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High-performance Second-Generation Controlled Current Conveyor CCCII and High Frequency Applications

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***Abstract*—**In this paper, a modified CCCII is presented. We have used a current mirror with low supply voltage. This circuit is operated at low supply voltage of ±1V. Tspice simulations for TSMC 0.18µm CMOS Technology has shown that the current and voltage bandwidth are respectively 3.34GHz and 4.37GHz, and parasitic resistance at port X has a value of 169.32Ω for a control current of 120µA.

In order to realize this circuit, we have implemented in this first step a universal current mode filter where the frequency can reach the 134.58MHz. In the second step, we have implemented two simulated inductors: one floating and the other grounded. These two inductors are operated in high frequency and variable depending on bias current I_0. Finally, we have used the two last inductors respectively to implement two sinusoidal oscillators domains of frequencies respectively: [470MHz, 692MHz], and [358MHz, 572MHz] for bias currents I_0 [80µA, 350µA].

***Keywords*—**Current controlled current conveyor CCCII, floating inductor, grounded inductor, oscillator, universal filter.

I. Introduction

IN recent years, the current conveyor has improved especially for high operating frequencies, low power and low supply voltage.The concept of circuit current controlled conveyor CCCII was introduced in 1995 [1]. These circuits based on modern electronics allow the design of many electronic functions as well as the voltage mode instead of the current mode. These circuits represent a logical evolution of second generation current conveyor. They become used in high frequency applications filtering [2]-[5] and, oscillator [6].The second generation current controlled conveyor has three port networks X, Y and Z. the relation between terminal voltage and current is given by the following matrix equation:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_x & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \times \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \quad (1)$$

The plus and minus signs in the third row specified the polarity of the current conveyor (CCCII+, CCCII-).Due to the architecture used for the design of CCCII, the circuit will introduce parasitic elements. The characteristic equation has become:

$$\begin{bmatrix} I_y \\ V_x \\ I_z \end{bmatrix} = \begin{bmatrix} Y_y & 0 & 0 \\ \beta & Z_x & 0 \\ 0 & \pm\alpha & Y_z \end{bmatrix} \times \begin{bmatrix} V_y \\ I_x \\ V_z \end{bmatrix} \quad (2)$$

On the terminal Y and Z, two impedances Z_y and Z_z are specific to a parallel resistor with a capacitor. The impedance Z_x on terminal X is a parasitic resistor R_x. Where α and β denotes respectively current and voltage gains.

In this article, we have improved the current controlled conveyor. Subsequently, we will use it to implement a current mode universal filter. Second, we will use it to produce two inductors: floating and tied to ground. Based, on these last two experiences, we have made two oscillators functioning at high frequency.

II. New CCCII Configuration

The circuit current controlled conveyors CCCII classic introduced by [7]-[11] is shown in Fig.1.a. In intention to ameliorate bandwidth in current mode of this circuit, we present two current mirrors FVF (M8, M9, and M14) and (M12, M13, M16) which works in low voltage and characterized by low input impedance [12-15] (Fig.1.b). The two current mirrors can duplicate the current in the borne X on to the borne Z. The transistors M14 and M16 are used to adjust the linearity of the transfer characteristic of two mirrors of the output current and have currents in the paths equal X and Z ($I_Z = I_X = I_{d2}$-I_{d4})

The second property of CCCII is a voltage follower between terminal X and Y. the last pair is linked together by a mixed trans-linear loop (M1, M2, M3, M4).

$$V_{xy} = (V_{GS3})_P - (V_{GS4})_P = (V_{GS1})_N - (V_{GS2})_N \quad (3)$$

With: $(V_{GS})_N = \sqrt{\frac{(I_d)_N}{\frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_N}} + V_{THn}$

and $(V_{GS})_P = -\sqrt{\frac{(I_d)_P}{\frac{1}{2}\mu_p C_{ox}(\frac{W}{L})_P}} + V_{THp}$

The current through transistors M1 and M3 is equal to I_0. In this case, the potential difference V_{xy} is equal to:

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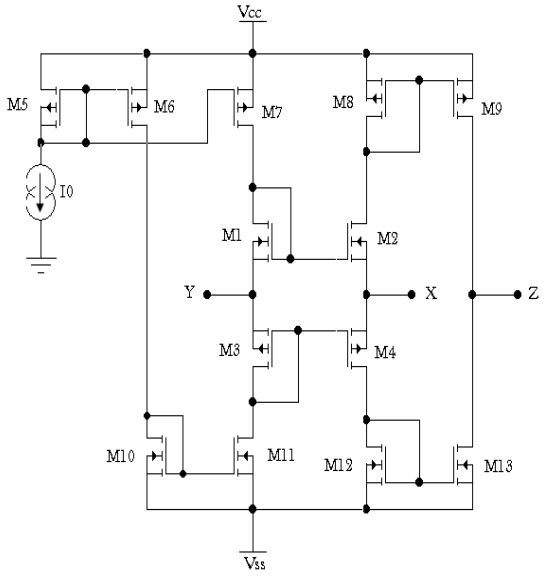
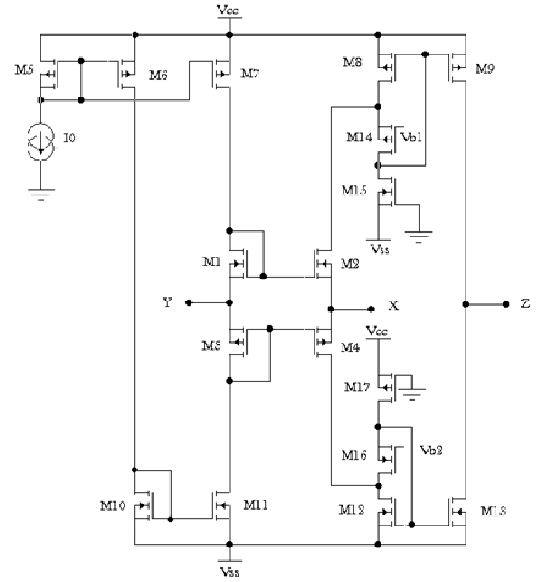


(a)



(b)

Fig. 1 Circuit current controlled conveyor CCCII (a) Classic (b) Modified

$$V_{xy}=(V_{GS1})_N-(V_{GS2})_N=\sqrt{\frac{I_0}{\frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_N}}-\sqrt{\frac{(I_{d2})_N}{\frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_N}} \quad (4)$$

$$V_{xy}=(V_{GS3})_P-(V_{GS4})_P=-\sqrt{\frac{I_0}{\frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_P}}+\sqrt{\frac{(I_{d4})_P}{\frac{1}{2}\mu_p C_{ox}(\frac{W}{L})_P}} \quad (5)$$

By determining relationships $(I_{d2})_N$ and $(I_{d4})_P$ according to I_0 and V_{xy} from (4) and (5) and applying the relationship $I_X=(I_{d2})_N - (I_{d4})_P$ and after taking everything into account we find:

$$V_x \cong V_y+\frac{I_X}{\sqrt{2I_0C_{ox}}(\sqrt{\mu_p(\frac{W}{L})_P}+\sqrt{\mu_n(\frac{W}{L})_N}} \quad (6)$$

By identifying the characteristic equations CCCII circuit, we have:

$$R_x=\frac{1}{\sqrt{2I_0C_{ox}}(\sqrt{\mu_p(\frac{W}{L})_P}+\sqrt{\mu_n(\frac{W}{L})_N})} \quad (7)$$

If $\mu_p(\frac{W}{L})_P=\mu_n(\frac{W}{L})_N$

The expression of input resistance becomes:

$$R_x=\frac{1}{\sqrt{8C_{ox}\mu\frac{W}{L}I_0}} \quad (8)$$

To achieve a current controlled conveyor with negative transfer (CCCII-) we just need to reverse the current in the terminal Z. This inversion is carried out in two additional current mirrors (M1P, M2P) and (M1N, M2N) whose entries are crossed [16]-[19] (Fig.2).

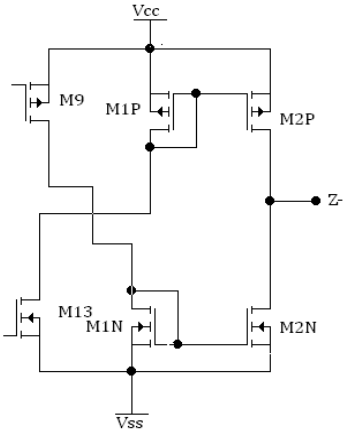


Fig. 2 Block circuit output current controlled conveyor transfer negative

A. Simulation Results of CCCII

The results are optimized by the size of transistors summarized in table I and II for a bias current I_0 of 120µA and a supply voltage of ±1V. These different schemes are simulated using Tspice based BSIM3v3 transistor model for the TSMC 0.18µm CMOS process available from MOSIS [20].

TABLE I
DIMENSIONS OF TRANSISTORS OF CLASSIC CCCII

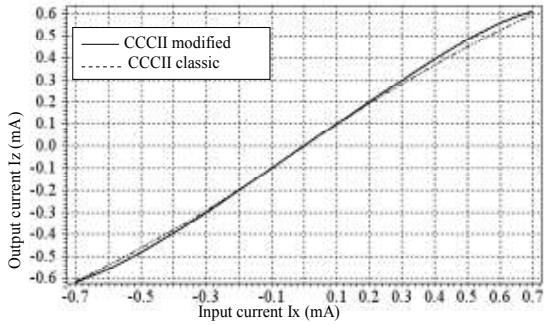
Transistors	W /L
M1, M2	60 µm /0.18 µm
M3, M4	90 µm /0.18 µm
M5, M6	20 µm /0.18 µm
M7	22 µm /0.18 µm
M8, M9	28 µm /0.18 µm
M10, M11	2 µm /0.18 µm
M12, M13	17 µm /0.18 µm

TABLE II
DIMENSIONS OF TRANSISTORS OF AMENDED CCCII

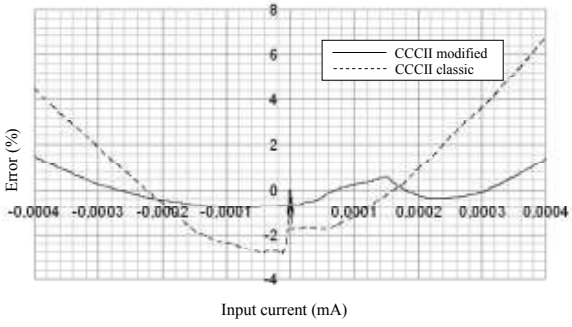
Transistors	W /L
M1, M2	60 µm /0.18 µm
M3, M4	90 µm /0.18 µm
M5, M6	20 µm /0,18 µm
M7	22 µm /0.18 µm
M8, M9	10 µm /0.18 µm
M10, M11	2 µm /0.18 µm
M12, M13	8 µm /0.18 µm
M14	22 µm /0.18 µm
M15	0.55 µm /0.18 µm
M16	12 µm /0.18 µm
M17	1.52 µm /0.18 µm

B. Simulation Static

The Fig.3.a represents the characteristic transfer of output current I_z according to Ix in the range ±0.7mA. The linearity error is shown in Fig.3.b. It does not exceed 0.8% in the range ± 0.35mA for the improved circuit. In contrast, the reference circuit, this error is much greater approximation of 5% over the same interval. The change in input resistance as a function of bias current I_0 is shown in Fig.4.



(a)



(b)

Fig. 3 (a) Variation of the output current Iz on function input current Ix (b) Variation of error as a function of input current

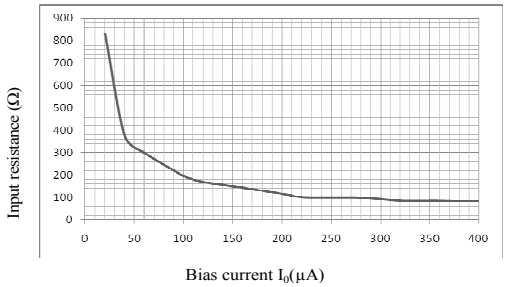


Fig. 4 Input resistance R_X as a function of bias current I_0

Fig. 5 shows the variation of the voltage Vx vs. voltage Vy. It shows a good linearity in the interval [-0.45V, 0.45V].

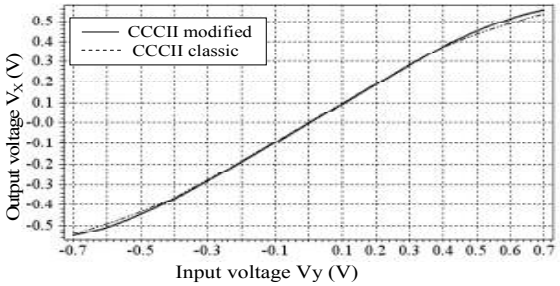
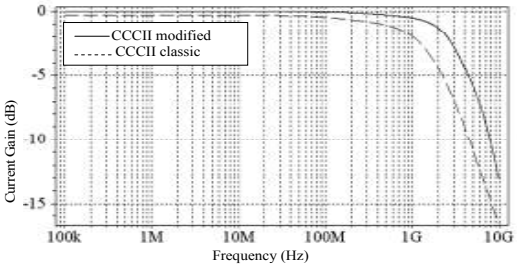


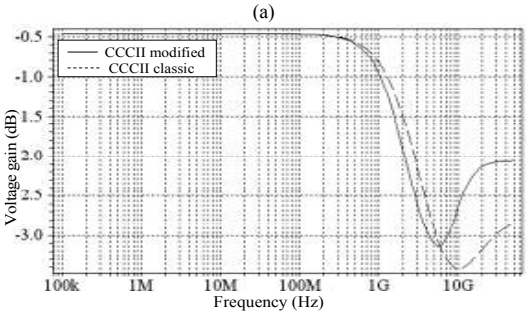
Fig. 5 Variation of output voltage Vx as a function of input voltage Vy

C. Simulation AC

Dynamic simulation is for a resisting load of 1kΩ. The frequency response of the current gain is shown in Fig.6.a. The bandwidth of the current gain at -3dB is 3.34GHz instead of 1.45GHz. Dynamic simulation mode voltage (Fig.6.b) gives a bandwidth of 4.37GHz and a static gain of 0.948. In Table 3, we have synthesized all the results of circuit simulation with the modified circuit of [8], [9], [11].



(a)



(b)

Fig. 6 (a) Current Gain as a function of frequency(b) Voltage gain as a function of frequency

TABLE III
SIMULATION RESULTS OF CIRCUIT CCCII

	Modified circuit	Classic circuit
Technology	0,18µm TSMC	0,18µm TSMC
Bias voltage (Vcc-Vss)	2V	2V
Voltage Gain	0.948	0.948
Current gain	1	0.97
Bandwidth current F_{CI}	3.34GHz	1.45GHz
Bandwidth voltage F_{cv}	4.37GHz	5.38GHz
Error voltage (±0.4V) (%)	1.5	2,3
Error current (±0.35mA) (%)	0.8	5.16
Input resistor R_x	169.32Ω	196Ω
Input Impedance (R_y//C_y)	5.67KΩ//164fF	8.12KΩ//149fF
Output impedance (R_z//C_z)	6.81KΩ//37.5fF	0.876KΩ//108.01fF
THD at 1 MHz @ 0.3mA	0.24%	0.86%
THD at 1 MHz @ 0.3V	0.41%	0.47%

III. Applications

A. Universal Filter

Circuit current conveyors are widely used in filtering applications. In recent years, several studies are have been made specifically to improve the universal filter [2]-[5], [21]-[31]. We will use three circuits current controlled conveyors multi-output (MOCCCII) (Fig.7) to achieve a universal filter current-mode [7].

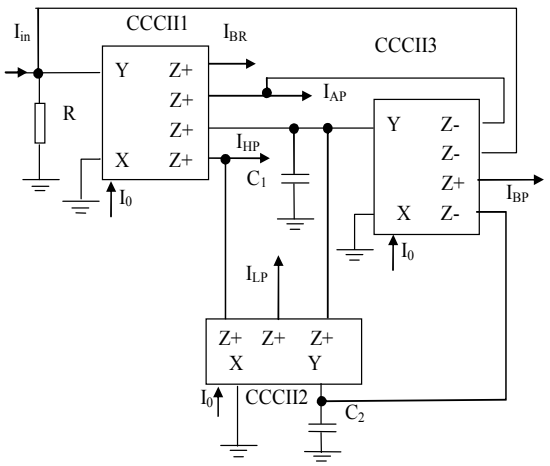


Fig. 7 Diagram of universal filter based on three MOCCCII

The transfer functions of the universal filter: Low-pass, High-pass, Band-pass, Notch and All-pass are given respectively by the following expressions

$$\frac{I_{LP}}{I_{in}} = \frac{R}{R_{x1}} \frac{\frac{-1}{R_{x2}R_{x3}C_1C_2}}{p^2 + p\frac{R}{R_{x1}R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \quad (9)$$

$$\frac{I_{HP}}{I_{in}} = \frac{R}{R_{x1}} \frac{p^2}{p^2 + p\frac{R}{R_{x1}R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \quad (10)$$

$$\frac{I_{BP}}{I_{in}} = \frac{R}{R_{x1}} \frac{p\frac{1}{R_{x3}C_1}}{p^2 + p\frac{R}{R_{x1}R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \quad (11)$$

$$\frac{I_{BR}}{I_{in}} = \frac{R}{R_{x1}} \frac{p^2 + \frac{1}{R_{x2}R_{x3}C_1C_2}}{p^2 + p\frac{R}{R_{x1}R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \quad (12)$$

$$\frac{I_{AP}}{I_{in}} = \frac{R}{R_{x1}} \frac{p^2 - p\frac{1}{R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}}{p^2 + p\frac{R}{R_{x1}R_{x3}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \quad (13)$$

The proper frequency (f_0) and the gain (G_0) of the current mode universal filter are given by the following terms:

$$f_0 = \frac{1}{2\pi\sqrt{R_{x2}R_{x3}C_1C_2}} \quad (14)$$

$$G_0 = R / R_{x1} \quad (15)$$

To confirm the theoretical results obtained, we have performed simulations based on CMOS technology Tspice with TSMC 0.18µm and with a voltage bias of ±1V. The bias currents of CCCII three circuits are equal to 120µA. The values of passive components used are C_1=C_2= 15pF and R=R_X. Subsequently, we have obtained a center frequency of 67,45MHz (Fig.8). In the contrast with the calculated theoretical value which is about 62.7MHz.

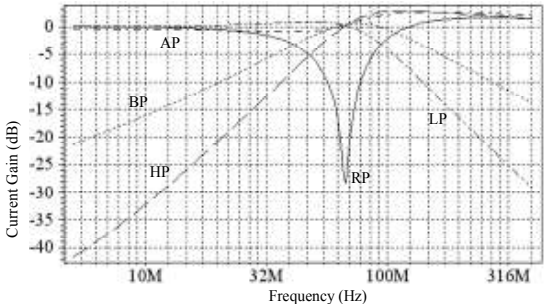


Fig. 8 Result of simulation of the module universal filter

The variation of f_0 based bias current I_0 is shown in Fig.9, with C_1= C_2=15pF.

Table IV shows the comparison of our results with other work on the current-mode universal filter.

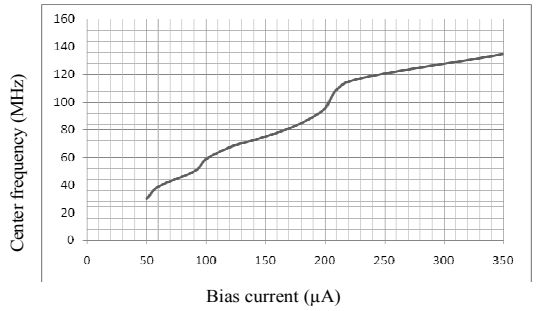


Fig. 9 Change in frequency as a function of bias current I_0

TABLE IV
COMPARISON OF RESULTS OF UNIVERSAL FILTER WITH OTHER WORK

Ref	*Information about the circuit*	*Numbers of active elements*	*Center frequency*	*Quality factor*
[2]	0.5µm CMOS Spice V_{CC}= -V_{SS}= 1.5V	4-DOICCII	10MHz	0.707
[3]	Rspice	3-MOCCCII	110KHz	1
[5]	0.35µm TSMC H-Spice V_{CC}=-V_{SS}= 1.65V	3-MOCCII	1.27MHz	1
Our results	0.18µm CMOS T-Spice V_{CC}= -V_{SS}=1V	3-MOCCCII	134.58MHz	1

B. Implementing an inductance

This problem has drawn the attention of many researchers. They have decided to make inductors based on active elements such as current conveyors, resistors and capacity. In this section, we present the creation of types of inductors, floating and related to ground, based on CCCII circuit modified.

1. Floating inductor

Scheme of a floating active inductor using four CCCII+ [33]-[35] is shown in Fig.10.

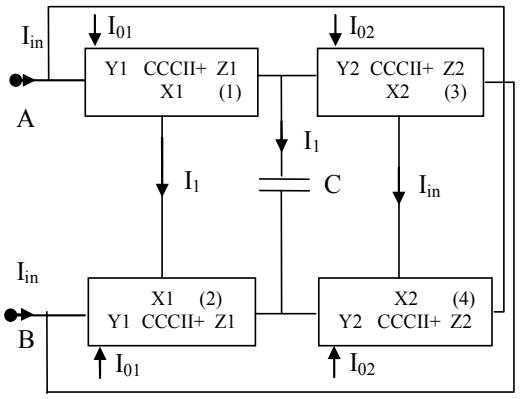


Fig. 10 Realization of floating inductance using four CCCII

The circuits CCCII 1 and 2 are biased by an identical current I_{01}, so that the capacitance C is covered by the same current. Similarly, the conveyor CCCII 3 and 4 are biased by I_{02} to have equal currents in A and B. R_{x1} is the parasitic resistance associated with the CCCII1 and 2 for the current I_{01}. Similarly, R_{x2} is the parasitic resistance associated with the CCCII3 and 4 for the current I_{02}.

$$V_{AB} = 2\,R_{x1} I_1 \tag{16}$$

$$V_1 = \frac{1}{pC} I_1 = 2\,R_{x2} I_{in} \tag{17}$$

$$V_{AB} = p(2R_{x1})(2R_{x2})C\,I_{in} \tag{18}$$

$$L = (2R_{x1}) \times (2R_{x2})C \tag{19}$$

2. Inductor connected to ground

Subsequently, based on [33]-[37], we have introduced another inductor based two current conveyor, one with positive transfer and the other with negative transfer and capacity.

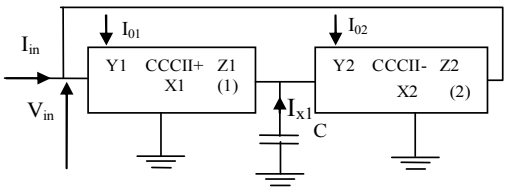


Fig. 11 Realization of an inductor connected to ground

The implementation of this inductance is illustrated in Fig.11. Taking into account the presence of parasitic resistors R_{x1} and R_{x2}:

$$V_{in} = V_{x1} = -R_{x1} I_{x1} \tag{20}$$

$$V_{y2} = V_{x2} = \frac{-1}{jC\omega}\, I_{x1} = R_{x2}\, I_{in} \tag{21}$$

According to equation (21), we have:

$$I_{x1} = -jR_{x2} C\omega\, I_{in} \tag{22}$$

The confusion of two expressions (20) and (22) gives:

$$V_{in} = j\; R_{x1}\, R_{x2} C\omega\, I_{in} \tag{23}$$

The input impedance is given by the following expression:

$$Z_{in} = \frac{V_{in}}{I_{in}} = j\; R_{x1}\, R_{x2} C\omega \tag{24}$$

It is equivalent to an inductance L for:

$$L_{eq} = R_{x1}\, R_{x2} C \tag{25}$$

3. Simulation results

In both structures, we have minimized the number of circuits used. We have used only the conveyors current to single output and only one capacity.Both inductors have an operating frequency zone and L values vary with bias current I_0. At each change in bias current I_0, we have found the area of operation frequency with an accuracy of ± 5 degrees of phase (table 5).

TABLE V
THE VALUES OF INDUCTORS ACCORDING TO THE BIAS CURRENT I_0

	Inductance connected to ground		Floating inductance	
I_0 (μA)	Frequency (MHz)	L(μH)	Frequency max (MHz)	L (μH)
10	98.56-120.46	0.2830	24.07	0.0705
20	120.36-152.11	0.1410	45.66	0.0804
30	135.31-181.31	0.0844	66.99	0.0882
60	177.8-238.25	0.0270	170.42	0.102
80	216.1-295.27	0.0155	172	0.1025
90	220.36-301.1	0.0161	184.93	0.104
100	242.9-301.1	0.0158	212.32	0.1035
120	252.6-325.5	0.0092	252.93	0.107
130	266.77-334.07	0.00924	300.61	0.109
140	273.18-338.32	0.00775	305.14	0.11
150	276.03-345.92	0.00785	311.53	0.1090
160	287.35-361.94	0.00777	315.5	0.1086
180	301.33-373.58	0.00629	316.96	0.1082
200	324.22-401.35	0.00504	728.62	0.117
220	329.39-409.4	0.005	701.46	0.1168
250	344.7-423	0.0036	719.46	0.144
280	354.42-436.6	0.00358	726.11	0.1132
300	361.86-439.2	0.00357	731.14	0.1124
320	363.36-440.5	0.0035	1180	0.116
350	376.2-456.78	0.003	1200	0.115

C. Sinusoidal Oscillator

We have given the importance of oscillators in the field of signal processing; many researchers have proposed many structures to improve their frequency performance, low power and low voltage. The proposed oscillator circuit based on an operational amplifier is shown in Fig.12.

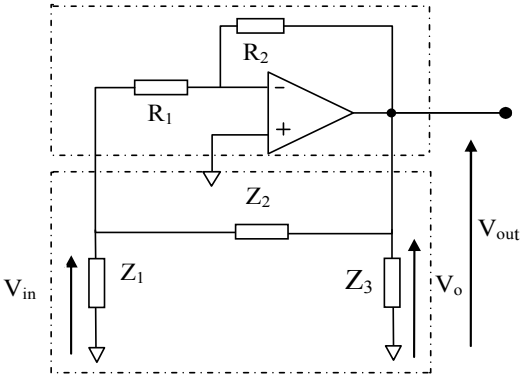


Fig.12 Implementation of an oscillator

Based on the equivalent circuit, the network reaction has as input impedance:

$$Z_{in} = Z_3 /\!/ (Z_2 + Z_1) = \frac{Z_3 (Z_2 + Z_1)}{Z_1 + Z_2 + Z_3} \quad (26)$$

The transfers function of the amplifier:

$$H = \frac{V_o}{V_{in}} = \frac{A_0 V_{in} \dfrac{Z_{in}}{Z_{in} + R_s}}{V_{in}} = \frac{A_0 Z_{in}}{R_s + Z_{in}} \quad (27)$$

With A_0: The gain of the direct chain. ($A_0 = -\dfrac{R_2}{R_1}$).

R_s: The output resistance characteristic of the amplifier.

The transfer function of the chain reaction is given by

$$K = \frac{V_{in}}{V_o} = \frac{Z_1}{Z_1 + Z_2}$$

According to the Barkhausen condition $H \times K = 1$.

We have:

$$A_0 Z_3 Z_1 = R_S (Z_1 + Z_2 + Z_3) + Z_3 (Z_2 + Z_1),$$

With $Z_i = j X_i$, $i = 1,2,3$

The oscillation condition becomes;

$$-A_0 X_3 X_1 = jR_S (X_1 + X_2 + X_3) - X_3 (X_2 + X_1)$$

In our case $A_0 < 0$, by identifying:

$A_0 X_1 = -X_3$, X_1 and X_3 have the same sign as in both similar components

$X_1 + X_2 + X_3 = 0$, the second condition requires X_2 component of a different nature.

Based on some work [38]-[40], we have transformed the oscillator circuit of Fig.12 based conveyor CCCII as shown in Fig.13. This figure shows two types of oscillators: the first based on an inductor connected to ground (Fig.13.a) and the second based on a floating inductance (Fig.13.b). We used the same reactors studied previously.

A basis of an inductor connected to ground, this circuit has an oscillation frequency and gain:

$$f_0 = \frac{1}{2\pi \sqrt{(L_1 + L_2).C}} \quad (28)$$

$$A_0 = -\frac{L_2}{L_1} = -\frac{R_2}{R_1} \tag{29}$$

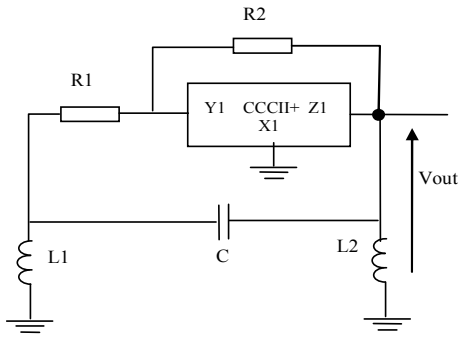
A basis of a floating inductor, the circuit has an oscillation frequency and gain:

$$f_0 = \frac{1}{2\pi\sqrt{\frac{C_1 C_2}{C_1 + C_2} L}} \tag{30}$$

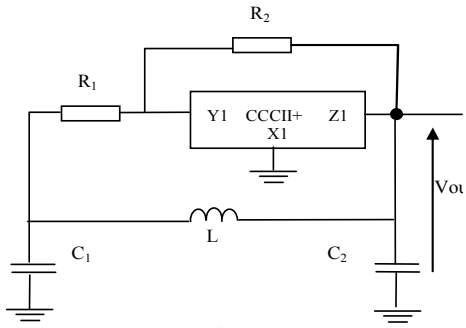
$$A_0 = -\frac{C_1}{C_2} = -\frac{R_2}{R_1} \tag{31}$$

We performed simulations with a supply voltage of ± 1V. The choice of components is as follows: C = 100nF to the first circuit and $C_1 = C_2 = 0.1$ pF for the second with the condition R2 = 10 R1. By the current variation of I0 [80µA, 350µA], we obtained an oscillation frequency variable [358MHz, 572MHz] and [470MHz, 694MHz], respectively the first and second circuit (Fig.14)

For a bias current $I_0 = 120\mu A$, the signal of the oscillator is shown in Fig.15

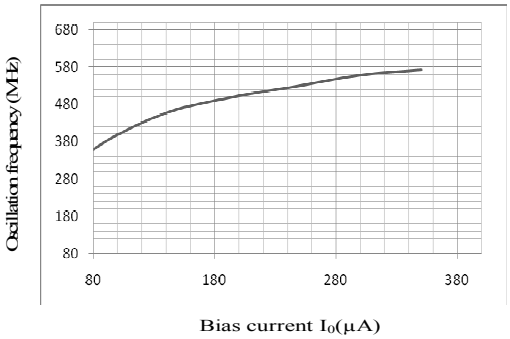


(a)

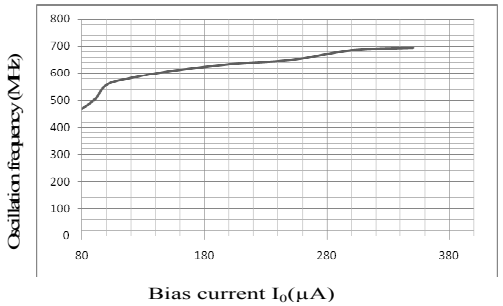


(b)

Fig. 13 Implementation of two oscillator circuit based on CCCII (a). a basis of an inductor connected to ground(b). a basis of a floating inductor

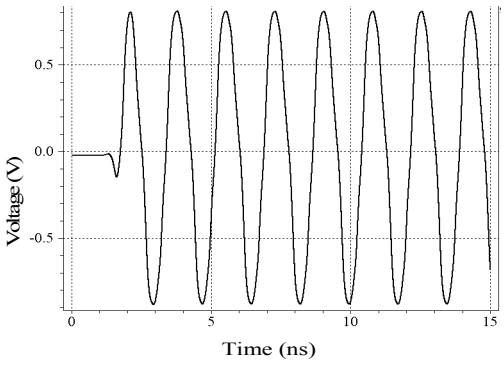


(a)

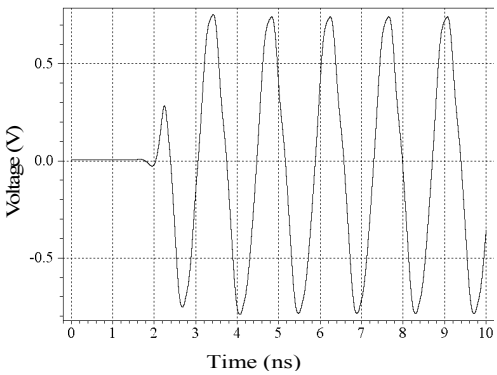


(b)

Fig. 14 Frequency of the oscillator based on current I_0(a). A basis of an inductor connected to ground(b). A basis of a floating inductor



(a)



(b)

Fig. 15 Output signal of the oscillator(a). A basis of an inductor connected to ground(b). A basis of a floating inductor

IV. Conclusion

In this paper we have made several improvements to the circuit current conveyor CCCII controlled using current mirrors with low supply voltage. This circuit operates at low supply voltage of ± 1V and present to a bias current of 120μA, a bandwidth of 3.34GHz and 4.37GHz respectively in current mode and voltage mode for expenses and a 1kΩ parasitic resistance Rx of 169.32 Ω. Based on this circuit, we have implemented first a universal filter, current mode. The frequency can reach the 134.58MHz. In the second, we have implemented two inductors, one floating and the other tied to ground, operating in high frequency and variable depending on bias current I0. We have used the last two, respectively, to implemented two sinusoidal oscillators frequency one [358MHz, 572MHz], second [470MHz, 692MHz] for bias currents I_0 [80μA, 350μA].

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