Single OTRA Based Low Frequency Sinusoidal Oscillator Realization

Gurumurthy Komanapalli\textsuperscript{1}, Neeta Pandey\textsuperscript{2}, Rajeshwari Pandey\textsuperscript{3}

\textsuperscript{1,2,3} Dept of Electronics & Communication Engineering, Delhi Technological University, Delhi, India

murthykgm@gmail.com, n66pandey@rediffmail.com, rajeshwaripandey@gmail.com

Abstract: In this paper, single Operational Transresistance Amplifier (OTRA) based low frequency (LF) oscillator has been put forward. It employs six passive elements namely four resistors and two capacitors. The circuit is also analysed for non-ideal effects and sensitivity analysis is carried out. The proposed oscillator is verified through SPICE simulations using 0.18µmAGILENT CMOS process parameters. A total harmonic distortion (THD) of 2.14% for 7.96Hz oscillation and 0.6% at 796 KHz is observed.

Keywords: OTRA, Oscillator, sensitivity, THD.

1. INTRODUCTION

The oscillator is an electronic circuit which produces periodic waveforms and find wide application in communication, instrumentation, measurement and control systems [1, 2]. A large number of sinusoidal oscillators are available in literature which uses single /multiple active building block (ABB) [3-4] in the forward path and frequency shifting networks in feedback loop. Various ABBs are used in designing these topologies as specified in [5-27]. Operational transresistance amplifiers (OTRA) [28,29] is one of these ABBs whose input terminals are virtually grounded leading to circuits that are insensitive to stray capacitances, has a bandwidth independent of the device gain and is also not slew limited. Due to these advantages researchers have shown considerable interest in designing various signal generating circuits using [5-6, 21-23].

Low frequency oscillators (LFOs) are specific class of oscillators which produce periodic waveforms at a very low frequency generally in subsonic (0 – 20 Hz) range. The LFOs are very commonly used for music and speech synthesis. The LFOs also find applications in various other fields such as testing of various servo mechanisms, geophysical systems; biological and biomedical fields. An extensive literature review suggests that despite its wide application only a limited literature is available on LFOs. It is observed that these LFOs

- are designed using opamp [17], CFOA [18, 19 ] CDBA [20] and OTRA[26]
- use large number of passive components [17-20use more than one ABB [19,20]
- use a total of six [26], eight [18,20] and ten [17,19] components respectively.
In this paper a new LFO realization based on single OTRA is proposed which uses four resistors and two capacitors. Although, the proposed structure uses an extra component as compared to [26] the main advantage of this circuit is the multiplication factor ‘K’ in the calculation of frequency of oscillation (FO) which may be chosen greater or less than unity which is useful in obtaining frequencies ranging from low to medium by choosing moderate component values which is not applicable for [26].

The work reported in this paper is organized in six sections. The second section describes properties of OTRA and proposed structure. The non-ideal analysis is presented in section 3. Sensitivity analysis with respect to passive component variations is discussed in section 4. Section 5 comprises of various simulation results performed using SPICE. Finally conclusion is given in section 6.

2. PROPOSED CIRCUIT

The circuit symbol of OTRA is shown in Fig. 1. It is a three terminal device comprises of two current inputs ($I_p, I_n$) and one voltage output ($V_0$) and it is characterized by (1). The transresistance gain ($R_m$) is quite high.

\[
\begin{bmatrix}
V_p \\
V_n \\
V_0
\end{bmatrix}
- \begin{bmatrix}
C & 0 & 0 \\
0 & C & 0 \\
-R_m & 0 & 0
\end{bmatrix}
\begin{bmatrix}
I_p \\
I_n \\
V_0
\end{bmatrix}
\]

(1)

Fig.1. OTRA Symbol

Fig. 2 shows single OTRA based LFO realization which consists of six passive components namely two capacitors and four resistors. Characteristic equation of (2) is obtained by applying the properties of OTRA and following the feedback loop.

\[
s^2C_1C_2R^2R_1R_2 + s[C_1R_1R_2 + C_1R^2(R_1 + R_2) - C_2R^2R_1] + R_1R_2 - R^2 + RR_1 - 2RR_2 = 0
\]

(2)

Fig.2. Proposed Single OTRA Based LFO Realization
The condition of oscillation (CO) and frequency of oscillation (FO) \((f)\) are obtained as

CO: \(C_iR_2(R + R_1) = RR_1(C_2 - C_i)\);

\[
CO: \quad f = \frac{1}{2\pi R\sqrt{C_1C_2}} \left[ \frac{(R_1 - R)(R + R_2) - RR_2}{R_1R_2} \right]^{1/2} \tag{3}
\]

The OF can be written as

\[
OF: \quad f = \frac{1}{2\pi R\sqrt{C_1C_2}} [K]^{1/2} \tag{4}
\]

Where \(K = 1+n\), and \(n\) denotes the resistor ratio \(R\).

The multiplication factor \(K\) can be selected to be greater than or less than unity by choosing the appropriate values of \(R, R_1, R_2\). By making \(R_1 > (R + 2R_2)\), the \(K\) value may be chosen to be greater than unity whereas, if \(R_1 < (R + 2R_2)\), \(K\) value is set to be less than one. Thus the proposed oscillator can provide frequencies ranging from LF to MF by simply adjusting \(K\).

3. NON-IDEAL ANALYSIS

Ideally the transresistance gain \(R_{m_0}\) is assumed to approach infinity. However, practically \(R_m\) is a frequency dependent finite value. With single pole model, the trans-resistance gain, \(R_m\) can be expressed as

\[
R_m(s) = \frac{R_0}{1 + \frac{s}{\omega_0}} \tag{5}
\]

where \(R_0\) is dc transresistance gain. For applications which work at high frequencies the transresistance gain \(R_m(s)\) reduces to

\[
R_m(s) = \frac{1}{sC_p} \quad \text{where} \quad C_p = \frac{1}{R_0\omega_0}. \tag{6}
\]

Due to non ideality of OTRA the output of the oscillator may deviate from ideal value [28, 29]. The characteristic equation (2) changes to (7) by considering the nonidealities (5)

\[
s^2(C_1 + C_p)C_2R^2R_1R_2 + s(C_1 + C_p)R_1R_2R + (C_1 + C_p)R^2(R_1 + R_2) - C_2R^2R_1 - R^2 + R_1R_2 + RR_1 - 2RR_2 = 0 \tag{7}
\]

The altered CO and FO are computed as

CO: \((C_1 + C_p)R_2(R + R_1) = RR_1(C_2 - (C_1 + C_p))\); 

\[
CO: \quad f = \frac{1}{2\pi R\sqrt{(C_1 + C_p)C_2}} \left[ \frac{(R_1 - R)(R + R_2) - RR_2}{R_1R_2} \right]^{1/2} \tag{8}
\]
There is slight deviation in FO in presence of non idealities. The effect of parasitic capacitances $C_p$ can be eliminated by preadjusting $C_1$ thus achieving self-compensation.

4. SENSITIVITY ANALYSIS

The sensitivity of an analog circuit can be defined as mathematical variation of performance characteristics due to small changes in parameters of the circuit. In this section sensitivity of $f$ is calculated using direct method with respect to all passive components used in the circuit.

The most widely used formula to calculate sensitivity is normalized sensitivity defined as

$$\left| S_{fX} \right| = \left| \frac{f}{X} \cdot \frac{\partial f}{\partial X} \right|$$

where $X$ denotes different circuit parameters.

The sensitivities of $f$ w.r.t $C_1$, $C_2$, $R_2$, $R_1$, $R$ are

$$\left| S_{C1} \right| = \left| \frac{1}{2} \cdot \frac{R(R - R_1)}{2[(R - R_1)(R + R_2) - RR_2]} \right|$$

$$\left| S_{C2} \right| = \left| \frac{R(R + 2R_1)}{2[(R - R_1)(R + R_2) - RR_2]} \right|$$

$$\left| S_{R2} \right| = \left| \frac{RR_1 + 2R_2(R_1 - R)}{2[(R - R_1)(R + R_2) - RR_2]} \right|$$

(9)

The sensitivities of FO w.r.t various capacitances are recomputed in the presence of non-ideality of OTRA and are given by

$$\left| S_{Cp} \right| = \frac{1}{2} \cdot \frac{C_p}{(C_2 + C_p)}$$

$$\left| S_{C1} \right| = \frac{1}{2} \cdot \frac{C_1}{(C_2 + C_p)}$$

(10)

From (9) and (10) it can be seen that all the sensitivities with respect to passive components and parasitic capacitances are less than unity in magnitude.

5. SIMULATION RESULTS

The workability of the proposed structure is tested using SPICE simulations and the CMOS implementation [29] of OTRA is used. The process parameters are taken as 0.18µm provided by MOSIS (AGILENT) for the transistors used in OTRA. The VSS and VDD used are ±1.5V. Simulations are performed for an $f = 7.96$ Hz by selecting $R = 50$ KΩ; $R_1=R_2 = 100$ KΩ, $C_1 = 100$ nF, $C_2 = 400$ nF. The corresponding transient response and frequency spectrum are shown in Figs. 3 and 4 respectively. By adjusting the multiplication factor $K$ in (5) the proposed structure can provide higher frequency oscillations. To verify this fact the oscillator was tested at 796 KHz by choosing component values as $R = 0.5$KΩ, $R_1=R_2 = 1$KΩ, $C_1 = 100$pF, $C_2 = 400$pF. The simulated transient response and corresponding frequency spectrum are plotted in Figs.5 and 6 respectively. The percentage total harmonic distortion (%THD) is 2.14 for 7.96Hz oscillation and 0.6 at 796 KHz.
Fig. 3. Transient waveform of proposed LFO ($f=7.96\text{Hz}$)

Fig. 4. Frequency spectrum of proposed LFO ($f=7.96\text{Hz}$)

Fig. 5. Transient waveform of proposed oscillator ($f=796\text{KHz}$)

Fig. 6. Frequency spectrum of proposed oscillator ($f=796\text{KHz}$)
6. CONCLUSION

In this paper, single Operational Transresistance Amplifier (OTRA) based LFO has been presented. It employs six passive elements namely four resistors and two capacitors. The proposed structure can be used for medium frequency generation as well. The circuit is also analysed for non-ideal effects and sensitivity analysis is carried out. The proposed oscillator is verified through SPICE simulations using 0.18μm AGILENT CMOS process parameters. A total harmonic distortion (THD) of 2.14% for 7.96Hz oscillation and 0.6% at 796 KHz s observed.

REFERENCES

[1] A. S. Sedra and K. C. Smith, Microelectronic circuits. New York: Oxford University Press, vol. 1,2004.
[2] R. Senani, D. R. Bhaskar, V. K. Singh, and R. K. Sharma, “Sinusoidal oscillators and waveform generators using modern electronic circuit building blocks,” Springer, Switzerland, Nov 2016.
[3] C. Toumazou, C. A Makris, F. J. Lidgey and D. G. Haigh, “Towards a new generation of analogue ic design architectures,” IET, EE Colloquium on Analogue IC Design: Obstacles and Opportunities, London, pp. 9/1-916., June 1990.
[4] S. A. Bashir and N. A. Shah, “Active device usage in filter design- An overview,” International Journal of Scientific and Research Publications, vol. 2, no. 6, June 2012.
[5] R. Pandey, N. Pandey, R. Kumar, and Garima Solanki, “A Novel OTRA Based Oscillator with Non Interactive Control,” International conference on computer & communication technology (ICCCT ‘10), IEEE, pp. 658-660, Nov 2010.
[6] R. Senani, A. Singh, A. Gupta, and D. Bhaskar, “Simple Simulated Inductor, Low-Pass/Band-Pass Filter and Sinusoidal Oscillator Using OTRA,” Circuits and Systems, vol. 7, pp. 83-99, Mar 2016.
[7] J. Horng, C. Hou, C. Chang, H. Chou, C. Lin and Y. Wen, “Quadrature Oscillators with Grounded Capacitors and Resistors Using FDCCIIs,” ETRI J, vol. 28, no. 4, pp. 486-494, Aug 2006.
[8] A. Lahiri, W. Jaikla and M. Siriruchyanun, “First CFOA-based explicit-current-output quadrature sinusoidal oscillators using grounded capacitors,” International Journal of Electronics, vol. 100, no. 2, pp. 259-273, Jun 2012.
[9] S. Gupta, R. Sharma, D. Bhaskar and R. Senani, “Sinusoidal oscillators with explicit current output employing current-feedback op-amps,” Int. J. Circ. Theor. Appl, vol. 38, no. 2, pp. 131-147, Aug 2008.
[10] D. Prasad and D. Bhaskar, “Electronically Controllable Explicit Current Output Sinusoidal Oscillator Employing Single VDTA,” ISRN Electronics, vol. 2012, pp. 1-5, Aug 2012.
[11] M.Srivastava, D.Prasad and D. R. Bhaskar, “Voltage mode quadrature oscillator employing single VDTA and grounded passive elements,” CES, vol. 7, no. 27, pp. 1501-1507, Nov 2014.

[12] J. Ahmad and D.Prasad, “Novel applications of VDVTA: as current-mode SIMO-type biquad and electronically controllable sinusoidal oscillator,” CES, vol. 8, no. 29, pp. 1383-1391, Oct 2015.

[13] S. Maiti and R. Pal, “Voltage Mode Quadrature Oscillator Employing Single Differential Voltage Current Controlled Conveyor Transconductance Amplifier,” IJEEE, vol. 3, no. 5, pp. 344-348, Oct 2015.

[14] B. Chaturvedi and S. Maheshwari, “Second Order Mixed Mode Quadrature Oscillator using DVCCs and Grounded Components,” International Journal of Computer Applications, vol. 58, no. 2, pp. 42-45, 2012.

[15] S. Celma, P. Martinéz and A. Carlosena, “Reply: Minimal realisation for single resistor controlled sinusoidal oscillator using a single CCII,” Electron. Lett, vol. 28, no. 13, p. 1265, Jun 1992

[16] R. Senani and V. Singh, “Comment: Synthesis of canonic single-resistance-controlled-oscillators using a single current-feedback-amplifier,” IEE Proceedings - Circuits, Devices and Systems, vol. 143, no. 1, pp. 71, Jun 1996.

[17] R. Senani and D. Bhaskar, “Single op-amp sinusoidal oscillators suitable for generation of very low frequencies,” IEEE Trans. Instrum. Meas, vol. 40, no. 4, pp. 777-779, Aug 1991.

[18] D. K.Srivastava, V. K. Singh, and R. Senani. “New very low frequency oscillator using only a single CFOA,” American Journal of Electrical and Electronic Engineering, vol 3, no.1 pp. 1-3, Oct 2015.

[19] A. S. Elwakil, “Systematic Realization of Low-Frequency Oscillators Using Composite Passive–Active Resistors,” IEEE Transactions On Instrumentation And Measurement, vol. 47, pp. 584 – 586, Apr 1998.

[20] A. Lahiri, “Low-frequency quadrature sinusoidal oscillators using current differencing buffered amplifiers,” Indian Journal of Pure and Applied Physics, vol. 49, pp. 423-428, Jun 2011.

[21] U. Cam, “A Novel Single-Resistance-Controlled Sinusoidal Oscillator Employing Single Operational Transresistance Amplifier,” Analog Integrated Circuits and Signal Processing, vol. 32, pp. 183–186, Aug 2002.

[22] H.C. Chien, “New realizations of single otera-based sinusoidal oscillators,” Active and Passive Electronic Components, vol. 2014, Jan 2014.

[23] K. Salama and A. M. Soliman, “Novel oscillators using the operational transresistance amplifier,” Microelectronics Journal, vol. 31, no.1, pp. 39–47, Jan 2000.

[24] P.Chandrasekharand A.Srinivasulu, “A Sinusoidal Oscillator Using Single Operational Transresistance Amplifier,” Fifth International Conference on Advanced Computing (ICoAC), IEEE, pp. 508-511. Oct 2014.
[25] A. Srinivasulu and P. Chandrasekhar, “Grounded resistance/capacitance-controlled sinusoidal oscillators using operational transresistance amplifier,” WSEAS transactions on circuits and systems, vol. 13, no. 2224-266, pp. 145-152, Jul 2014.

[26] K. Gurumurthy, R. Pandey and N. Pandey “Minimum component count low frequency sinusoidal oscillator based on Single OTRA,” IJCTA, vol. 9, no. 22, pp. 181-187, International Science Press, Oct 2016.

[27] A. Srinivasulu and P. Chandrasekhar, “Two Simple Sinusoidal Oscillators Using Single Operational Transresistance Amplifier,” 3rd International Conference on Signal Processing, Communication and Networking (ICSCN), IEEE, pp. 1-5, Aug 2015.

[28] K. N. Salama and A. M. Soliman, “Cmos operational transresistance amplifier for analog signal processing,” Microelectronics Journal, vol. 30, no. 3, pp. 235–245, Mar 1999.

[29] H. Mostafa and A. M. Soliman, “A Modified cmos realization of the operational transresistance amplifier (OTRA),” Frequenz, vol. 60, no. 3-4, pp. 70–77, Jul 2006.

Gurumurthykomanapalli received his B.Tech. (Electronics and Communication) from JNTU Kakinada, Andhra Pradesh and his MTECH in VLSI design from Delhi Technological University (DTU) (formerly Delhi College of Engineering), New Delhi in 2014 and Currently he is working towards Ph.D degree from DTU. His research interests are in analog circuit design and Microelectronics

Neeta Pandey received her M.E. in Microelectronics from Birla Institute of Technology and Sciences, Pilani and Ph.D. from Guru Gobind Singh Indraprastha University, Delhi. She has served in Central Electronics Engineering Research Institute, Pilani, Indian Institute of Technology, Delhi, Priyadarshini College of Computer Science, Noida and Bharati Vidyapeeth’s College of Engineering, Delhi in various capacities. At present, she is Associate professor in ECE department, Delhi Technological University. A life member of ISTE, and member of IEEE, USA, she has published papers in international, national journals of repute and conferences. Her research interests are in analog and digital VLSI design.

Rajeshwari Pandey is currently working as an Associate Professor in Department of Electronics and Communication Engineering, Delhi Technological University, Delhi, India. She did her M.E (Electronics and Control) from BITS, Pilani, Rajasthan, India and Ph. D. from Faculty of Technology, Delhi University, India. Her research interests include Analog Integrated Circuits, and Microelectronics. She has published papers in International, National Journals of repute and conferences. She is life member of IETE, ISTE and member of IEEE, IEEE WIE for 10 years.