Current-mode multiphase sinusoidal oscillator using CDTA-based allpass sections

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INTRODUCTION

- In this work, a current tunable current-mode multiphase sinusoidal oscillator (MSO) employing current differencing transconductance amplifier (CDTA)-based first-order allpass sections is presented.

- The proposed MSO circuit, which uses only two CDTAs and one virtually grounded capacitor for each phase, can generate arbitrary 2n-phase current-output signals (n=2, 3, 4, . . .) equally spaced in phase, all at high output impedance terminals.

- The oscillation condition and the oscillation frequency can be controlled electronically and independently by adjusting the bias current of the CDTA.

- Simulation results are also given to verify the functionality of the proposed oscillator.

INTRODUCTION

- **Multiphase sinusoidal oscillators (MSOs) are widely used in**
- instrumentation control,
- power electronics,
- signal processing,
- measurement systems.

Current differencing transconductance amplifier (CDTA)

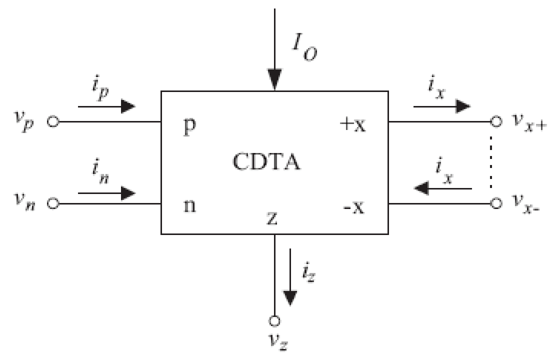


Figure 1. Circuit representation of CDTA

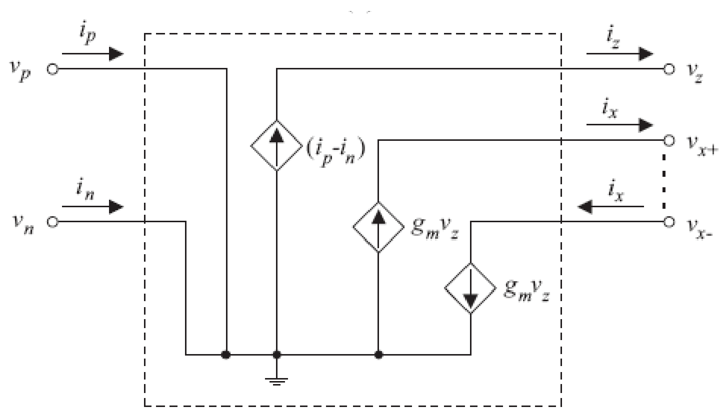


Figure 2. Equivalent circuit of CDTA

- The circuit representation and the equivalent circuit of the CDTA are shown in Figure 1 and 2.
- The terminal relation of the CDTA can be characterized by the following set of equations.

$$V_p = V_n = 0$$
$$i_z = i_p - i_n$$
$$i_x = g_m V_z = g_m Z_z i_z$$

- *p* and *n* are input terminals.
- *z* and ±*x* are output terminals.
- g_m is the transconductance gain which is electronically controllable by an external bias current (I_O).
- Z_z is an external impedance connected at the terminal *z*.

Current differencing transconductance amplifier (CDTA)

- CDTA is a current-mode active element which has advantages of the current differencing buffered amplifier (CDBA) and a multiple-output transconductance amplifier.

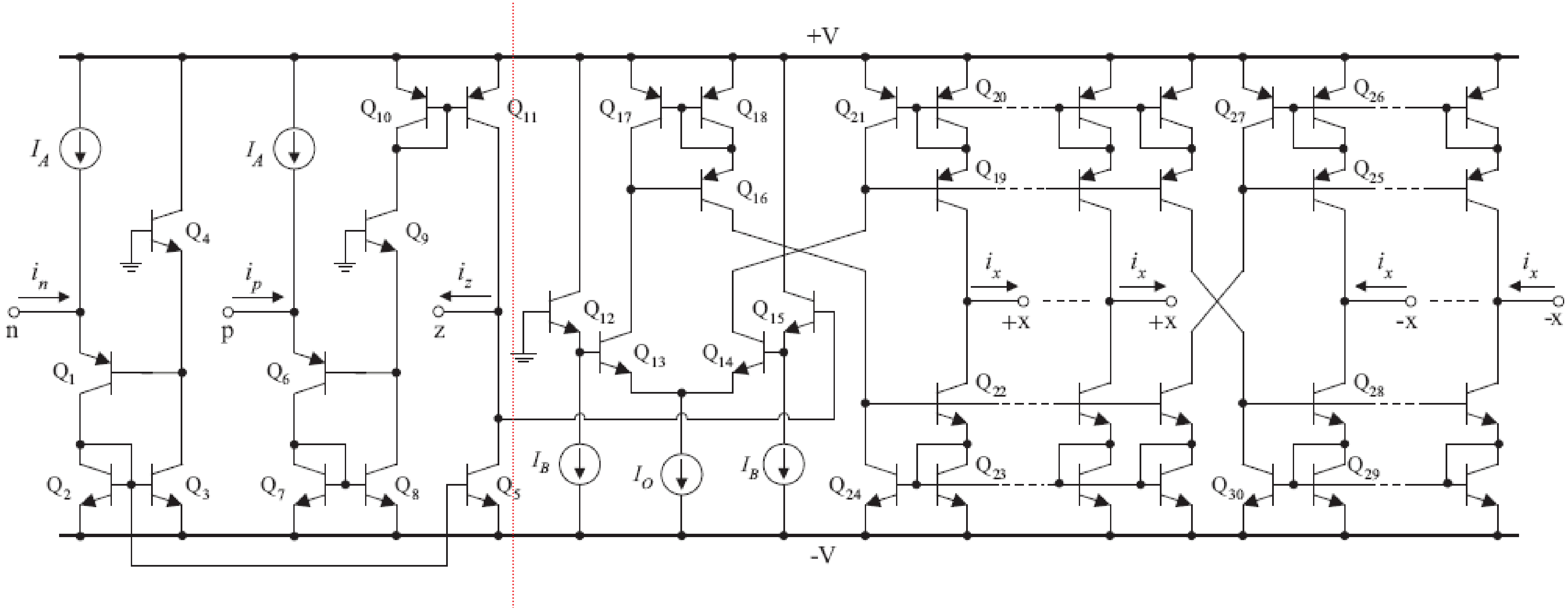


Figure 3. Possible bipolar realization of the CDTA.

CDTA-based current-mode first-order allpass section

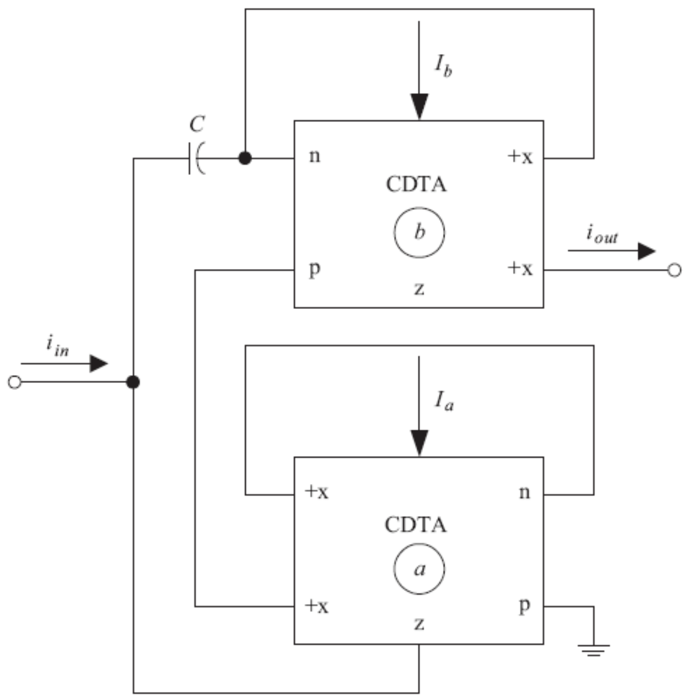


Figure 4. CDTA-based current-mode first-order allpass section.

- Figure 4 shows the resistorless current-mode first-order allpass section employing two CDTAs and one virtually grounded capacitor.
- The current transfer function of the circuit

$$\frac{i_{out}}{i_{in}} = \frac{1 - s(C/g_m)}{1 + s(C/g_m)}$$

- The phase response of this section is expressed as

$$\phi = -2\tan^{-1}\left(\frac{\omega C}{g_{ma}}\right)$$

- which varies from 0◦ to −180◦ as ω goes from zero (DC) to infinity.
- The shifted phase value can be controlled electronically by adjusting the transconductance g_{ma}.

CDTA-based current-controlled current amplifier

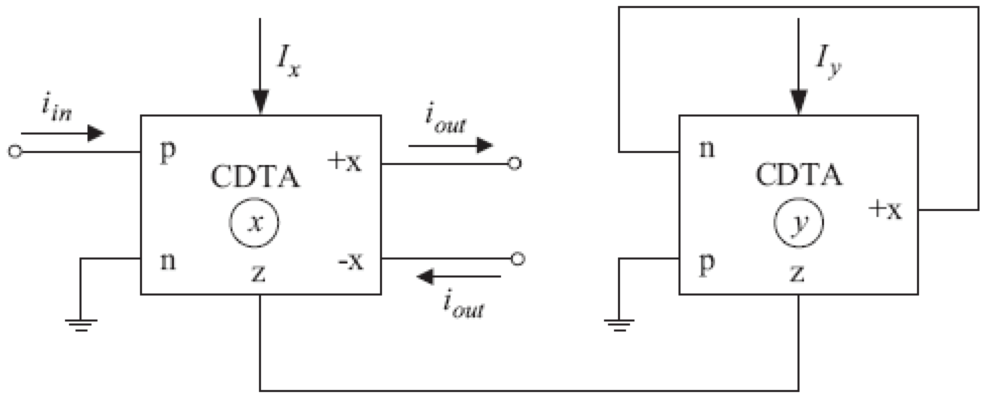


Figure 5. CDTA-based current-controlled current amplifier.

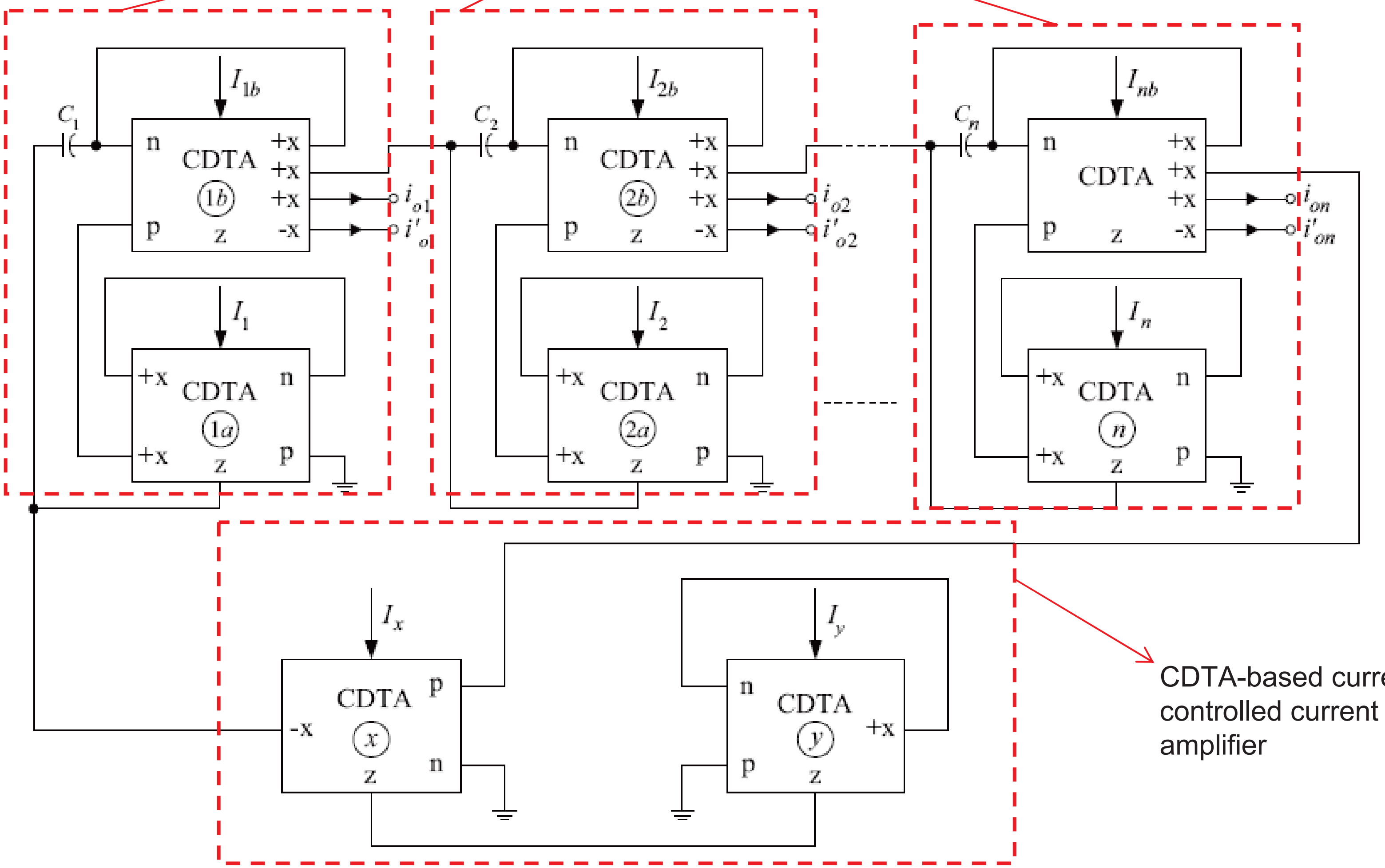
- In Figure 5, a current tunable current amplifier, which is composed of two CDTAs without the use of external passive elements, is shown.
- The current gain (*K*) can be expressed as

$$\frac{i_{out}}{i_{in}} = K = \frac{g_{mx}}{g_{my}}$$

- The amplifier gain K can be tuned linearly and electronically by adjusting the ratio of the bias current Ix/Iy.

Proposed current-mode MSO circuit

CDTA-based current-mode first-order allpass sections.



CDTA-based current-controlled current amplifier

Figure 6. Proposed current-mode MSO circuit.

Proposed current-mode MSO circuit

- The current amplifier has a feedback path,whose gain of −*K*. An advantage of this circuit is the absence of the external passive resistor, which is suitable for integration point of view.

- Assuming that $g_{m1a} = g_{m2a} = \cdots = g_{mn} = g_m$ and $C_1 = C_2 = \cdots = C_n = C$, the loop gain *L(s)* of the proposed structure in Figure 6 can be given by

$$L(s) = -K\left[\frac{1-s(C/g_m)}{1+s(C/g_m)}\right]^n$$

$$L(s) = -\frac{g_{mx}}{g_{my}}\left[\frac{1-s(C/g_m)}{1+s(C/g_m)}\right]^n$$

- According to the Barkhausen criterion, the condition for the proposed MOS circuit of Figure 6 to produce and sustain sinusoidal oscillations of frequency $(=\omega_o)$ is that

$$L(j\omega_0) = -\frac{g_{mx}}{g_{my}}\left[\frac{1-s(C/g_m)}{1+s(C/g_m)}\right]^n = 1 \qquad \phi = \frac{\pi}{n} \qquad \text{where } n \geq 2$$

Proposed current-mode MSO circuit

- There are *n* outputs i_{oi} (i = 1, 2, . . . , n) of each shifted in phase by 180◦/n available from the topology.

$$\frac{g_{mx}}{g_{my}} = 1 \quad \longrightarrow \quad \frac{I_x}{I_y} = 1$$

$$\omega_0 = \frac{g_m}{C}\tan\left(\frac{\pi}{2n}\right) \quad \longrightarrow \quad \omega_0 = \frac{I_0}{2V_T C}\tan\left(\frac{\pi}{2n}\right)$$

- ω_o can be tuned electronically and linearly through the bias current I_O without affecting the condition of oscillation, which can also be controlled electronically by the ratio of I_x/I_y without influencing the ω_o. Therefore, the circuit provides independent linear-current control of the frequency and the condition of oscillations.

- Additionally, by the use of an inverted version of the output current of the CDTA, the 2n-phase output currents are also obtained from the same topology.

Effects of CDTA non-idealities

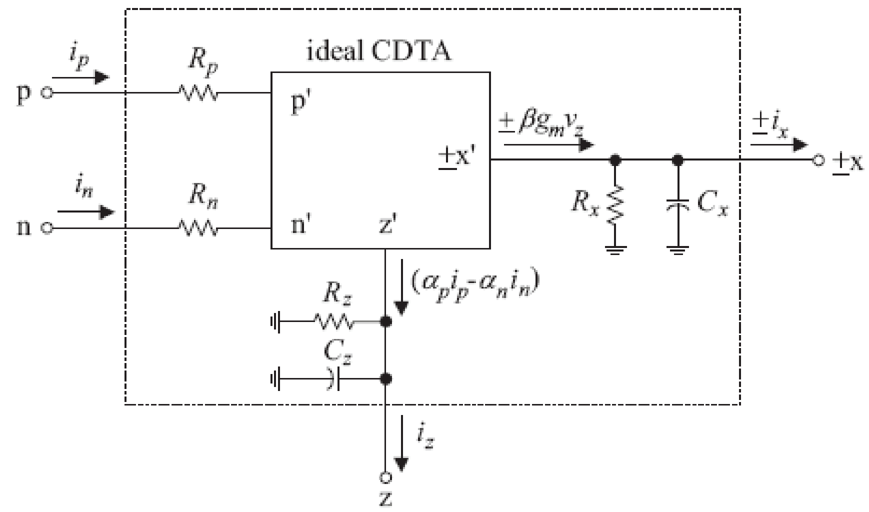


Figure 7. Simplified equivalent circuit of the non-ideal CDTA.

- Figure 7 shows the simplified equivalent circuit of the non-ideal CDTA.
- at terminals p and n, there are parasitic resistances (R_p and R_n),
- parasitic resistances and capacitances (R_z,C_z and R_x,C_x) from terminals z and x to the ground, .
- $\alpha_p=1-\varepsilon_p$, $|\varepsilon_p|>1$ is the current transfer error from p to z terminals.
- $\alpha_n=1-\varepsilon_n$, $|\varepsilon_n|>1$ is the current transfer error from n to z terminals.
- β is the transconductance inaccuracy factor from z to x terminals.

Effects of CDTA non-idealities

- Taking into account the non-ideal CDTA characteristics, the modified current transfer functions of Figures 4 and 5 can respectively be rewritten as

$$\frac{i_{out}}{i_{in}} = \left[\frac{\alpha_p/\alpha_n}{1+s(C_Z/\alpha_n\beta g_{mb})}\right]\times\left[\frac{1-s(C/\alpha_p\beta g_{ma}+\alpha_n R_p/\alpha_p-R_n)}{1+s(C/\alpha_n\beta g_{ma}+R_p+R_n)}\right]$$

$$\frac{i_{out}}{i_{in}} = K = \frac{(\alpha_p/\alpha_n)(g_{mx}/g_{my})}{(1+2sC_Z/\alpha_n\beta g_{my})(1+sR_xC_x)}$$

- C»Cz, Cx and $1/g_{ma}$ » R_p,R_n, the modified oscillation condition and ωo can be described as

$$\frac{g_{mx}}{g_{my}} = \left(\frac{\alpha_n}{\alpha_p}\right)^{n+1}$$

$$\omega_0 = \left(\frac{\alpha_n\beta g_m}{C}\right)\tan\left(\frac{\pi}{2n}\right)$$

Effects of CDTA non-idealities

- The oscillation condition is mainly affected by the current transfer errors (α_p and α_n) of the CDTAs. However, the effect of these errors can be easily accommodated by tuning the ratio of g_{mx}/g_{my} (or I_x/I_y).
- ω_o is slightly deviated from the ideal case by the factor of n. To compensate this effect, it can be done by slightly adjusting the *g*m-value.
- The ω_o-sensitivity analysis with respect to the parameters of the active and passive element used can be given by:

$$S_{\alpha_p}^{\omega_0} = 0$$

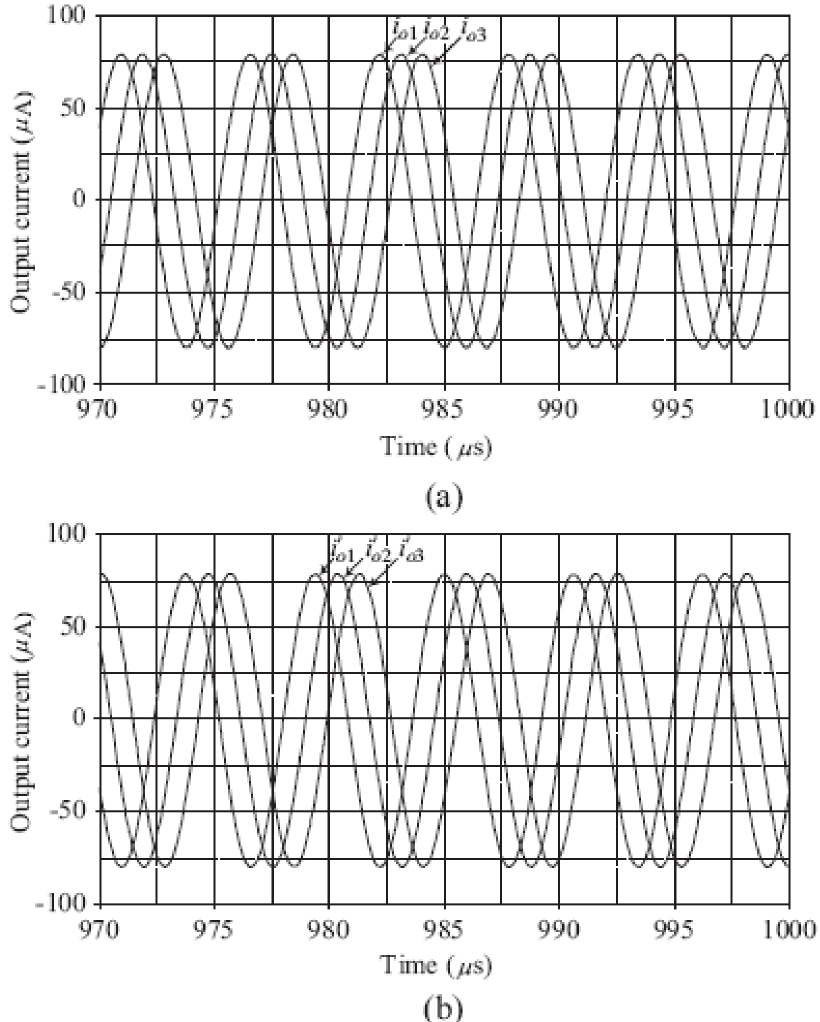
$$S_{\alpha_n}^{\omega_0} = S_{\beta}^{\omega_0} = S_{g_m}^{\omega_0} = 1$$

$$S_{C}^{\omega_0} = -1$$

Simulation results

- The proposed current mode MSO topology in Figure 6, a six-phase MSO (n = 3) has been designed.
- The circuit was simulated using PSPICE program.
- The CDTA was performed by the schematic bipolar implementation given in Fig. 3.
- The power supply voltages +V=−V=3V
- The bias currents I_A=100μA and I_B=50 μA.

Simulation results



I_O = 100 μA and C = 1nF

Figure 8. Simulated output waveforms of the proposed current-mode MSO of Fig. 5. (a) *i*o1, *i*o2, *i*o3; (b) *i*o1, *i*o2, *i*o3.

Simulation results

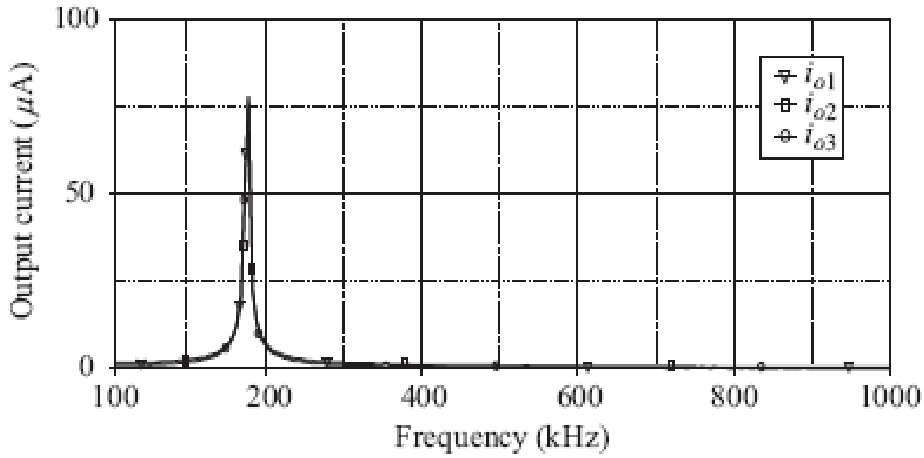


Figure 9. Simulated frequency spectrums *i*o1, *i*o2 and *i*o3.

- The simulated frequency of the oscillation was found to be 180 kHz, when theoretically calculated frequency was 183 kHz.
- From the simulation results, the phase differences of i_{o2}, i_{o3}, i_{o1}', i_{o2}' and i_{o3}' comparing with i_{o1} were respectively measured as 62◦, 121◦, 181◦, 241◦ and 300◦.
- The total harmonic distortion (THD) in the output waveforms i_{o1}, i_{o2} and i_{o3} were approximated to 1.4%.

Simulation results

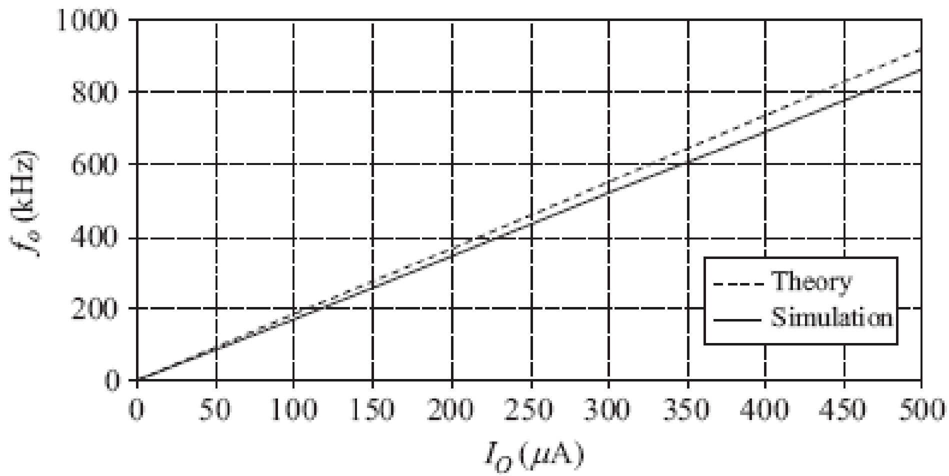


Figure 10. Oscillation frequency *(fo)* as a function of the bias currents I_O.

- The variability of the oscillation frequency (f_o) as a function of the bias current (I_O) is shown in Figure 10.
- The difference between the theoretical and the simulation results especially in high bias current value region (because of the deviation of the gm-value that differs from the calculation value).

CONCLUSION

- The proposed MSO is implemented through the proposed CDTA-based current-mode first-order allpass filters and current-controlled current amplifier as the building blocks.
- The circuit can produce 2n phase of equally spaced in-phase output currents, and all of them have high output impedance, which can be directly cascaded in current-mode operations.
- The circuit provides the electronic control of the oscillation frequency ω_o and the oscillation condition by varying the bias current of the CDTA.

REFERENCE

[1] Worapong Tangsrirat, Wason Tanjaroen, Tattaya Pukkalanun, Current-mode multiphase sinusoidal oscillator using CDTA-based allpass sections , Int. J. Electron. Commun. (AEÜ) 63 (2009) 616 – 622