations (FO). The really simple and resistor-less circuit structure of the oscillator in Fig. 1(b) offers this feature. Notice that electronic controllability of

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
Publicized September 4, 2015
Copyedited October 10, 2015

the parameters of the MCDU is indicated by the DC control voltages (V_{SET_B1}, etc.). Characteristic equation and FO of the solution in Fig. 1(b) are of the following forms:



(a) (b)

Fig. 1. (a) Ideal model of CDU with advanced features referred as modified CDU (MCDU), (b) Proposed oscillator based on MCDU providing phase shift $\pi/4$ between outputs.

$$s^2 + \frac{(C_2 - C_1 B_2)}{R_n C_1 C_2} s + \frac{B_1}{R_p R_n C_1 C_2} = 0, \tag{1}$$

$$\omega_0 = \sqrt{\frac{B_1}{R_p R_n C_1 C_2}}, \tag{2}$$

where a condition for oscillation (CO) is: $C_2/C_1 \leq B_2$. A concept of the oscillator is based on the electronically controllable parameters available in frame of the MCDU. The controllable current gain B_2 serves for adjusting of CO and simultaneously adjusted intrinsic input resistances ($R_p = R_n = R_{p,n}$) ensure linear control of FO. The generated signals in nodes 1 and 2 are of the following amplitude and phase relation:

$$\frac{V_1}{V_2} = \frac{1}{1 + sC_1 R_n} = \frac{\sqrt{1 + \frac{R_n B_1 C_1}{R_p C_2}}}{2} \exp\left[\tan^{-1}\left(-\sqrt{\frac{R_n B_1 C_1}{R_p C_2}}\right) j\right]. \tag{3}$$

Supposing $R_p = R_n = R_{p,n}$, $C_1 = C_2 = C_{1,2}$, $B_1 = 1$, it leads to:

$$\frac{V_1}{V_2} = \frac{\sqrt{2}}{2} \exp[\tan^{-1}(-1) j] \quad \Rightarrow \quad V_1 = \frac{\sqrt{2}}{2} \exp\left(-\frac{\pi}{4} j\right) V_2. \tag{4}$$

Voltage V_2 foreruns V_1 by phase distance of 45 degrees and their amplitude ratio is constant if FO is tuned and equal to $\sqrt{2}/2$. This ratio can be adjusted by simple attenuator after separation (voltage buffer) of the high-impedance output node 2.

3 Experimental verification by laboratory tests

We prepared following behavioral model/emulator (including system for amplitude stabilization) of the oscillator based on commercially available active elements. The behavioral model (Fig. 2) employs several electronically controllable current con-

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
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Copyedited October 10, 2015

veyors of second generation ECCIIs [18, 19, 20]) available in the frame of the current mode multiplier EL2082 and diamond transistor (DT) OPA860. This MCDU model was firstly reported in [11]. Input resistances and current gains are defined as: $R_p \cong R_i^{/}/V_{SET\_Rp}$, $R_n \cong R_j^{/}/V_{SET\_Rn}$, $B_1 \cong V_{SET\_B1}$ and $B_2 \cong V_{SET\_B2}$ [21]. Supposing $R_p = R_n = R_{p,n}$ (and $R_i^{/} = R_j^{/} = R_{ij}^{/}$ in frame of the model) and constant $B_1 = 1$ (V_{SET_B1}), we can use specified equation for FO:

$$f_0 \cong \frac{V_{SET\_Rp,n}}{2\pi R_{i,j}^{/} C_{1,2}}. \tag{5}$$

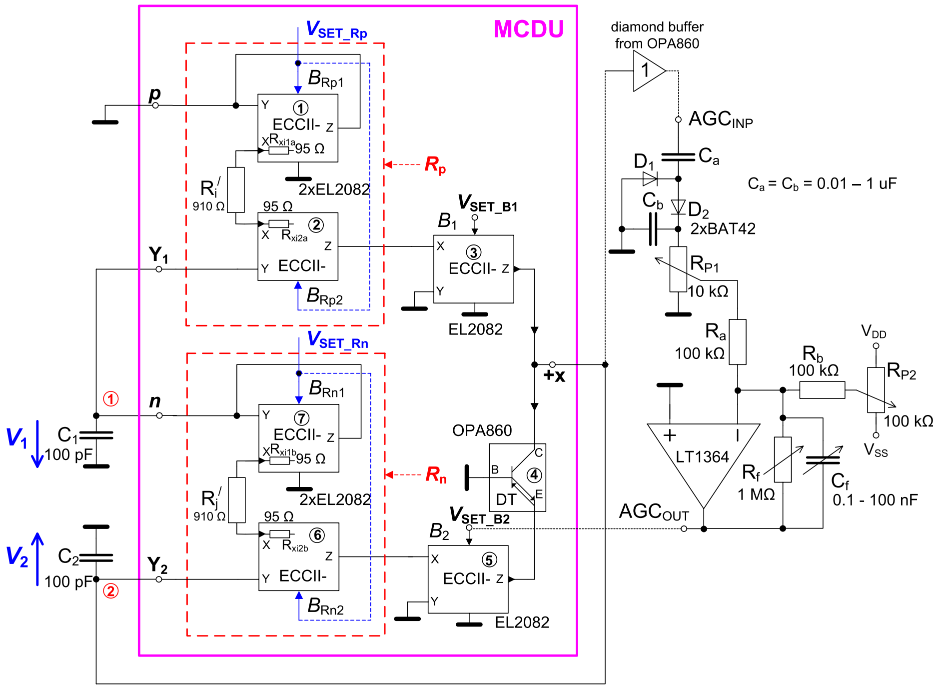

Fig. 2. Manufactured oscillator based on MCDU behavioral model/emulator employing commercially available active devices including automatic gain control (AGC) circuit for laboratory tests.

The parameters of the circuit are selected as $C_{1,2} = 100\,\text{pF}$, $B_1 = 1$ ($V_{SET\_B1} = 1\,\text{V}$) and $R_{p,n} = 3.2\,\text{k}\Omega$ ($V_{SET\_Rp,n} = 0.32\,\text{V}$). Such setting yields ideal $f_0 = 0.507\,\text{MHz}$, simulations with behavioral model (Fig. 2) provided 0.459 MHz and experimentally measured value was 0.499 MHz. Laboratory results are given in Fig. 3 (we used oscilloscope RIGOL DS1204B and spectrum analyzer HP4395A). An example of both measured transient responses (blue color - V_1; red color - V_2) is shown in Fig. 3(a), spectrum of output responses (upper spectrum - V_1; lower spectrum - V_2) in Fig. 3(b) and dependence of FO on $V_{SET\_Rp,n}$ in Fig. 3(c). Manufactured MCDU module, used for experimental study of the oscillator, is shown in Fig. 3(d). AGC was provided as an independent part. Measured outputs were separated by voltage buffers and matched to 50 Ω load. Phase difference 46 degrees of both signals was observed. Experimental verification in laboratory brings the results that indicate behavioral model/emulator suitability for operation up to units of MHz

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
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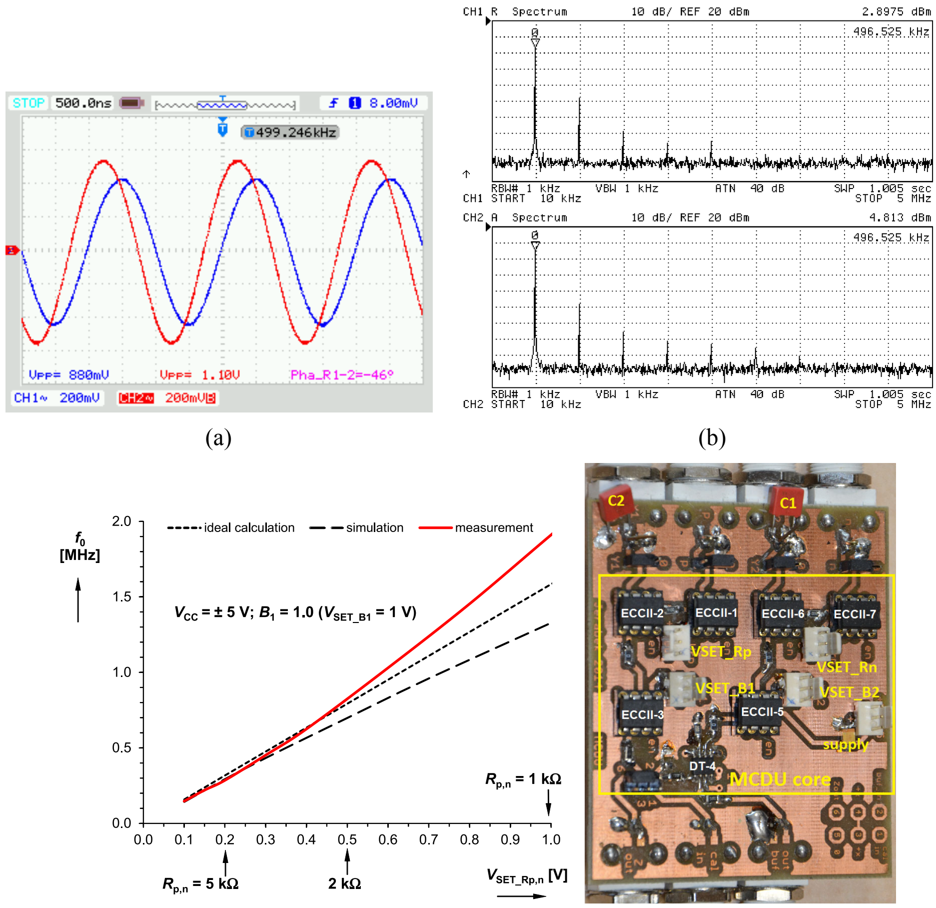
Copyedited October 10, 2015

IEICE Electronics Express, Vol.12, No.19, 1–7

(FO was adjusted from 0.147 to 1.911 MHz by DC control voltage from 0.1 to 1.0 V). An analysis of total harmonic distortion yields value about 1.5% (suppression of higher harmonic components more than 35 dBc).



(a) (b) (c) (d)

Fig. 3. (a) Measured transient responses of produced signals (blue color - V_1, red color - V_2), (b) Measured spectrum of both outputs (upper spectrum - V_1; lower spectrum - V_2), (c) Ideal, simulated and measured dependence of FO on $V_{SET\_Rp,n}$, (d) Manufactured MCDU module used for experimental study of the oscillator.

4 Conclusion

The resulting features of the designed oscillator confirmed usefulness of advanced controllable properties in the frame of the MCDU (behavioral emulator) for the design of the interesting applications and suitability of this active device for future IC implementation. Functionality was verified from frequencies of hundreds of kHz up to units of MHz. Complexity of the MCDU emulator balances its four useful controllable features and it is not an important issue for IC implementation. Except the beneficial features of the MCDU in reconfigurable reconnection-less filters [11], the discussed results here indicate that such advanced active device can offer the useful features also for design of oscillators.

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
Publicized September 4, 2015
Copyedited October 10, 2015

Acknowledgments

Research described in this paper was financed by Czech Ministry of Education in frame of National Sustainability Program under grant LO1401. For research, infrastructure of the SIX Center was used.

DOI: 10.1587/elex.12.20150557
Received June 24, 2015
Accepted June 29, 2015
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Copyedited October 10, 2015