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AN ELECTRONICALLY TUNABLE ACTIVE-ONLY CURRENT-MODE QUADRATURE OSCILLATOR AND UNIVERSAL BIQUAD FILTER

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ABSTRACT
In this article, a novel circuit, which can function both as current-mode quadrature oscillator and as a universal biquad filter (lowpass, highpass and bandpass) is introduced. For working as quadrature oscillator, the oscillation condition and oscillation frequency can be independently adjusted by the corresponding input bias currents. For functioning as universal biquad filter, the quality factor and cutoff frequency can be tuned orthogonally via the corresponding input bias currents. The proposed circuit can work as either the quadrature oscillator or the universal biquad filter without changing any circuit topology. The circuit description is very simple, comprises only active elements, which are 6 OTAs and 2 operational amplifiers (OAs), this circuit is then suitable for IC architecture. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation.

Index Terms—OTA, Operational amplifier, Active-only, Quadrature, Biquad Filter

1. INTRODUCTION
Electronically tunable filters and oscillator find wide applications in automatic control, instrumentation and communication system and etc. The both circuits have been developed much effort. Among several types of the oscillators, a quadrature oscillator is widely used because it can provide two sinusoids with 90° phase difference, for example in telecommunications for quadrature mixers and single-sideband systems [1-2]. Similarly, the modern applications and advantages in the realization of various active transfer functions, called universal biquad filters, have received considerable attention. A universal filter may be used in phase locked loop FM stereo demodulators and crossover networks, used in three-way high fidelity loudspeakers [3]. Since the last two decade, there has been much effort to reduce the supply voltage of analog systems, this is due to operating in low-voltage environments, such as portable and battery-powered equipments. As a low-voltage operating circuit becomes necessary, the current-mode technique is more ideally suited to this purpose, owing to their larger dynamic range, wider bandwidth, greater linearity, simpler circuitry, and lower power consumption [4].

It is well known that the pole-model of OAs in place of external capacitors have the advantages of small chip area for monolithic implementation [5-6]. Moreover, the employment of OA-pole model in the synthesis of filters and oscillators, renders the circuit stable with extended range of frequency [6-7]. OTAs provide highly linear electronic tunability and wide tunable range of their transconductance gains [6]. These varied performance enhancing features motivates the circuit designers to develop filters and oscillator using only OAs and OTAs.

Until now, previous works have proposed versatile quadrature oscillator and biquad filter devices for compactness purpose using different high-performance active building blocks [8-11] such as current-controlled current differencing buffered amplifiers [8] (CCCDBAs), current-controlled current differencing transconductance amplifiers (CCCDTAs) [10-11]. Reportedly, the outputs of these circuits do not have high output impedances, making the cascade ability challenging. The presented circuit in [10] is simple, the output current signals are provided at passive element terminals. Thus, it needed to employ a current mirror or current buffer to obtain the usable output currents, this makes the circuit more complicated. The reported circuits in [11] exhibit good performance in terms of electronic tunability, high-output impedances, independent control of quality factor and pole frequency via input bias currents. Its oscillation condition and oscillation frequency can be also adjusted independently by the input bias currents. However, the circuit has low output impedance, it requires an additional current follower, for some output filter functions. Furthermore, these reported circuits [8-11] suffer from one or more of external passive elements.

2. PRINCIPLE AND OPERATION

2.1. The Operational Transconductance Amplifier (OTA)
An ideal OTA has infinite input and output impedances. The output current of an OTA is given by

\[ I_O = g_m(V_i - V_C) \]  \hspace{1cm} (1)
where $g_m$ is the transconductance of the OTA. For a bipolar OTA, the transconductance can be expressed by

$$g_m = \frac{I_g}{2V_T},$$  \hspace{1cm} (2)$$

where $I_g$ and $V_T$ are the bias current and thermal voltage (26mV at 300K$^{-1}$), respectively. The symbol and the equivalent circuit of the OTA are illustrated in Figs. 1(a) and (b), respectively.

![Figure 1. OTA (a) Symbol (b) Equivalent circuit.](image)

2.2. Operational Amplifiers

The open-loop gain of a practical internally frequency compensated OA is represented by following transfer function

$$A(s) = \frac{A_0 \omega_p}{s + \omega_p},$$  \hspace{1cm} (3)$$

where $A_0$ is open-loop DC gain, $\omega_p$ is the first pole frequency and $B = A_0 \omega_p$ is the gain-bandwidth product of the OA. For the frequencies $\omega < \omega_p$, (3) is approximately given by [5-7]

$$A(s) = \frac{B}{s},$$  \hspace{1cm} (4)$$

2.3. The proposed circuit operating as a universal biquad filter

The completely active-only high output impedance current-mode universal biquad filter is shown in Fig. 2. From the OTA and OA properties in Section 2.1-2.2, the following current transfer functions are subsequently obtained

$$I_{LP} = \frac{B_1 B_2 g_m g_{n6}}{s^2 + (g_{m} - g_{n5}) s + \frac{B_2 B_1 g_m g_{n6}}{g_{n5}}},$$  \hspace{1cm} (5)$$

$$I_{LP'} = \frac{B_1 B_2 g_m g_{n6}}{s^2 + (g_{m} - g_{n5}) s + \frac{B_2 B_1 g_m g_{n6}}{g_{n5}}},$$  \hspace{1cm} (6)$$

$$I_{BP} = \frac{g_m}{s^2 + (g_{m} - g_{n5}) s + \frac{B_2 B_1 g_m g_{n6}}{g_{n5}}},$$  \hspace{1cm} (7)$$

![Figure 2. Proposed circuit working as universal filter.](image)

From (5), (6) and (7), the parameters $\omega_0$ and $Q_0$ can be expressed as

$$\omega_0 = \sqrt{\frac{B_1 B_2 g_m g_{n6}}{g_{m} g_{n5}}},$$  \hspace{1cm} (8)$$

$$Q_0 = \sqrt{\frac{B_1 B_2 g_m g_{n6}}{g_{m} g_{n5}} \frac{g_{m} - g_{n5}}{g_{m} - g_{n5}}}. $$  \hspace{1cm} (9)$$

If letting $B_1 = B_2 = B$ and substituting the transconductances as depicted in (2), it yields

$$\omega_0 = \frac{B_1 B_2 g_m g_{n6} g_{n5}}{g_{m} g_{n5}},$$  \hspace{1cm} (10)$$

$$Q_0 = \frac{B_1 B_2 g_m g_{n6} g_{n5}}{g_{m} g_{n5} (g_{m} - g_{n5})}. $$  \hspace{1cm} (11)$$

From (10) and (11), it can be seen that quality factor ($Q_0$) can be adjusted independently from the pole frequency ($\omega_0$) by varying $I_m$ and $I_n$, while the pole frequency can be adjusted by $I_{BP}$ - $I_{BP}$. Thus, bandwidth ($BW$) is given by

$$BW = \frac{\omega_0}{Q_0} = \frac{I_{BP}}{I_m + I_{BP}},$$  \hspace{1cm} (12)$$

2.4. Proposed circuit operating as a quadrature oscillator

If no input current is applied to the circuit as shown in Fig. 3, the system characteristic equation can be expressed as

$$s^2 + (g_{m} - g_{n5}) \frac{g_{m} - g_{n5}}{g_{m} g_{n5}} s + \frac{B_2 B_1 g_m g_{n6} g_{n5}}{g_{m} g_{n5}} = 0.$$  \hspace{1cm} (13)$$

From (13), it can obviously be seen the proposed circuit can be set to be oscillator if

$$g_{m m} = g_{m 5}.$$  \hspace{1cm} (14)$$

$\omega$
Substituting the corresponding transconductances as shown in (2) into (14), the condition of oscillation is given by

$$I_g = I_{a2}.$$  \hspace{1cm} (15)

Then, the characteristic equation of the system becomes

$$s^2 + \frac{B_2B_5g_m}{g_m} = 0.$$  \hspace{1cm} (16)

From (16), the oscillation frequency of this system can be obtained as

$$\omega_{osc} = \sqrt{\frac{B_2B_5g_m}{g_m}}.$$  \hspace{1cm} (17)

Substituting the corresponding transconductance as shown in (2) into (17), the oscillation frequency ($\omega_{osc}$) is given by

$$\omega_{osc} = B_2 \sqrt{\frac{I_{g2}I_{g3}}{I_{g1}}}.$$  \hspace{1cm} (18)

It is obviously found that, from (18), the oscillation frequency can be electronically adjusted by setting $I_{g1}$, $I_{g2}$, $I_{g3}$, or $I_{g4}$, where the condition of oscillation can be tuned by either $I_{g1}$ and $I_{g2}$.

From Fig. 3, the voltage transfer function from $V_{C2}$ to $V_{CH}$ is

$$\frac{V_O(s)}{V_{C2}(s)} = \frac{g_m}{sBg_m}.$$  \hspace{1cm} (19)

Under sinusoidal steady state, (18) becomes

$$\frac{V_O(s)}{V_{C2}(s)} = B_2 \frac{g_m}{g_m} e^{-j\omega t}.$$  \hspace{1cm} (20)

The phase difference $\phi$ between $V_{C2}$ and $V_{CH}$ is

$$\phi = -90^\circ.$$  \hspace{1cm} (21)

Ensuring the voltages $V_{C2}$ and $V_{CH}$ to be in quadrature.

![Figure 3. Proposed circuit working as quadrature oscillator.](image)

3. SIMULATION RESULTS AND DISCUSSION

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examination. The PNP and NPN transistor employed in the proposed circuit were simulated by respectively using the parameter of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [12]. Fig. 4 depicts schematic description of the OTA used in the simulations. The circuit was biased with $\pm$5 V supply voltages. LM741 opamp with the gain bandwidth product of $B = 2\pi(1.0027) \times 10^6$ rad.$s^{-1}$ is used.

![Figure 4. Internal construction of OTA.](image)

Figure 5. Gain responses of the proposed circuit working as universal filter.

![Figure 6. BP responses for different values of $I_{g1}$.](image)

![Figure 7. BP responses for different values of $I_{g2}$.](image)
The result in Fig. 5 illustrates the magnitude responses of the universal filter. It shows that the proposed filter provides LP, HP and BP responses at the same time. Fig. 6 confirms that the quality factor can be adjusted by $I_d$, which is not affect the pole frequency, as analyzed in (11). Fig. 7 shows the responses of the band-pass function where $I_{BE}$ is set to $140\mu A$, $240\mu A$ and $340\mu A$. This shows that the pole frequency can be adjusted electronically, as depicted in (10).

Fig. 8 shows the output transient responses when the proposed circuit operates as quadrature oscillator. Fig. 9 shows the simulated output spectrum, it is found that the total harmonic distortion (THD) is about 3.57% for oscillation frequency of 275kHz. Fig. 10 depicts the plots of the oscillation frequencies relative to the bias currents, $I_{BE}$ and $I_{BE}$, where $I_{BE} = 85\mu A$, $95\mu A$, $105\mu A$, and $I_{BE} = 20\mu A$, $30\mu A$, $40\mu A$.

**4. CONCLUSION**

The novel circuit, which can function bolts as current-mode universal biquad filter and quadrature oscillator obtained from the same network based on 6 OTAs and 2 OAs. The proposed circuit can work as either a quadrature oscillator or a universal biquad filter without changing the circuit topology. Working as current-mode universal biquad filter, the pole frequency can be tuned which electronically and the quality factor can be tuned independently from the pole frequency. With no input current and under suitable condition, the proposed circuit functions as a quadrature oscillator. Its oscillation condition and oscillation frequency can be also adjusted independently by the input bias currents. In addition, it is also found that the circuit can be electronically tunable. As mentioned advantages, the proposed circuit is convenient to fabricate integrated circuit (IC). The PSPICE simulation results agree well with the theoretical anticipation.

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**6. REFERENCES**


