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Voltage-mode Second-order Filter and Quadrature Oscillator Based-on Differential Difference Current Conveyors and Only Grounded Elements

***Abstract**. The voltage-mode second-order filter and quadrature oscillator are presented. The proposed configuration provides two differential difference current conveyors, three grounded resistors and two grounded capacitors. The grounded elements are designed for implementation of integrated circuit. The second-order filter is simultaneously produced three output responses of highpass, bandpass and lowpass with only single input. The quality factor and pole frequency can be independently controlled when operating in second-order filter. Moreover, the second-order filter can be modified to operate in the quadrature oscillator with the same configuration. The oscillation condition can be adjusted without effecting of the oscillation frequency. The results of simulation are in accordance with the theoretical analysis.*

Streszczenie.** Przedstawiono filtr drugiego rzędu I generator wykorzystujące dwa różnicowe konvejery DDCC, trzy uziemione rezystory i dwa uziemione kondensatory. Filtr ma trzy wyjścia dolno-, górno- i środkowoprzepustowe. Przy jednym wejściu. **Filtr drugiego rzędu i kwadraturowy oscylator bzaujący na układzie DDCC i kilku uziemionych elementach

Keywords: Differential Difference Current Conveyor, voltage-mode, second-order filter, quadrature oscillator
Słowa kluczowe: układ DDCC, filtr, oscylator.

Introduction

The second-order filters with a single-input and multi-outputs responses are popular [1-8] because they provides three functions output simultaneously that are lowpass (LP), bandpass (BP) and highpass (HP) responses. Moreover, they are very important for applications in communication systems and audio systems [9], such as tone control circuit, modulator, demodulator etc [7, 10-14]. In addition, sinusoidal oscillator is the most common for use in modulation/demodulation system, power electronic, measurement system, audio system [15-20]. Therefore, the researches for development of second-order filter and sinusoidal oscillator are interesting.

The research on the active element called DDCC or differential difference current conveyor was published in 1996 by Chiu W. et al. [21]. It is more versatile and flexible to use analog circuits, thus, researches and publications using DDCC have been presented in the literatures [1-20].

The researches second-order filters using DDCC are proposed in [1-14]. Some of proposed filters [4-5, 10,13-14] are used only grounded elements that are expediently minimized area for fabrication integrated circuit [21]. However, the proposed circuits in [6, 12] are designed to use of floating capacitors that despite in parasitic affect. Also, the corresponding pole frequency and quality factor of [1-7, 9, 11, 14] will be simultaneously adjusted which be inconvenienced to use. The filter circuits present in [1-3, 5-6, 11] can be operated with multi-outputs function but there are necessary required three DDCCs. As the same time, the proposed quadrature oscillator circuits using DDCC have been many published [15-20]. The oscillator circuit in [15] is compacted with using single DDCC but it stills from the oscillation condition cannot be freely adjusted without effect of oscillation frequency. The oscillation frequency of [15, 18, 20] will be simultaneously adjusted with oscillation condition. The sinusoidal oscillators in [17, 20] are designed to use floating passive elements which is difficult for implementation in IC [22-24]. In addition, the implementation of proposed circuits can only use either second-order filter [1-14] or quadrature oscillator [15-20].

This paper is presented the second-order filter and quadrature oscillator with the same configuration. The proposed configuration is used DDCCs and only grounded elements. The feature of second-order filter is independently adjusted the pole frequency without effect of the quality factor. Moreover, the quadrature oscillator is archived by a little modification of filter without changing the configuration. As well, the oscillation condition can be succeeded adjusted without effect of the oscillation frequency. The details of proposed configuration will be explained in the next topic.

Proposed configuration

This proposes configuration of second-order filter and quadrature oscillator. First, the electrical characteristic of differential difference current conveyor as an active element. Second, the configuration of proposed second-order filter and its transfer function. Then, the operation of proposed quadrature oscillator. The lastly are non-ideal analysis and sensitivities of parameters of proposed configuration.

Differential Difference Current Conveyor

Differential difference current conveyor or DDCC was designed and published in 1996 by Chiu W. and etc [21]. The symbol and equivalent circuit can be shown in Fig. 1 (a) and (b), respectively, it has differential input voltage with high impedance terminals that are y_1, y_2 and y_3. The terminal of DDCC for feeding input current and low impedance is x terminal. Then, z terminal is output current of DDCC with high impedance terminal and it can be extend the number of terminal by adding current mirror circuit. The ideal of electrical characteristic of DDCC is described by using matrix form in (1).

$$\begin{bmatrix} I_{y1} \\ I_{y2} \\ I_{y3} \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} V_{y1} \\ V_{y2} \\ V_{y3} \\ I_x \\ V_z \end{bmatrix} \quad (1)$$

Proposed second-order filter

The proposed second-order filter can be realized and illustrated in Fig.2, it constructs two DDCCs, three grounded resistors and two grounded capacitors. The grounded elements are suitability designed for integrated circuit fabrication. Especially the grounded capacitors are connected at high impedance ports of DDCC that is subsidiary reduced the effect of internal capacity at nodes/ports of circuit. As well the resistors are connected to ground which is completely absorbed the internal resistance at ports of DDCC. The input impedances V_{in} is high and output impedances V_{O1} and V_{O2} are low that is a good for voltage-mode configuration. However, V_{O3} can be used voltage buffer for connection to load or next stages. From the electrical characteristic in last topic, the transfer function of proposed second-order filter can be realized to

$$\frac{V_{O1}}{V_{in}} = \frac{s^2}{s^2 + \frac{R_3}{R_1 R_2 C_1} s + \frac{1}{R_1 R_2 C_1 C_2}}, \tag{2}$$

$$\frac{V_{O2}}{V_{in}} = \frac{\frac{R_3}{R_1 R_2 C_1} s}{s^2 + \frac{R_3}{R_1 R_2 C_1} s + \frac{1}{R_1 R_2 C_1 C_2}}, \tag{3}$$

and

$$\frac{V_{O3}}{V_{in}} = \frac{\frac{1}{R_1 R_2 C_1 C_2}}{s^2 + \frac{R_3}{R_1 R_2 C_1} s + \frac{1}{R_1 R_2 C_1 C_2}}. \tag{4}$$

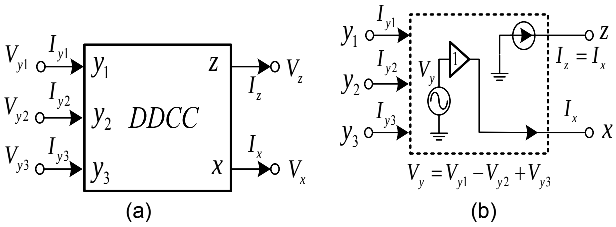


Fig.1. DDCC (a) Symbol (b) Equivalent circuit

It is found that the output voltage V_{O1}, V_{O2} and V_{O3} are simultaneously provided highpass (HP), bandpass (BP) and lowpass (LP) responses, respectively. The corresponding quality factor (Q_p) and pole frequency (ω_p) can be analyzed and depicted as

$$Q_p = \frac{1}{R_3} \sqrt{\frac{R_1 R_2 C_1}{C_2}}, \tag{5}$$

and

$$\omega_p = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}. \tag{6}$$

For easy configuration, the passive resistors and capacitors can be set $R_1 = R_2 = R$ and $C_1 = C_2 = C$, respectively. The quality factor and pole frequency become to (7) and (8), respectively.

$$Q_p = \frac{R}{R_3}, \tag{7}$$

and

$$\omega_p = \frac{1}{RC}. \tag{8}$$

It can be seen that the quality factor can easily be achieved by adjusting the value of R_3 without influence of the pole frequency. As well the pole frequency can be tuned without affecting the quality factor that the value of R_1, R_2 and R_3 must be equal and tuning by simultaneously changing the values of them.

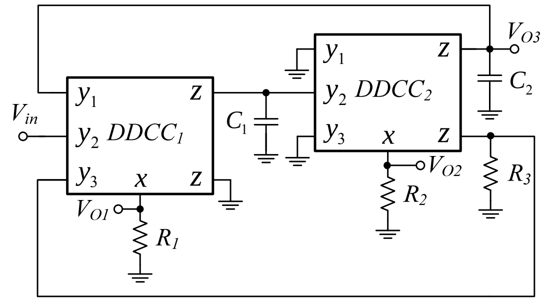


Fig.2. Proposed second-order filter

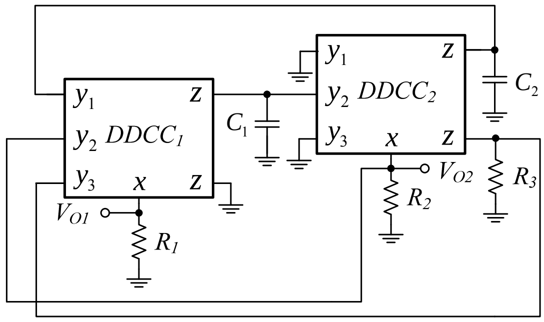


Fig.3. Proposed quadrature oscillator

Proposed quadrature oscillator

The proposed second-order filter can be fully operated in quadrature oscillator by appropriately feeding output voltage V_{O2} into V_{in} that easily is rewritten in Fig.3. The realization of the characteristic equation of proposed quadrature oscillator can be obtained as

$$s^2 + \left(\frac{R_3}{R_2} - 1\right)\frac{s}{R_1 C_1} + \frac{1}{R_1 R_2 C_1 C_2} = 0. \tag{9}$$

The oscillation condition is easily set for generation the quadrature signal by

$$\frac{R_3}{R_2} \approx 1. \tag{10}$$

When the oscillation condition is fully succeeded, the oscillation frequency (ω_{osc}) will be produced the quadrature signal with the frequency as

$$\omega_{osc} = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}. \tag{11}$$

It is interested that the oscillation condition can easily be set by the values of R_3 without effecting of oscillation frequency. At the same time the oscillation frequency can be adjusted without influenced the oscillation condition by adjusting the values of R_1. The relationship of output signals V_{O1} and V_{O2} can be shown in (12).

$$\frac{V_{O2}}{V_{O1}} = -\frac{1}{R_1 C_1 s}. \tag{12}$$

From (12) the output signals V_{O1} and V_{O2} have been differenced of 90 phase shift that well known as quadrature signal. The phase of output signal V_{O1} is lags the phase of output signal V_{O2}. The ratio of magnitude of the output signals V_{O1} and V_{O2} can be related as

(13) $$\left|\frac{V_{O2}}{V_{O1}}\right| = \frac{1}{R_1 C_1 \omega},$$

Substituting (11) into (13), the ratio of signals are becalmed to

(14) $$\left|\frac{V_{O2}}{V_{O1}}\right| = \sqrt{\frac{R_2 C_2}{R_1 C_1}}.$$

It is evident that the amplitude of the output signals V_{O1} and V_{O2} can be configured for equal by setting $R_1 = R_2$ and $C_1 = C_2$.

Non-ideal analysis

For non-ideal analysis, the tracking errors will be considered that the relation of terminals of DDCC can be rewritten in matrix form in (15).

(15) $$\begin{bmatrix} I_{y1} \\ I_{y2} \\ I_{y3} \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ \beta_1 & -\beta_2 & \beta_3 & 0 & 0 \\ 0 & 0 & 0 & \alpha & 0 \end{bmatrix} \begin{bmatrix} V_{y1} \\ V_{y2} \\ V_{y3} \\ I_x \\ V_z \end{bmatrix},$$

where β_1, β_2 and β_3 are voltage tracking errors between y terminal to x terminal as well as α is current tracking error of x terminal to z terminal. These errors are commonly occurred by the internal construction and internal parasitic elements of DDCC. However the values of them are unity only in ideal. The transfer function of low pass, band pass and high pass responses of proposed second-order filter are re-analyzed and given in (16) – (18), respectively.

(16) $$\frac{V_{HP}}{V_{in}} = \frac{\beta_{12} s^2}{s^2 + \frac{\beta_{13}\beta_{22}\alpha_1\alpha_2 R_3}{R_1 R_2 C_1} s + \frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}},$$

(17) $$\frac{V_{BP}}{V_{in}} = \frac{\frac{\beta_{12}\beta_{13}\beta_{22}\alpha_1\alpha_2 R_3}{R_1 R_2 C_1} s}{s^2 + \frac{\beta_{13}\beta_{22}\alpha_1\alpha_2 R_3}{R_1 R_2 C_1} s + \frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}},$$

and

(18) $$\frac{V_{LP}}{V_{in}} = \frac{\frac{\beta_{11}\beta_{12}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}}{s^2 + \frac{\beta_{13}\beta_{22}\alpha_1\alpha_2 R_3}{R_1 R_2 C_1} s + \frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}}.$$

Then the pole frequency and the quality factor are becalmed to

(19) $$\omega_p = \sqrt{\frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}}, \; Q_p = \frac{1}{\beta_{13}\beta_{22}\alpha_1\alpha_2 R_3}\sqrt{\frac{R_1 R_2 C_1}{C_2}}$$

For non-ideal analysis, the proposed quadrature oscillator can be given the characteristic equation in (20). Also the oscillation frequency and oscillation condition are represented by (21) and (22), respectively.

(20) $$s^2 + \left(\frac{R_3}{R_2}\beta_{13}\beta_{22}\alpha_1\alpha_2 - \beta_{12}\beta_{22}\alpha_1\right)\frac{s}{R_1 C_1} + \frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}.$$

(21) $$\frac{R_3}{R_2}\beta_{13}\beta_{22}\alpha_1\alpha_2 = \beta_{12}\beta_{22}\alpha_1.$$

and

(22) $$\omega_{osc} = \sqrt{\frac{\beta_{11}\beta_{22}\alpha_1\alpha_2}{R_1 R_2 C_1 C_2}}.$$

It can be seen that the tracking errors of voltage and current of DDCC have been slightly affected the performance of proposed configuration. However these errors can easily be solved by adjusting the values of resistors of proposed configuration.

Proposed configuration sensitivities

The sensitivities of parameters of proposed second-order filter and quadrature oscillator are given by (23) – (24) which are less than only unity.

(23) $$S^{\omega_p}_{\beta_{11}} = S^{\omega_p}_{\beta_{22}} = S^{\omega_p}_{\alpha_1} = S^{\omega_p}_{\alpha_2} = \frac{1}{2},$$

$$S^{\omega_p}_{R_1} = S^{\omega_p}_{R_2} = S^{\omega_p}_{C_1} = S^{\omega_p}_{C_2} = -\frac{1}{2}.$$

(24) $$S^{Q_p}_{\beta_{13}} = S^{Q_p}_{\beta_{22}} = S^{Q_p}_{\alpha_1} = S^{Q_p}_{\alpha_2} = S^{Q_p}_{R_3} = -1,$$

$$S^{Q_p}_{R_1} = S^{Q_p}_{R_2} = S^{Q_p}_{C_1} = \frac{1}{2}, S^{Q_p}_{C_2} = -\frac{1}{2}.$$

Also the sensitivities of oscillation frequency are same as pole frequency which is depicted in (23).

Computer simulation

This section shows the computer simulation. The configuration of the structure of DDCC is depicted in Fig. 4. It modifies by containing differential difference voltage (AD833) [25] as an input stage and current conveyor (AD844) [26] as an output stage. AD833 has several advantaged such as a fully differential signal path, low power, low noise and etc. AD844 is fully operated of current conveyor and it has many features such as wide bandwidth, high slew rate, very fast signal response and etc. The micro model of AD830, AD844 and Pspice program were used for investigation of the performance of proposed circuits. The voltages of power supply of active elements are defined as $\pm 5V$. For verifying of the second-order filter, the passive elements will be set by standard values that are $R_1 = R_2 = R_3 = 1\text{k}\Omega$ and $C_1 = C_2 = 500\text{pF}$. The pole frequency and the quality factor are archived by calculation as 318.30kHz and 1, respectively. The first results in Fig. 5 are simultaneously frequency responses of output that are highpass, bandpass and lowpass responses. Furthermore, the output respones are clearly compared with the theoretical and simulation results. The simulated of the pole frequency is about 303.38kHz that is slightly deviated of theoretical about 4.68%. The adjusting of the quality factor of (7) by the passive resistor R_3 without affecting of pole frequency can be plotted in Fig. 6. The corresponding quality factors are varied from 0.5, 1, 2 and 4 by changing the values of the passive resistor R_3 from $2\text{k}\Omega, 1\text{k}\Omega, 500\Omega$ and 250Ω, respectively. The tuning of the corresponding pole frequency can be simultaneously changed the values of the passive resistors R_1, R_2 and R_3 as $4\text{k}\Omega, 2\text{k}\Omega, 1\text{k}\Omega$ and 500Ω. The simulated frequencies are varied as 78.70kHz, 155.59kHz, 303.38kHz and 583.44kHz, respectively, re-presented in Fig.7. The testing of the transient responses of the second-order filter can be demonstrated by feeding the sinusoidal signal with 303.38kHz and 1Vp-p amplitude into input. As well the waveforms of the transient response of bandpass can be illustrated in Fig.8.

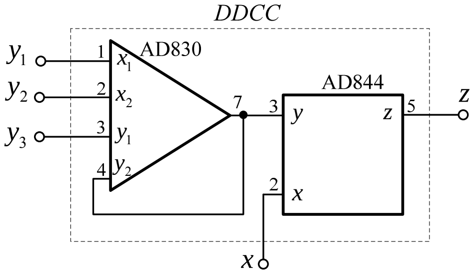


Fig.4. The implementation of DDCC

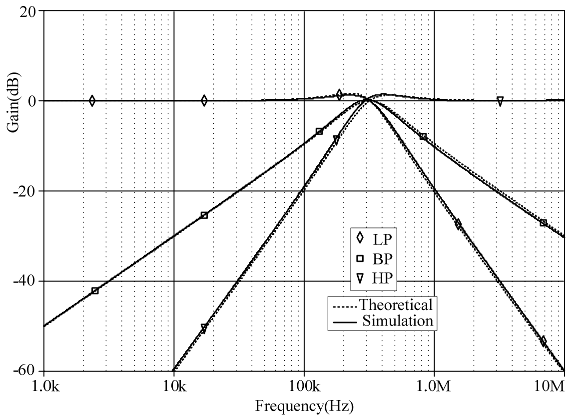


Fig.5. Frequency responses of voltage output

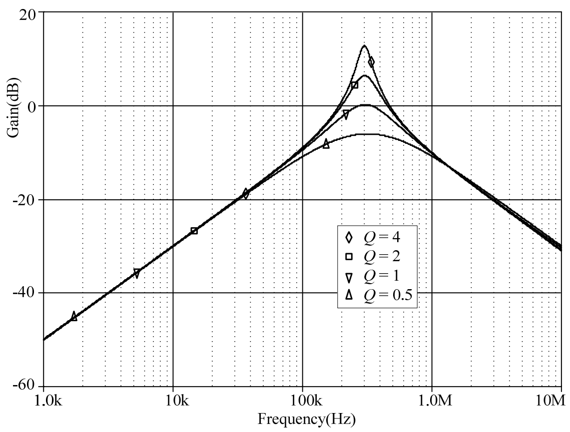


Fig.6. The variation of quality factor

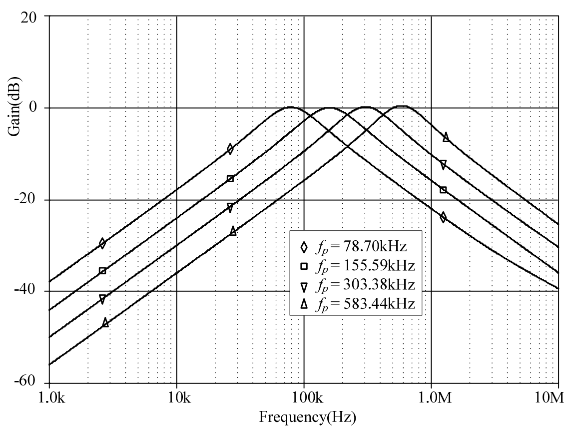


Fig.7. The variation of frequency

The details of %THD (total harmonics distortion) of all output voltages (HP, BP and LP) between the amplitude of input voltages can be concurrently plotted in Fig.9. It can be pleased that %THD of output voltages are low which is less than 1%. However in practice the passive elements of proposed circuit have been deviated by the tolerance errors. These errors are caused for deviation of the corresponding pole frequency and quality factor of theory. In this case the Monte Carlo Analysis will be properly used. The tolerance errors of passive elements are determined by 5% and the Gaussian probability distributions with 100 trials were used. The simulated responses of bandpass and histograms of the pole frequency can be possibility presented in Fig.10 and Fig.11, respectively. The maximum and minimum of the pole frequency are 376.33kHz and 283.09kHz, respectively. Also the median and deviation of the pole frequency are 335.53kHz and 18.49kHz, respectively.

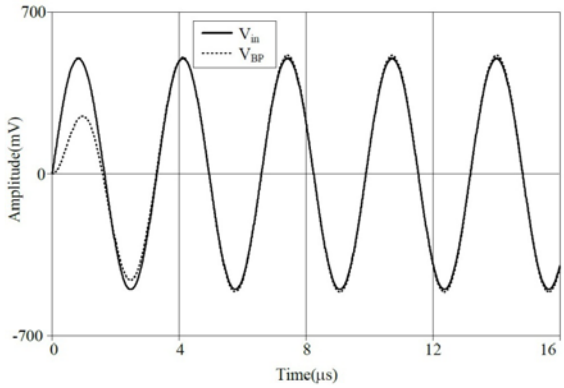


Fig.8. The transient response of bandpass

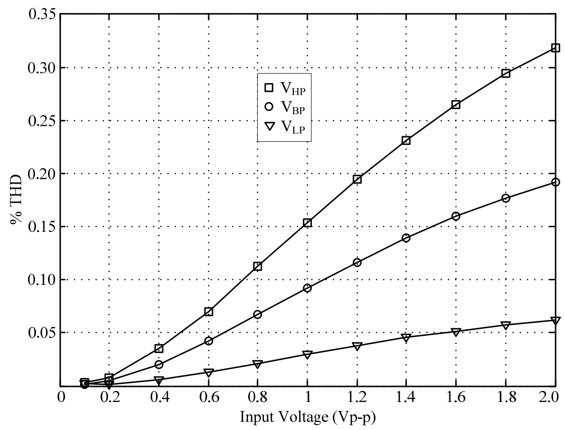


Fig.9. %THD for output voltage

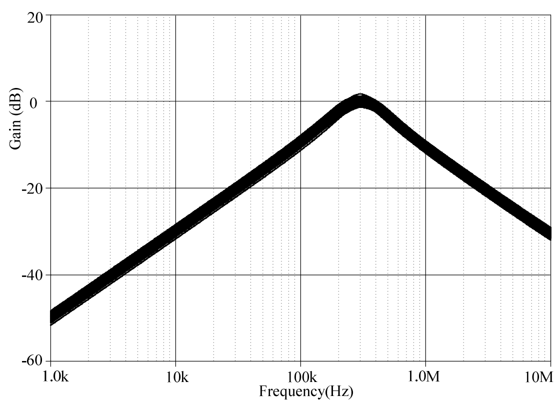
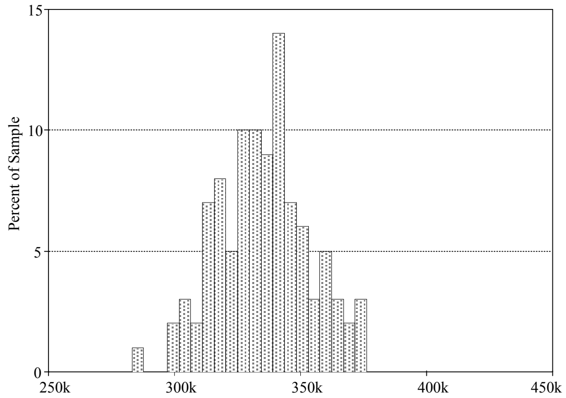


Fig.10. Simulated responses of bandpass for Monte Carlo Analysis



n samples	= 100	minimum	= 283099	maximum	= 376336
n divisions	= 20	10th %ile	= 312129	3*sigma	= 55486.9
mean	= 335305	median	= 335538		
sigma	= 18495.6	90th %ile	= 360903		

Fig.11. Histograms of bandpass responses for Monte Carlo Analysis

The configuration of the passive elements for testing the quadrature oscillator will be set by $R_1 = R_2 = 1\text{k}\Omega$, $R_3 = 980\Omega$ and $C_1 = C_2 = 500\text{pF}$. The explicit voltage outputs of transient responses are plotted in Fig.12. The steady-state responses of quadrature signals are simultaneously presented in Fig.13. Additionally the frequency spectrums of quadrature signals can be depicted in Fig.14. The simulate frequency is about 300kHz that is an error of theoretical about 5.74%. It is clearly that these errors are possibly occurred by tracking errors of DDCCs. The total harmonic distortion of V_{O1} and V_{O2} are about 0.96% and 1.93%, respectively. The Lissajous pattern of voltage output signals can be plotted in Fig.15.

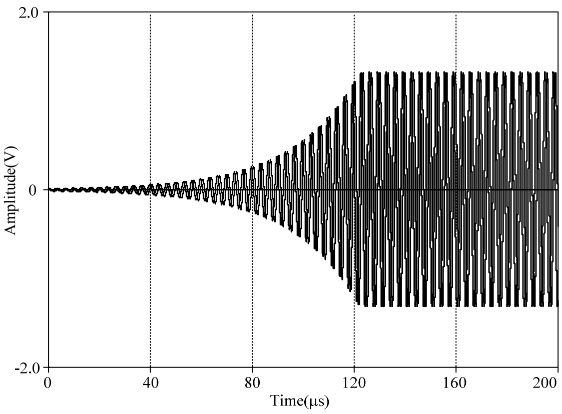


Fig.12. The transient response of output signals

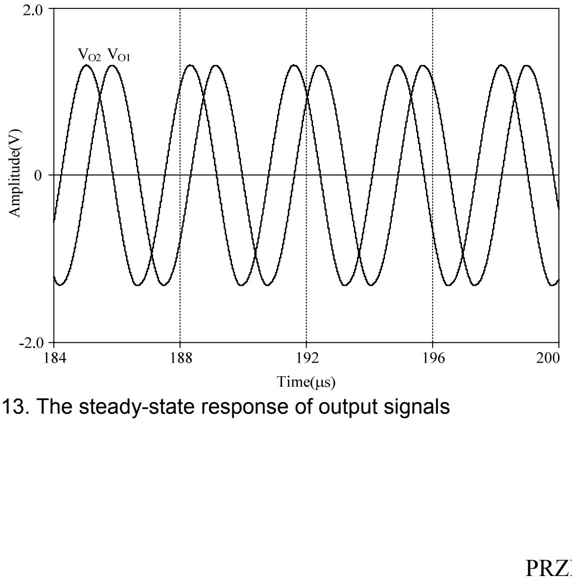


Fig.13. The steady-state response of output signals

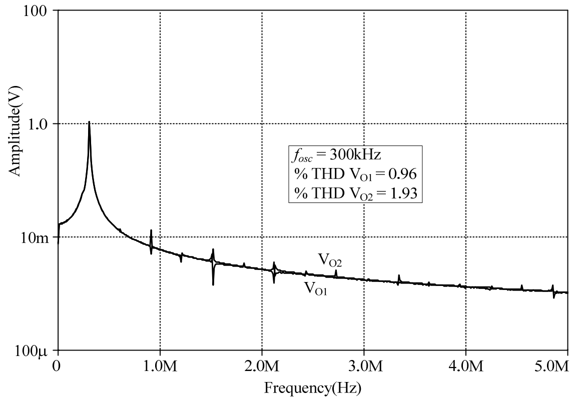


Fig.14. The frequency spectrum of output signals

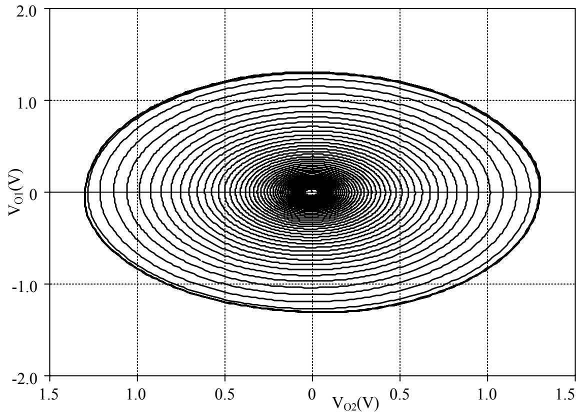


Fig.15. The Lissajous pattern of voltage output signals.

Conclusions

The voltage-mode second-order filter and quadrature oscillator with the same configuration are proposes. The propose circuit is contained DDCCs and only grounded elements. The advantage of second-order filter is freely tuned of corresponding of pole frequency and quality factor. Also, the input impedance is high and low active/passive sensitivities. Besides, the quadrature oscillator can be successfully operated by a little modification. It has many advantages such as the oscillation frequency can be independently adjusted without distribution of the oscillation condition. The output impedance of quadrature signals are low. The verification of the performance of circuit is used Pspice simulation and the simulated results accord with the theoretical analysis.

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