วงจร ZC-CFTA ชนิดซีมอสอย่างง่ายแบบใหม่และการประยุกต์ใช้งาน

New Simple CMOS Realization of Z-copy Current Follower Transconductance Amplifier and Its Applications

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บทคัดย่อ

บทความนี้นำเสนอวงจร ZC-CFTA ชนิดซีมอสที่มีรูปแบบอย่างง่าย ซึ่งวงจรที่นำเสนอมีจุดเด่นคือ มีโครงสร้างกะทัดรัด แรงดันไฟเลี้ยงต่ำ การใช้กำลังงานต่ำและแบนด์วิดท์กว้าง โดยวงจรที่นำเสนอได้แสดงการประยุกต์ใช้งานเป็นวงจรจำลองค่าความต้านทานชนิดลงกราวนด์ทั้งแบบค่าบวกและแบบค่าลบ วงจรขยายกระแสที่ทำงานได้ทั้งแบบไม่กลับเฟสและกลับเฟส และวงจรอนุพันธ์ในโหมดกระแส นอกจากนี้ยังมีการตรวจสอบถึงคุณสมบัติแบบไม่อุดมคติของวงจร ZC-CFTA ที่กระทบต่อการทำงานของวงจรเหล่านี้อีกด้วย ผลการจำลองการทำงานของวงจรที่นำเสนอและวงจรตัวอย่างการประยุกต์ใช้งานด้วยโปรแกรม SPICE ซึ่งใช้เทคโนโลยีชนิดซีมอสแบบ TSMC 0.18 µm ยังยืนยันการวิเคราะห์ทางทฤษฎีของวงจรดังกล่าวข้างต้นด้วย

Abstract

This paper introduces a simple CMOS realization of Z-copy current follower transconductance amplifier (ZC-CFTA). The proposed ZC-CFTA provides several advantageous features of compact topology, low supply voltage, low power consumption and wide bandwidth. The application examples of positive and negative grounded resistance simulators, current-mode non-inverting/inverting amplifier and current-mode differentiator are presented. The non-ideal effects of the proposed ZC-CFTA on these applications are investigated. Several SPICE simulation results of the proposed ZC-CFTA and its applications with TSMC 0.18 µm CMOS process are given to confirm the theoretical analysis.

1. Introduction

Active elements based low voltage operable current-mode circuit designs has become an attractive choice for the researchers because of their advantages and simplicity in design for signal processing applications such amplifier, filter, oscillator and signal conditioner etc. Some advantages of the current-mode active elements over their voltage mode counter parts such as larger bandwidth, lower supply voltage, higher slew rate, higher frequency operation and better signal linearity [1-3]. New circuit designs bring about new proposed active elements. In [4], various active elements are reviewed and several new active elements are introduced. One of these new elements is Z-copy current follower transconductance amplifier (ZC-CFTA), which is a modified version of CFTA. It is the combined features of current followers and multi output transconductance amplifier and then provide simple design facility of current-mode signal processing with a number of choices of current output ports and electronic control of parameters. Several ZC-CFTA applications are given in the literature [5-11]. In the literature, ZC-CFTA realization using bipolar transistor scheme is given in [5-6]. In [7-10], CMOS transistor structure of the ZC-CFTA is used. However, these structures realize the complexity of ZC-CFTA circuit because a large number of transistors are employed. Consequently, those circuits suffer from high supply voltage, high power consumption and large area occupation in integrated circuit fabrication. So, it is the purpose of this paper to present such a simple structure of ZC-CFTA.

In this paper, a new CMOS structure of ZC-CFTA is given. It consists of a simple transconductor and a multi-output current follower. The proposed circuit employs only fourteen CMOS transistors. Thus, it exhibits several attractive features of compact structure, low supple voltage, low power consumption and need of small chip area. The performances of the proposed ZC-CFTA and its applications are tested by SPICE simulations.

2. Proposed ZC-CFTA Circuit Description

The electrical symbol and the equivalent circuit of the ZC-CFTA are shown in Fig. 1, where f terminal is a low-impedance input and z, zc, x+ and x- terminals are high-impedance outputs. Using standard notation, the terminals relation of an ideal ZC-CFTA can be defined by the following equation [5]:

$$I_z = I_{zc} = I_f , I_{x+} = -I_{x-} = g_m V_z \quad (1)$$

where g_m is the transconductance of the voltage-controlled current source.

Consequently, the realization of the proposed ZC-CFTA based on a simple transconductor is presented. From the equivalent circuit of ZC-CFTA as depicted in Fig. 1 (b), the new CMOS realization of the ZC-CFTA is shown in Fig. 2. Transistors of M_1 – M_{10} as a dual-output current follower that follows an input current (I_f) to output currents (I_z and I_{zc}). The V_{BB} is the voltages which control the bias currents of the current follower [12].

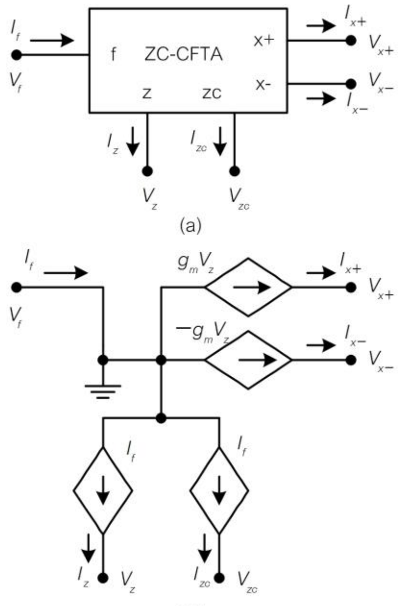

Fig. 1 ZC-CFTA (a) electrical symbol

(b) equivalent circuit

Transistors of M_{11} – M_{14} as a dual-output transconductor which converts the voltage of V_z into the current outputs of I_{x+} and I_{x-}. Assuming all transistors operate in the saturation region. The transconductance of the transconductor can be defined as [13]

$$g_m = \sqrt{\mu_n C_{ox} \frac{W}{L} I_B} \tag{2}$$

where the parameters of μ_n, C_{ox}, W/L and I_B are the electron mobility, the oxide capacitance, the aspect ratio of the NMOS transistor and the bias current of the transconductor section of the ZC-CFTA, respectively. It should be noted that the structure of proposed ZC-CFTA requires less number of transistors than that of the previous ZC-CFTAs [5-10].

3. Application Examples

The ZC-CFTA is very flexible in various circuit applications such as amplifier, integrator, universal filter, capacitor multiplier and oscillator [5-11]. To illustrate the applications of the proposed ZC-CFTA of Fig. 2, some circuits are depicted in Fig. 3 to Fig. 6.

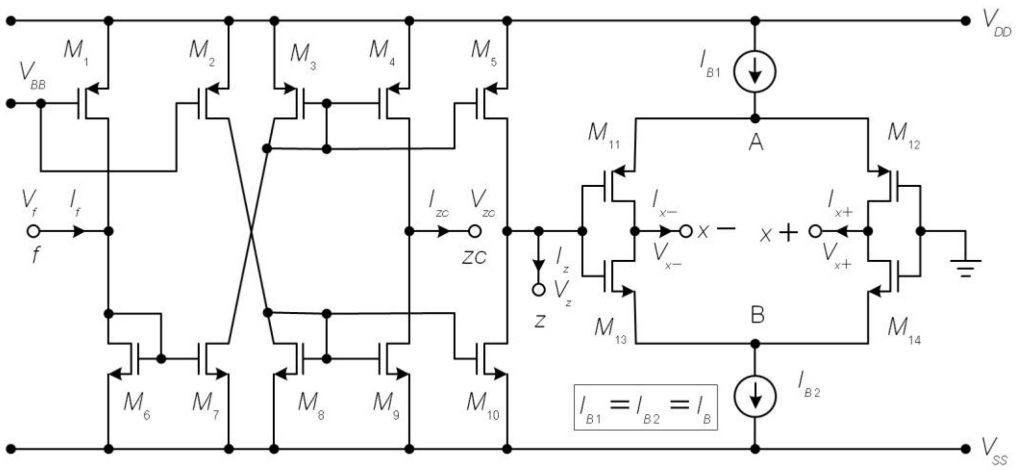

Fig. 2 the new CMOS schematic of ZC-CFTA

Fig. 3 shows a positive grounded resistance simulator using ZC-CFTA. A routine analysis of the circuit yields the following input impedance:

$$Z_i = \frac{V_1}{I_1} = \frac{1}{g_{m1}} \quad (3)$$

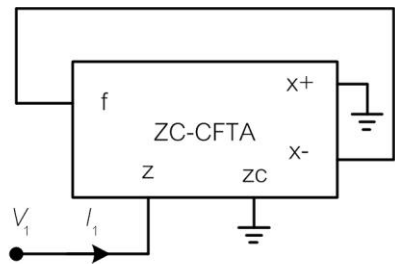

Fig. 3 positive grounded resistance simulator.

A negative grounded resistance simulator using ZC-CFTA is shown in Fig. 4. The input impedance of the circuit is then

$$Z_i = \frac{V_1}{I_1} = -\frac{1}{g_{m1}} \quad (4)$$

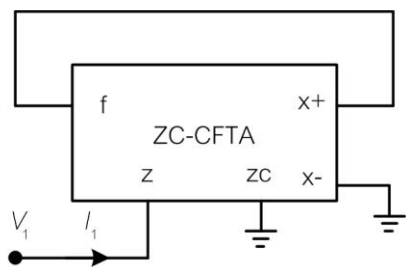

Fig. 4 negative grounded resistance simulator.

Fig. 5 depicts a current-mode non-inverting/inverting amplifier using ZC-CFTAs without passive resistor. A routine analysis of the amplifier gives the following current gain:

$$\frac{I_{o1}}{I_1} = -\frac{I_{o2}}{I_1} = \frac{g_{m2}}{g_{m1}} \quad (5)$$

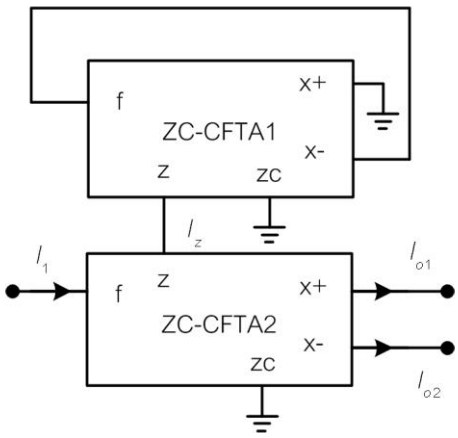

Fig. 5 current-mode non-inverting/inverting amplifier.

A ZC-CFTA-based current-mode differentiator is shown in Fig. 6. A straightforward analysis of the circuit yields the following transfer function as

$$\frac{I_o}{I_1} = \frac{sC}{g_{m2}} \quad (6)$$

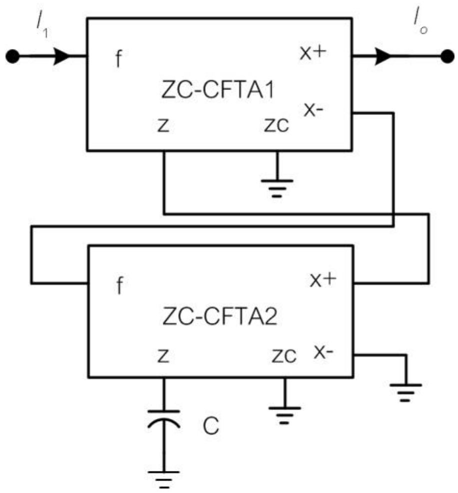

Fig. 6 current-mode differentiator.

It is clear from (3)-(6) that these parameters of the circuits can be adjusted electronically by changing the value of g_{mi} via the bias current of the i^{th} ZC-CFTA.

In non-ideal case of the ZC-CFTA, the currents of I_z, I_{zc}, I_{x+} and I_{x-} may differ from the ideal values due to the current tracking errors of the current transfer from terminal of *f* to terminals of *z* and *zc* and transconductance inaccuracies of the voltage to current transfer from terminal of *z* to terminals of *x*+ and *x*-. Taking the non-ideal factors into account, the terminal relation of the non-ideal ZC-CFTA can be rewritten as

$$I_z = \alpha I_f, I_{zc} = \alpha_c I_f, I_{x+} = \beta_p g_m V_z, I_{x-} = -\beta_n g_m V_z \quad (7)$$

where α and α_c are the current tracking errors and β_p and β_n are the transconductance inaccuracies. The repeated analysis of the circuits in Figs. 3-6 using the non-ideal ZC-CFTA, the input impedances of the positive and negative grounded resistance simulators and current transfer functions of the non-inverting/inverting amplifiers and differentiator are respectively obtained as

$$Z_i = \frac{V_1}{I_1} = \frac{1}{\alpha_1 \beta_{n1} g_{m1}} \quad (8)$$

$$Z_i = \frac{V_1}{I_1} = -\frac{1}{\alpha_1 \beta_{p1} g_{m1}} \quad (9)$$

$$\frac{I_{o1}}{I_1} = \frac{\alpha_2 \beta_{p2} g_{m2}}{\alpha_1 \beta_{n2} g_{m1}} \quad (10)$$

$$\frac{I_{o2}}{I_1} = -\frac{\alpha_2 \beta_{n2} g_{m2}}{\alpha_1 \beta_{n2} g_{m1}} \quad (11)$$

$$\frac{I_o}{I_1} = \frac{\alpha_1 sC}{\alpha_2 \beta_{p2} g_{m2}} \quad (12)$$

where α_i, β_{pi} and β_{ni} are the current tracking error and the transconductance inaccuracies of the i^{th} ZC-CFTA. Note that the values of these circuit parameters from (8)-(12) are slightly deviated by the non-ideal factors. To compensate the small deviations, the g_m can be tuned by changing the bias current of the ZC-CFTA.

4. Simulation Results

In this section, to verify the performances of the proposed ZC-CFTA, several SPICE simulations of the ZC-CFTA and its applications with 0.18 μm TSMC CMOS process parameters (BSIM3 level 7) are presented [14]. The proposed ZC-CFTA as depicted in Fig. 3 is designed with ± 0.7 V supply voltages and the aspect ratios of transistors as shown in table 1.

Table 1 aspect ratio of transistors.

Transistors	*L* (μm)	*W* (μm)
$M_1 - M_5$	0.36	9
$M_6 - M_{10}$	0.36	3.6
M_{11} and M_{12}	0.36	9
M_{13} and M_{14}	0.36	3.6

Fig. 7 shows the DC transfer characteristic of I_z and I_{zc} versus I_f with setting of V_{BB} = 0 V, I_B = 50 μA and I_f from -50 μA to 50 μA. It is noted that the simulated and ideal currents of I_z and I_{zc} are in good agreement with current of I_f from -30 μA to 30 μA.

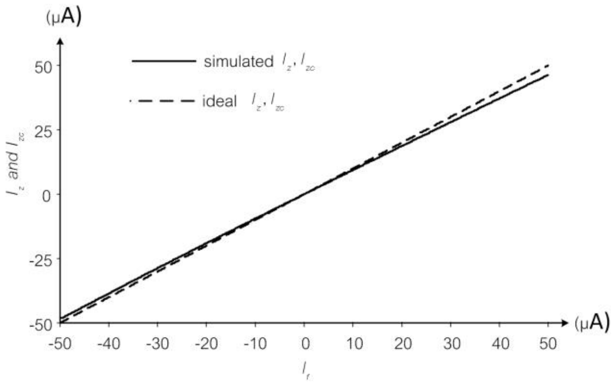

Fig. 7 currents of I_z and I_{zc} versus I_f.

To demonstrate the electronic tunning of g_m of the proposed ZC-CFTA, Fig. 8 shows the currents of I_{x+} and I_{x-} versus V_z by selecting of V_{BB} = 0 V, I_B = 20 μA, 50 μA, 100 μA and V_z from -0.5 V to 0.5 V.

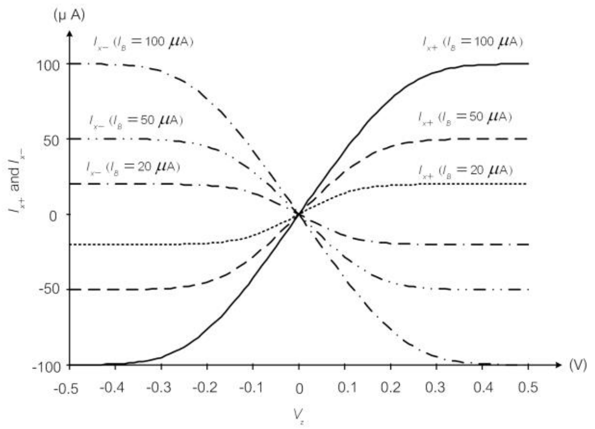

Fig. 8 currents of I_{x+} and I_{x-} versus V_z.

In Fig. 9 to Fig. 10, the frequency responses of the proposed ZC-CFTA are illustrated. The parameters of the ZC-CFTA are selected as V_{BB} = 0.1 V, I_B = 50 μA and loads of x+ and x- terminals of 10 kΩ. The frequency responses of the current follower section are shown in Fig.9. The power consumption of the ZC-CFTA is about 193 μW. It should be noted that the bandwidths of the sections of I_z / I_f and I_{zc} / I_f are about 422.92 MHz. Fig.10 shows the frequency responses of the transconductor section. The bandwidths of this section of I_{x+} / V_z and I_{x-} / V_z are about 2.16 GHz and 3.43 GHz, respectively. In addition, the ZC-CFTA of [6] offers the power consumption of 5.62 mW and the bandwidths of the sections of I_z / I_f and I_{zc} / I_f of 60.98 MHz. Consequently, the proposed ZC-CFTA presents better performance than the ZC-CFTA of [6].

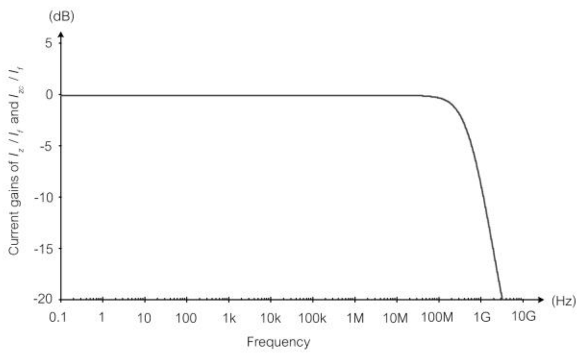

Fig. 9 current gains of I_z / I_f and I_{zc} / I_f versus frequency.

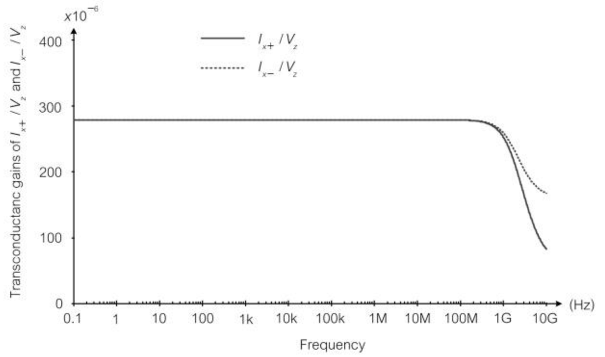

Fig. 10 transconductane gains of I_{x+} / V_z and I_{x-} / V_z versus frequency.

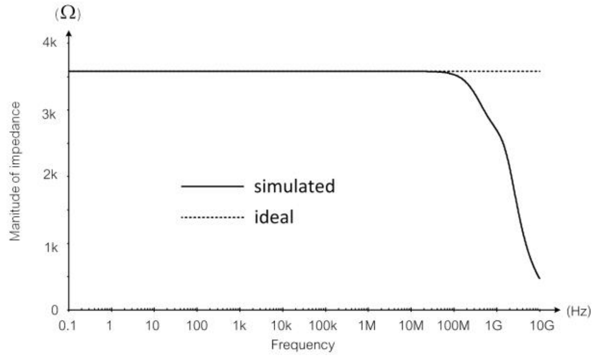

Fig. 11 impedance magnitude of the circuit of Fig. 3.

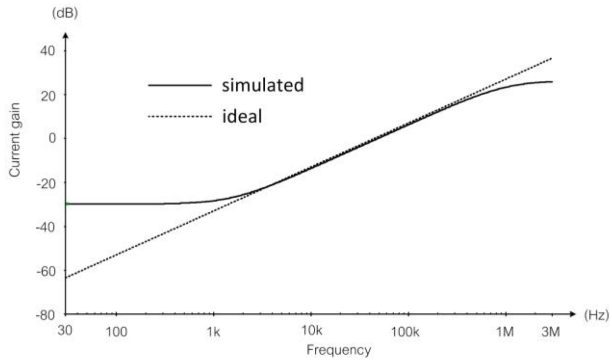

Fig. 12 frequency response of the circuit of Fig. 6.

Next, the circuit of the positive grounded resistance simulator as shown in Fig. 3 is designed as V_{BB} = 0.05 V and I_B = 50 μA to realize the resistance of 3.58 kΩ. The magnitude of impedance of the circuit is depicted in Fig. 11. It should be noticed that the simulated impedance result is very close to the ideal one from 0.1 Hz to 53.46 MHz.

Finally, the current-mode differentiator as depicted in Fig. 6 is selected as V_{BB} = 0.05 V, I_{B1} = I_{B2} = 50 μA and C = 20 nF. Fig. 12 shows the frequency response of the differentiator. It should be noticed that the simulated result agree well with the ideal one from 1.90 kHz to 540.75 kHz. In addition, the deviations of them in the low- and high-frequency regions in Fig. 11 and Fig. 12 come from the parasitic element effects of the ZC-CFTA.

5. Conclusion

A new CMOS configuration of ZC-CFTA has been presented. It employs only fourteen MOS transistors. The proposed ZC-CFTA enjoys the advantages of compact structure, low voltage supply and low power consumption. Some application examples of the ZC-CFTA with non-ideal effects are included. The results of the SPICE simulation confirm that the characteristics of the proposed ZC-CFTA and its applications are in good agreement with the theoretical predictions. The ZC-CFTA offers the operating frequency up to 422.92 MHz.

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