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The Configuration of Current-mode Single-input Multi-output, Multi-input Single-output Biquad Filter and Quadrature Oscillator based-on BiCMOS CCCTAs

***Abstract**. The current-mode single-input multi-output, multi-input single-output biquad filter and quadrature oscillator for the same configuration has been studied in this paper. It is configured with two BiCMOS CCCTAs and two grounded capacitors. The performing of proposed configuration can function as the single-input multi-output and multi-input single-output filter. It serves to be all standard functions; lowpass, highpass, bandpass, bandreject and allpass response. The pole frequency and the quality factor can be electronically/independently tuned with the DC bias currents of the BiCMOS CCCTAs. Furthermore, the proposed configuration can be operates in the quadrature oscillator. It has been featured as the condition of oscillation and the frequency of oscillation are freely adjusted with the DC bias currents of the BiCMOS CCCTAs. The performances for proposed configuration is simulated with PSPICE program that accordance to the theoretical analysis.*

Streszczenie.** W pracy przedstawiono układ umożliwiający realizację prądowego filtru czwartego stopnia z jednym wejściem i wieloma wyjściami oraz z jednym wyjściem i wieloma wejściami. Ten sam układ umożliwia realizację układu generatora. Układ wykorzystuje dwa obwpody BiCMOS CCCTAs i dwa uziemione kondensatory.* ***Filtr prądowy czwartego rzędu z jednym wejściem i wieloma wyjściami oraz układ generatora wykorzystujący obwody BiCMOS CCCTAs

Keywords: Current-mode, single-input multi-output, multi-input single-output, quadrature oscillator, BiCMOS CCCTA.
Słowa kluczowe: BiCMOS CCCTA, filtr z wieloma wyjściami, generator

Introduction

An analog signal processing, the universal and multifunction biquad filters are extremely for pay attention to research and publish [1-5] since they are essentially used in communication system, instrument, measurement system and etc [1-5]. The single-input multi-output (SIMO) biquad filter is realized standard-function filter outputs which are highpass filter (HPF), lowpass filter (LPF) and bandpass filter (BPF), bandreject filter (BRF) or notch filter and allpass filter (APF) with feeding single input signal. Simultaneously, multi-input single-output (MISO) multifunction filter can be performed filter outputs including HPF, LPF, BPF, BRF and APF by selection/connection the input signals. At the same time, the sinusoidal oscillator with 90 degree phase difference or the quadrature oscillator (QO) are favorably role for usefulness in measurement system, communication system, power electronics system and etc [5-10]. The most of the SIMO, MISO and QO have been reported in literature [11-48]. They are based current-controlled current conveyor transconductance amplifier (CCCCTA) or current-controlled conveyor transconductance amplifier (CCCTA). The explanation of them can be detailed as follows.

The proposed circuits in [11-12] can be achieved for biquad filter and quadrature oscillator without changing circuit configuration which is conveniently used. All circuits in [13-33] can be operated both filter in detail the SIMO [14, 16, 18, 23-28, 30-31] and the MISO [13, 15, 17, 19-22, 29-30, 32-33] filter. They are benefited for tuning with electronic method which is proper to utilize in communication system/automatic systems. Furthermore, the proposed filters in [13-22, 33] use single active element that is prettied and smarted. As well, the filter circuits in [14-16, 18-33] use grounded capacitors which are appropriated for fabrication to integrated circuit (IC). Simultaneously, the proposed circuits in [34-48] are capable of either performing in QO. The frequencies of oscillation of them are electronically adjusted which is smartly purposed for a modern circuit synthesis. Furthermore, they use only grounded capacitors that are pointed of view for development to IC. In addition, the circuit structures in [34-40, 45, 47] are fitted since they use only single active element.

However, all mentioned above, they have some restricted such as the biquad filter and oscillator circuit in [11] stills from the frequency limitation imposed by op-amps. The circuits structures are presented in [12-13, 16-17] use floating capacitors which are unsuitable for integrated circuit implementation. Because, it will be increased the chip areas and parasitic effects. Moreover, in Ref. [13-17, 22, 36-38, 46-47] also needed external passive resistors which may be caused of difficult to IC implementation [48]. Furthermore, the passive resistors may be elevated temperatures and power consumptions [48]. Also, the parameters pole frequency (ω_p) and quality factor (Q_p) of [11, 19-20, 23-24, 30-33] cannot independently tuned. The configurations of circuit in [23-26] require using the three of CCCCTAs. Then, proposed circuits in [13-33] can be either operated universal filter and in [34-48] are either capable to quadrature oscillator.

The purposed of this paper is studied for the configuration of current-mode single-input multi-output, multi-input single-output filter and quadrature oscillator. The configuration is constructed two BiCMOS CCCTAs and only two grounded capacitors. While, it operates of the SIMO and MISO biquad filter, the pole frequency and quality factor are independently adjusted. As well, it can be operated of quadrature oscillator with freely controllable of the frequency of oscillation and condition of oscillation. Also, the proposed configuration is suitability fabricated to IC since all parameters of them can be tuned with electronic method and also used of grounded capacitors. The performance analyses are investigated by PSPICE program with the parameters of 0.35μm BiCMOS.

The description of the BiCMOS CCCTA

CCCTA or current-controlled conveyor transconductance amplifier in BiCMOS technology is researched and published by Tangsrirat [33], on 2014. It was improved from the CCCCTA (current-controlled current conveyor transconductance amplifier) [35]. The CCCTA has several advantaged such as simple structure in BiCMOS since it composes solely difference pairs and simple current mirrors, the parasitic resistance R_x can be electronically/linearity adjusted with the external DC bias current, higher transconductance and etc. The electrical symbol and equivalent circuit of the CCCTA are shown in Fig. 1 (a) and (b), respectively. The electrical properties of the CCCTA can be detailed in the following equation:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_{zc} \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix} . \tag{1}$$

Where, the parasitic resistance R_x at x-terminal can be electronically/linearity controlled via the DC bias current I_A as follows:

$$R_x \cong \frac{2V_T}{I_A} . \tag{2}$$

The value of transconductance gain g_m of the CCCTA is proportionally adjusted by the DC bias current I_B that is:

$$g_m = \frac{I_B}{2V_T} . \tag{3}$$

The configuration of current-mode SIMO, MISO biquad filter and QO

The proposed configuration is presented in Fig. 2, it minimizes of component that is consisted of two BiCMOS CCCTAs and only two grounded capacitors. It well known that, the grounded capacitors can be reduced the parasitic effected of the nodes/ports of the circuit [49-50]. The proposed configuration can be discussed and realized the SIMO, MISO and QO in following sub-sections, respectively.

Current-mode SIMO biquad filter operation

The proposed configuration in Fig. 2 can be operated in current-mode single-input multi-output (SIMO) biquad filter, while feeding only single input signal I_{in1}. From the electrical properties of CCCTA, the current gain transfer function for the filter can be realized as:

$$\frac{I_{O1}}{I_{in1}} = \frac{C_2 s}{R_{x1}C_1C_2 s^2 + C_2\left(\dfrac{g_{m2}R_{x2}}{2} - \dfrac{1}{2}\right)s + g_{m1}} , \tag{4}$$

$$\frac{I_{O2}}{I_{in1}} = \frac{g_{m1}}{R_{x1}C_1C_2 s^2 + C_2\left(\dfrac{g_{m2}R_{x2}}{2} - \dfrac{1}{2}\right)s + g_{m1}} , \tag{5}$$

and

$$\frac{I_{O3}}{I_{in1}} = \frac{R_{x1}C_1C_2 s^2}{R_{x1}C_1C_2 s^2 + C_2\left(\dfrac{g_{m2}R_{x2}}{2} - \dfrac{1}{2}\right)s + g_{m1}} . \tag{6}$$

The current gain transfer functions are obtained in equation (4) – (6). They provide BP, LP and HP response at the output currents I_{O1}, I_{O2} and I_{O3}, respectively.

Clearly, the parameters pole frequency (ω_p) and quality factor (Q_p) of each transfer function can be calculated respectively by:

$$\omega_p = \sqrt{\frac{g_{m1}}{R_{x1}C_1C_2}} , \tag{7}$$

$$Q_p = \frac{1}{\dfrac{g_{m2}R_{x2}}{2} - \dfrac{1}{2}} \sqrt{\frac{g_{m1}R_{x1}C_1}{C_2}} . \tag{8}$$

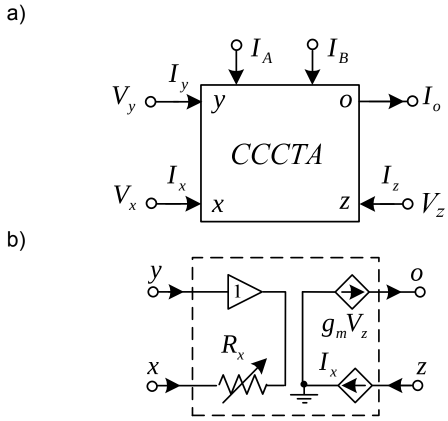

Fig.1 a) electrical symbol b) equivalent circuit

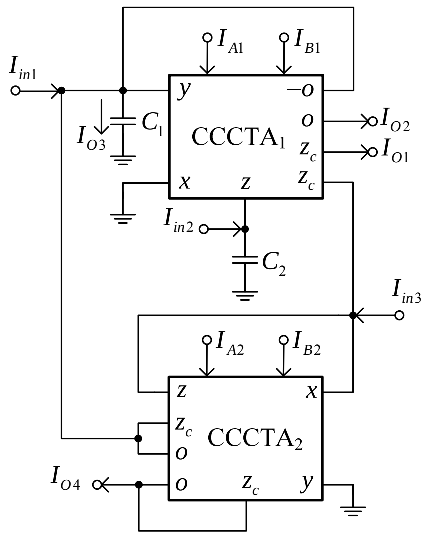

Fig.2 Proposed configuration

Substituting the parasitic resistances $R_{x1} \cong 2V_T / I_{A1}$, $R_{x2} \cong 2V_T / I_{A2}$ and the transconductance gains $g_{m1} = I_{B1} / 2V_T$, $g_{m2} = I_{B2} / 2V_T$, the both parameters of filter are satisfactory become:

$$\omega_p = \frac{1}{2V_T}\sqrt{\frac{I_{A1}I_{B1}}{C_1C_2}} , \tag{9}$$

and

$$Q_p = \frac{1}{\dfrac{I_{B2}}{2I_{A2}} - \dfrac{1}{2}} \sqrt{\frac{I_{B1}C_1}{I_{A1}C_2}} . \tag{10}$$

It can be considered that the parameter ω_p can be electronically and proportionally tuned by the bias currents I_{A1} and I_{B1} or both. As well, if kept to be $I_{A1} = I_{B1} = I_F$, the parameter ω_p can be independently tuned without affecting of the parameter Q_p. In practically, the bias currents I_{A1} and I_{B1} are equality by the use of the current mirror circuit for copy bias current I_F to I_{A1} and I_{B1}. Besides, the parameter Q_p can also be freely tuned by adjusting the bias currents I_{A2} or I_{B2}, which is also influenced the parameter ω_p.

Current-mode MISO biquad filter operation

The feature of the proposed configuration in Fig. 2, it can be operated in multi-input single-output (MISO) biquad filter. While feeding all input signals I_{in1}, I_{in2} and I_{in3}, the single output current is only utilized I_{O4}. Straightforward analysis of the proposed configuration yields the following current gain transfer functions.

(11)

$$I_{O4} = \left(\frac{g_{m2}R_{x2}}{2} - \frac{1}{2}\right)\left(\frac{C_2 s I_{in1} - g_{m1}I_{in2} + (R_{x1}C_1C_2s^2 + g_{m1})I_{in3}}{R_{x1}C_1C_2s^2 + C_2\left(\frac{g_{m2}R_{x2}}{2} - \frac{1}{2}\right)s + g_{m1}}\right)$$

From equation (11), it is obtained the standard biquadratic function of filter. The output current I_{O4} response can be obtained BP, inverting LP, HP, BR and AP by selection/connection the input currents in Table I. It can be observed that the input currents are not required double input current signals and easy controlled with digital method [3].

Table I Input selection/connection to obtain output filter response

Filter Response	Input Selection/Connection		
I_{O4}	I_{in1}	I_{in2}	I_{in3}
LP	0	1	0
HP	0	1	1
BP	1	0	0
BR	0	0	1
AP	-1	0	1

Furthermore, the valuable parameters the ω_p and the Q_p are the same properties with the SIMO filter. They can be electronically and independently tuned that is also discussed as above and described in equation (9) – (10)

Current-mode quadrature oscillator operation

It is interested that the proposed configuration can be worked as the current-mode quadrature oscillator (QO) without feeding the input currents I_{in1}, I_{in2} and I_{in3}. The output currents provide I_{O1} and I_{O2} and also have high impedances. The characteristic equation for the QO can be analyzed as follows:

(12) $$R_{x1}C_1C_2s^2 + C_2\left(\frac{g_{m2}R_{x2}}{2} - \frac{1}{2}\right)s + g_{m1} = 0$$

It is examined that the condition of oscillation (CO) and the frequency of oscillation (FO) can be respectivly expressed as:

(13) $$g_{m2}R_{x2} = 1,$$

and

(14) $$\omega_{osc} = \sqrt{\frac{g_{m1}}{R_{x1}C_1C_2}},$$

They can be clearly completed by substituting the parasitic resistance R_{x1}, R_{x2} and the transconductance gain g_{m1}, g_{m2} into the both parameters. The parameters CO and FO can be given by equation (15) and (16), respectively.

(15) $$\frac{I_{B2}}{I_{A2}} = 1,$$

(16) $$\omega_{osc} = \frac{1}{2V_T}\sqrt{\frac{I_{A1}I_{B1}}{C_1C_2}}.$$

It is evident that the parameters CO and FO can be electronically tuned by adjusting the bias currents of CCCTAs. Considerably, the CO is set by the ratio of the bias currents I_{A2} and I_{B2}. Also, the FO is electronically and proportionally increased or decreased by tuning the bias currents I_{A1} and I_{B1}, or both. Consequently, the CO and the FO for the QO are non-interactive tuned with the bias currents of CCCTAs. For the reasons mentioned above, this configuration may be called current-controlled current-mode quadrature oscillator. Then, the sinusoidal signals of output currents I_{O1} and I_{O2} for the QO can be calculated the phase difference as

(17) $$\frac{I_{O2}}{I_{O1}} = \frac{g_{m1}}{C_2 s}.$$

From equation (17), it is sure that the phase difference of sinusoidal signals I_{O1} and I_{O2} are 90°. These sinusoidal signals are called quadrature.

Non-ideal analysis

However, the non-ideal parameters of the CCCTA will be considered since these parameters have been degraded the performance of the proposed configuration. These parameters include the voltage and the current tracking errors that are γ and α, β respectively. The CCCTA properties are changed to

(18) $$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_{zc} \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & \gamma & 0 & 0 \\ \alpha_1 & 0 & 0 & 0 \\ \alpha_2 & 0 & 0 & 0 \\ 0 & 0 & \pm\beta g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}.$$

The valuable parameters ω_p and Q_p of the SIMO, MISO are modified respectively by

(19) $$\omega_p = \sqrt{\frac{\alpha_1\gamma_1\beta_1 g_{m1}}{R_{x1}C_1C_2}},$$

and

(20) $$Q_p = \frac{1}{\left[\frac{\beta_2 g_{m2}R_{x2}}{(1+\alpha_3)} - \frac{\alpha_4}{2}\right]}\sqrt{\frac{\beta_1 g_{m1}R_{x1}C_1}{\alpha_1\gamma_1 C_2}}.$$

Then, the CO and the FO of the QO are become

(21) $$\frac{\beta_2 g_{m2}R_{x2}}{(1+\alpha_3)} = \frac{\alpha_4}{2},$$

and

(22) $$\omega_{osc} = \sqrt{\frac{\alpha_1\gamma_1\beta_1 g_{m1}}{R_{x1}C_1C_2}}.$$

From (19) – (22), they depict that the effects of tracking error of voltage and current of CCCTAs for the proposed configuration. These errors often occur at high frequency, high temperature and the mismatch of internal construction of the CCCTA.

The simulation results and discussions

The theoretical analysis of the proposed configuration is verified by PSPICE program. The internal construction of the BiCMOS CCCTA in [33] has been used. The aspect ratios (W/L) of all CMOS transistors (PMOS and NMOS) are chosen as $7\mu m/0.7\mu m$. The voltages supply of the proposed configuration is set as ± 1.25 V.

The MISO biquad filter is chosen for example of filters. The CCCTAs are biased currents with $I_{A1} = I_{B1} = I_F = 100\mu A$, $I_{A2} = 50\mu A$ and $I_{B2} = 150\mu A$. The external grounded capacitors are chosen as $C_1 = C_2 = 680pF$. This set up is yielded $f_p = \omega_p / 2\pi = 450kHz$ and Q_p = 1. The simulation results of the current gain responses I_{O4} are depicted in Fig. 3 that are LP, BP, HP and BR responses by selection the input signals in Table I. As well, the AP responses include current gain and phase responses are shown in Fig. 4. The f_p of simulated results is about 430.52kHz. It has been deviated from equation (9) are about 4.32%. This deviation may be occurred with the voltage and current tracking errors of CCCTAs. Fig. 5 display the simulated results of the f_p for BP response. In this case the I_{A2} and I_{B2} are fixed and adjusted the bias currents $I_{A1} = I_{B1} = I_F = 50\mu A$, $100\mu A$ and $200\mu A$. The f_p are tuned as 219.78kHz, 430.52kHz and 827.94kHz, respectively. Moreover, the Q_p can be demonstrated with electronic adjusting in Fig. 6. The values of the Q_p are varied from 0.5, 1 and 2, respectively, by changing the bias currents $I_{A2} = 30\mu A$, $50\mu A$ and $75\mu A$, respectively. Note that, the Q_p are varied without the effecting of the f_p. The results in mentioned above are verified that the proposed MISO can be electronically and independently controlled for the f_p and the Q_p with the bias currents of CCCTAs as explained in equation (9) – (10).

The proposed configuration can be operated in current-mode quadrature oscillator, it can be simulated in time-domain responses. The externals grounded capacitor and bias currents I_{A1}, I_{B1} are chosen as mentioned above that are $C_1 = C_2 = 680pF$ and $I_{A1} = I_{B1} = I_F = 100\mu A$. The CO can be set by biasing the currents $I_{A2} = I_{B2} = 50\mu A$. The simulated results of the steady state response of output currents are displayed in Fig. 7. It can be found that, the phase relation of sinusoidal signals I_{O1} and I_{O2} are about 90 degrees. In addition, the frequency-domain response of sinusoidal signals can be displayed in Fig. 8. It is obvious that, the simulated results of the FO is about 430kHz and the THD of sinusoidal signals I_{O1} and I_{O2} are about 0.993% and 0.711%, respectively.

Nevertheless, the tolerances of the external capacitors have been influenced to the parameters of the configuration which are f_p, Q_p and FO. The errors of them can be used in Monte Carlo analysis. In this case, the FO is simulated for example. The Gaussian probability distributions with 100 trials and 10% for the tolerances of the external grounded capacitors are used to simulate the deviations. The possibility of the frequency-domain responses and the histograms of the FO are presented in Figure 9 (a) and (b), respectively. The median and the standard deviations of the FO are 427.792kHz and 25.798kHz, respectively. Also, the maximum and minimum of the FO are 470.985kHz and 373.018kHz, respectively.

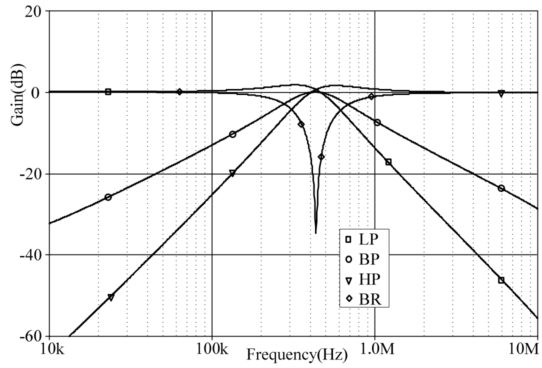

Fig. 3 The simulated results of LP, BP, HP and BR responses

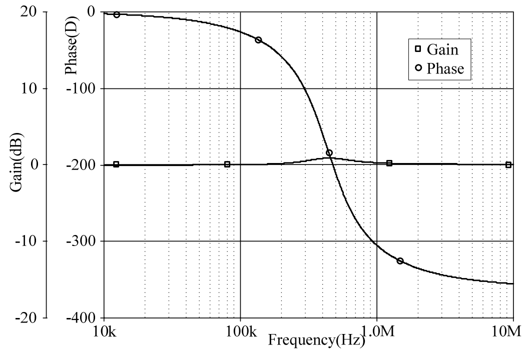

Fig.4 The current gain and phase responses of AP

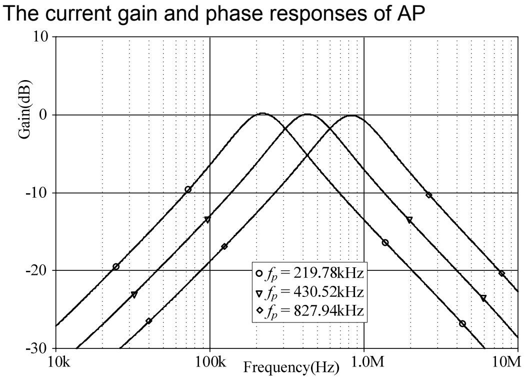

Fig.5 The simulated of BP responses with tuning f_p

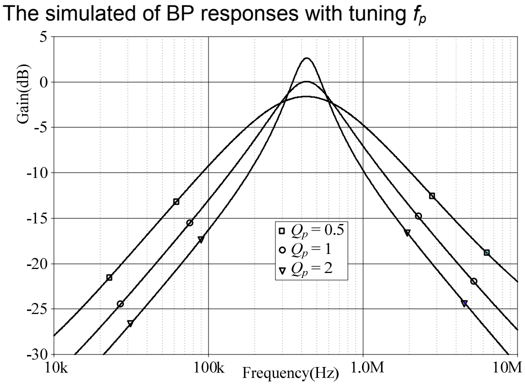

Fig.6 The Q_p are varied with difference the bias currents I_{A2}

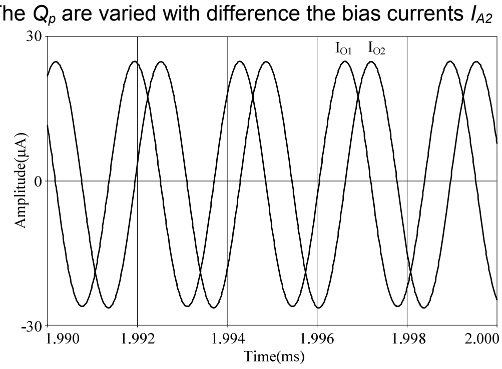

Fig.7 The steady state responses of the sinusoidal signals

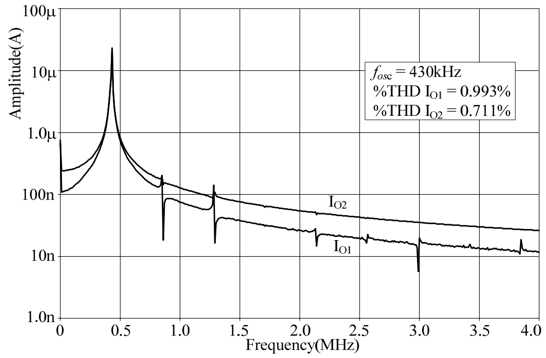

Fig.8 The frequency-domain of sinusoidal signals

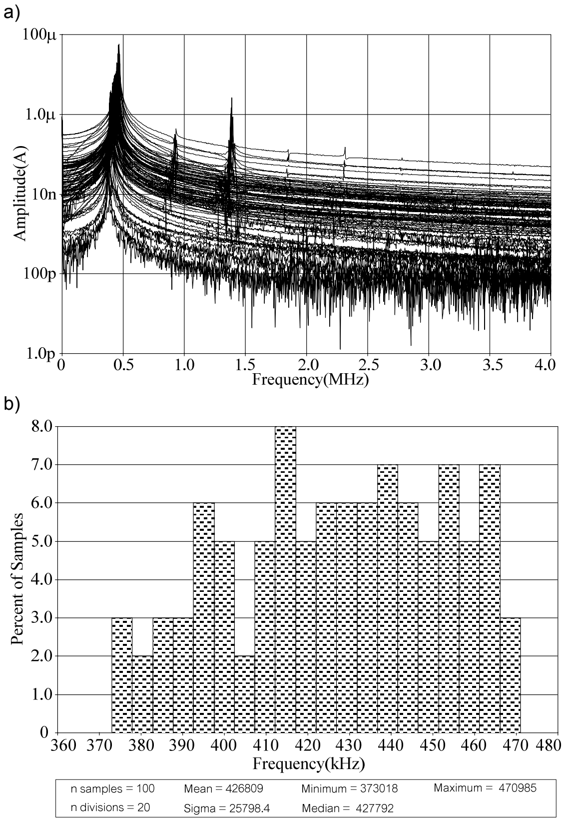

Fig.9 The Monte Carlo analysis (a) Possible spread of the frequency domain of the FO (b) Histograms of the FO

Conclusion

The current-mode single-input multi-output (SIMO), multi-input single-output (MISO) biquad filter and quadrature oscillator (QO) have been studied from the same configuration. It is configured as two BiCMOS CCCTAs and only two grounded capacitors. The features of SIMO and MISO biquad filters are performed lowpass, bandpass, highpass, bandreject and allpass responses. Also, the parameters f_p and Q_p of them can be freely and electronically adjusted with DC bias currents of the BiCMOS CCCTAs. As well, the input signals of MISO are not required double input currents and easily selected with digital method. In addition, the QO can be achieved by without feeding the input signals. The condition of oscillation (CO) and frequency of oscillation (FO) are non-interactive current controlled by adjusting the bias currents of BiCMOS CCCTAs. The output terminals of proposed configuration are high impedance which is directly and easily connected to load or next stages in current-mode configurations. The simulated results with PSPICE program are agreed well with the theoretical anticipation.

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