Performance Evaluation of Electronically Tunable Filter Using CCCII in 45nm CMOS Technology for Wi-Fi Applications

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Abstract: *Second generation Current Controlled Current conveyors are getting compelling recognition due to their AC performances with better linearity, high sensitivity, wider and nearly constant bandwidth, high slew rate, reduced supply voltage (nearly 0.5V), less chip area and larger dynamic range. CCCIIs are electronically tunable i.e. its parasitic resistance at current input port can be adjusted by an input bias current making it useful for wide range of applications. This paper presents an approach of designing a universal filter using CCCII as its active building block. Filter has been tuned for Wi-Fi applications and realised in 45nm CMOS technology while performances were examined through HSPICE simulations.*

Keywords: CCCII+, CCCII-, CCCII±, Electronic tunability, Universal filter

1. Introduction

A versatile current mode circuit, commonly known as Current Conveyor gains acceptance as theoretical as well as practical building block. Current Conveyor consists of one high and one low impedance input and one high impedance output ; hence, acts as an apt element for both voltage mode and current mode circuits. The classical op-amps suffer from confined gain- bandwidth product and low slew rate. Therefore, they remain undesirably at higher frequencies.

Nowadays supply voltage has become a severe concern in electronic circuit design scenario specifically for portable and battery efficient equipment and the breakdown voltage of short channel MOS transistors. Because of the increasing importance of low voltage operating circuit, current mode techniques are more convenient for such purposes as compared to voltage mode circuits. As a result of it, current mode circuits are becoming more popular and vital due to their huge dynamic range, higher bandwidth, greater linearity, simple circuitry, less power consumption and reduced chip area in comparison with their voltage mode counterparts such as Operational Amplifiers. Of late years, with advent of CMOS technology, current mode devices are gaining considerable significance in circuit designs.

2. Description of Current Controlled Current Conveyor

Fig 1. depict the symbol of the second generation CCCII. A CCCII based circuit, no matter whether positive, negative or dual output, gives electronic tunability and wide adjustable range of its parasitic resistance at X-terminal. Since CCCII doesn't require external resistors, therefore, it is very appropriate in the designing of integrated filters and oscillators. Moreover, as the CCCII is current controlled source, the CCCII based circuit is acceptable for high frequency operation.
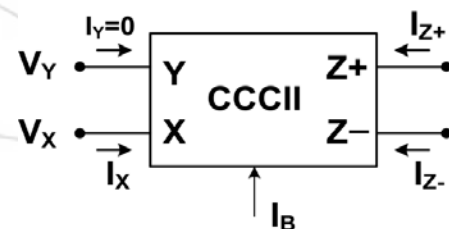

Figure 1: Symbol of CCCII

Circuit designers are lured by these interesting characteristics of CCCII. The following matrix depicts the relationship between the voltage and current variables at input and output ports X, Y and Z of the CCCII,

$$\begin{vmatrix} V_X \\ I_Y \\ I_Z \pm \end{vmatrix} = \begin{bmatrix} R_X & 1 & 0 \\ 0 & 0 & 0 \\ \pm 1 & 0 & 0 \end{bmatrix} \begin{vmatrix} I_X \\ V_Y \\ V_Z \end{vmatrix}$$

where the sign ± refers to plus type and minus type CCCII respectively and Rx stands for intrinsic resistance at X terminal. Rx is tunable by a supplied bias current Ib which can be expressed through a class AB translinear loop commonly used as input section, where

$$R_X = \frac{1}{2 g_m} = \frac{1}{\sqrt{8 \beta_n I_b}}$$

where, $\beta_n = \mu_n C_{ox} \dfrac{W}{L}$ is the physical parameter of the MOS transistor.

3. CMOS implementation of CCCII

The schematics of standard CMOS implementation of positive, negative and dual output CCCII are given by Fig 2, 3 and 4 respectively. Since both in common source and

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common gate amplifier configurations, the output signal is a current, hence MOS transistors are more suitable particularly for processing current rather than voltages. On the contrary, common drain amplifier configurations are almost useless at low supply voltages because of the bulk effect embedded in typical CMOS processes. Additionally, MOS current mirrors are more accurate and less sensitive to process variation rather than bipolar current mirrors because with the latter, the base currents reduce the accuracy.

Thus, MOS transistor circuits should be simplified by using current signals as compared to voltage signals. In case when the signal is conveyed as a current, the voltages in MOS – transistor circuits are proportional to the square root of the signal provided saturation region operation is assumed for the devices. Consequently, a compression of voltage signal swing and a reduction of supply voltage is possible. Moreover, maximum usable frequency of MOS will be achieved sooner with very high values for its drain currents.

Fig 2 shows the circuit which comprises of one mixed trans-linear loop(transistors M1 to M4) as input cell. Two current mirrors(transistors M5, M6 and M8, M9) allow the mixed loop to be dc biased by the current Ib. The input cell present a high level impedance input port Y and a low impedance input port X which acts as a voltage follower. The output Z that copies the current flowing through port X is achieved in the traditional manner using two complementary current mirrors.

As shown in Fig 3, current mirrors are build up of M11, M12 and M15, M17 and M14, M16 and M10, M13 are cross coupled to generate negative current at Z. On the other hand, current mirrors in Fig 4 generate both types of output.

For implementation of the filter, the class AB type CCCII± circuit adopted is shown in Figure 4, and is readily available in literature. It's bipolar version containing both positive as well as negative output terminal has been studied by many authors, [12, 13]. It's CMOS version can be found in the references [5, 10]. In the present work, this circuit is redesigned in 45 nm CMOS technology and is simulated and verified using HSPICE [14].
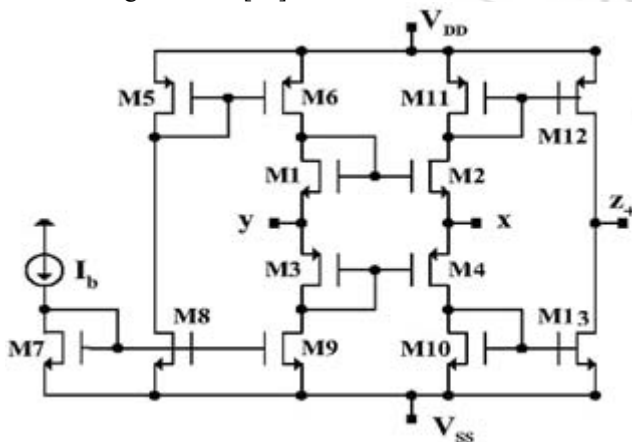

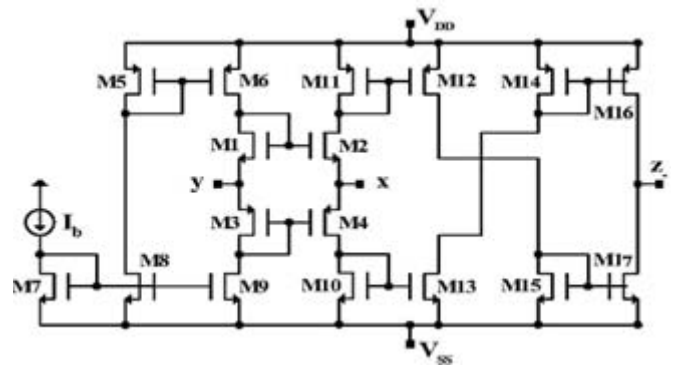**Figure 2:** CMOS based circuit of CCCII+
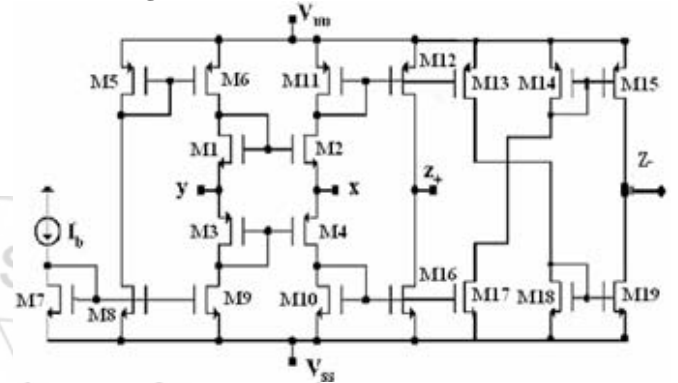

Figure 3: CMOS based circuit of CCCII-

Figure 4: CMOS based circuit of CCCII±

4. Analysis of CCCII

Fig. 5, 6, and 7 show the transient, AC and DC analysis of CCCII± respectively. Vdd/Vss is set to 0.54V and biasing current is 10μA.Transient analysis has been carried out with 100 MHz sinusoidal input, for which the current relationship equation i.e., Iz=+Ix, Iz=-Ix and Iz=±Ix is successfully verified.
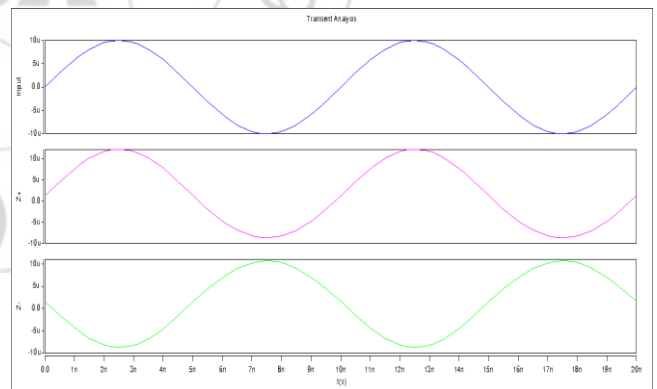

Figure 5: Transient analysis of DOCCCII

AC analysis for the CMOS-based CCCII± reveals excellent conformity between the input current (Ix) and the output current (Iz) and the bandwidth came out to be 28.9 Ghz. DC analysis has also been done to find the linearity between input and output ports. So in this way CCCII± verified the current relationship equation i.e. Iz=+Ix, Iz=-Ix and Iz=±Ix respectively.
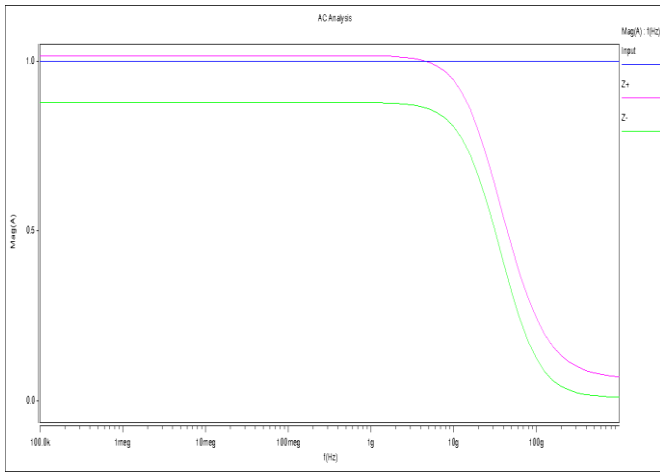
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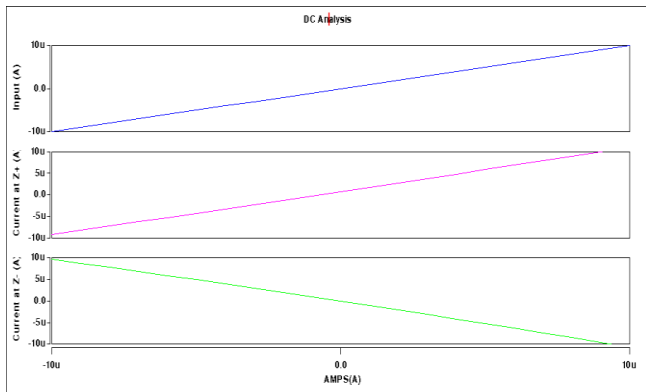
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Figure 6: AC analysis of DOCCCII

Figure 7: DC analysis of DOCCCII

4.1 Performance Comparison at different Technologies

Performance analysis of CCCII± has been done at 180nm, 90nm and 45nm CMOS technology. Power supplies, bias currents and the obtained 3-dB bandwidth are compared in Table 1.

It is observed that as there is improvement in technology from 180nm to 45nm, biasing current decreases from 30u to 10u. Supply voltage is also reduced to 0.45V which shows that CCCII± at 45nm is power efficient as well. 3-db bandwidth increases from 5.4 Ghz to 29.8 Ghz which shows that it is very suitable for high frequency applications and due to its excellent electronic tunability property (shown in fig. 8) its frequency can be set to a specific application based frequency (for eg. 2.4 Ghz in case of Wi-Fi).

Table 1: Performance Comparison at different technologies

	180nm	**90nm**	**45nm**
I_b	30μ	18μ	10μ
Vdd/Vss	±0.72 V	±0.54 V	±0.45 V
Bandwidth	5.4 Ghz	12.8 Ghz	29.8 Ghz

5. Application as a Universal filter

CCCIIs are broadly used as fundamental active building blocks to realize various current-mode active filters. The universal filter is one of the most popular analog filters as it can provide various standard functions like low pass, high pass, band pass, band reject and all pass.

In this section, a current mode universal filter has been implemented with single input and three different outputs for low, high and band pass filters. Implementation of Universal filter is depicted in Fig.8 using only two CCCII± and two capacitors as the dual-output current conveyors are useful in the derivation of current-mode single input and three output filters using a decreased number of active components [8, 9, 10].

The analysis i.e. transfer function of the Universal filter can be summarized as follows:

$$\frac{I_{HP}}{I_{in}} = \frac{(-s^2)}{\left(s^2 + \frac{s}{R_{X1}C_1} + \frac{1}{R_{X1}R_{X2}C_1C_2}\right)} \tag{1}$$

$$\frac{I_{LP}}{I_{in}} = \frac{(-1/R_{X1}R_{X2}C_1C_2)}{\left(s^2 + \frac{s}{R_{X1}C_1} + \frac{1}{R_{X1}R_{X2}C_1C_2}\right)} \tag{2}$$

$$\frac{I_{BP}}{I_{in}} = \frac{(s/R_{X1}C_1)}{\left(s^2 + \frac{s}{R_{X1}C_1} + \frac{1}{R_{X1}R_{X2}C_1C_2}\right)} \tag{3}$$

In addition to this, the response of band-pass i.e. notch filter can be obtained by connecting $I_{HP \& } I_{LP}$ together as follows:

$$\frac{I_{BR}}{I_{in}} = \frac{-(s^2 + 1/R_{X1}R_{X2}C_1C_2)}{\left(s^2 + \frac{s}{R_{X1}C_1} + \frac{1}{R_{X1}R_{X2}C_1C_2}\right)} \tag{4}$$

In the same way, all pass filter transfer functions can be implemented by connecting I_{HP}, $I_{LP,}$ I_{BP} together or I_{BR} and I_{BP} together as follows:

$$\frac{I_{AP}}{I_{in}} = \frac{-(s^2 - s/R_{X1}C_1 + 1/R_{X1}R_{X2}C_1C_2)}{\left(s^2 + \frac{s}{R_{X1}C_1} + \frac{1}{R_{X1}R_{X2}C_1C_2}\right)} \tag{5}$$

Table 2: Comparison between different filters

	High pass	**Low pass**	**Band pass**
Peak frequency	10.2 Ghz	850 Mhz	3.16 Ghz
Bandwidth	8.6 Ghz	4.8 Ghz	2.82 Ghz
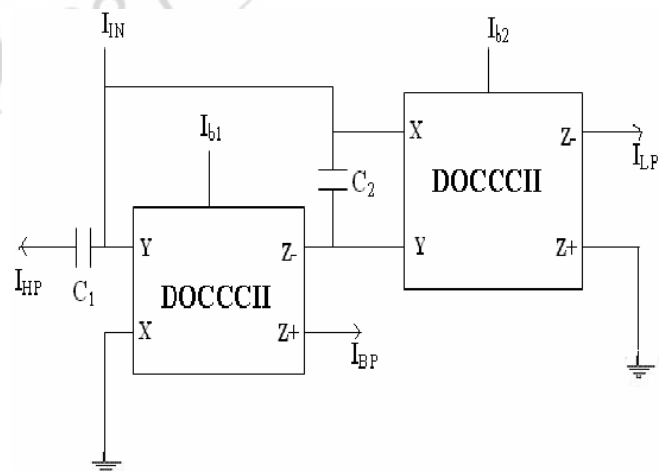
Figure 8: Universal filter using DOCCCII

The natural frequency ω_0, the bandwidth $\frac{\omega_0}{Q}$ and the quality factors are given as below:

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$$\omega_0 = \left(1/R_{x1}R_{x2}C_1C_2\right)^{1/2} \qquad (6)$$

$$\omega_0/Q = 1/R_{x1}C_1 \qquad (7)$$

$$Q = \left(R_{x1}C_1/R_{X2}C_2\right)^{1/2} \qquad (8)$$

The above mentioned equations clearly indicate that $\frac{\omega_0}{Q}$ & ω_0 can be adjusted by the bias currents of I_{b1} and I_{b2} of the respective ±CCCII. Transmission of universal filter is given by –

$$T(s) = \frac{(a_2 s^2 + a_1 s + a_0)}{s^2 + \frac{\omega_0}{Q}s + \omega_0{}^2} \qquad (9)$$

In this implementation, a_2 a_1 & a_0 are 1, $1/R_{x1}C_1$ and $\omega_0{}^2$ respectively.

For the successful implementation of universal filter, the following values of capacitors & bias currents have been used.

$$C_1 = C_2 = 5fF$$
$$I_{b1} = I_{b2} = 1u$$

Fig. 9 shows the adjustability in low pass filter as its response in changing with the variation in bias currents. This also shows how good CCCII acts as an electronically tunable active building block. Fig 10, 11 and 12 depict frequency responses for low and high, notch filter and band pass filter respectively. After simulation with HSPICE using 45nm CMOS parameters, we get the following conclusions.
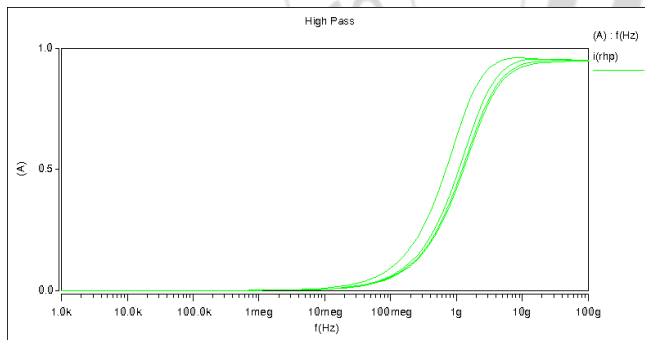

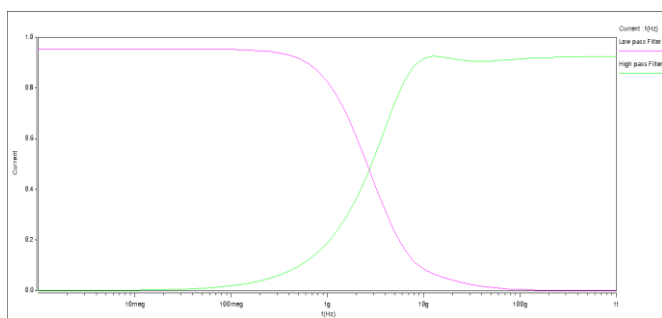**Figure 9:** High pass filter response with variation in bias current

Figure 10: Frequency response of high pass and low pass filter
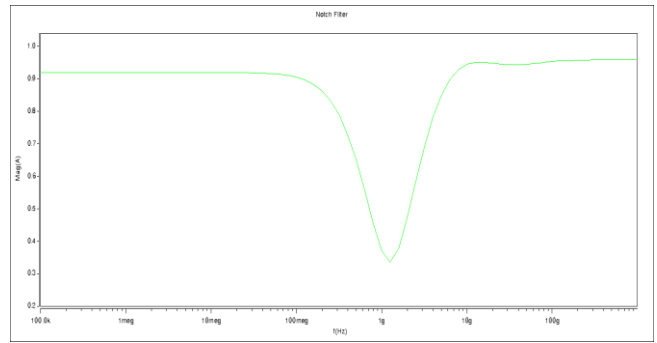

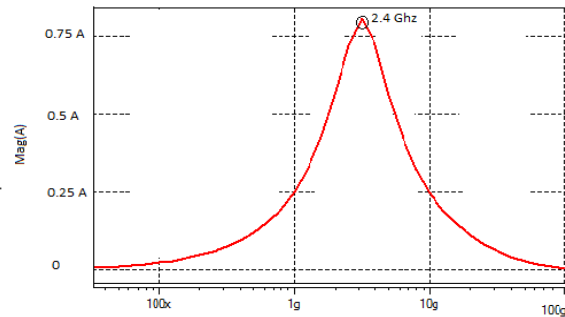**Figure 11:** Frequency response of notch filter

Figure 12: Frequency response of band pass filter

Results are showing good response and resemblance with the expected values. Now band pass filter has been tuned at 2.4 Ghz frequency so that it can be used for Wi-Fi applications.(Fig. 12).The values of capacitors are varied in accordance to the desired frequency.

6. Conclusions

In this paper, Second generation Current Controlled Current conveyor is implemented using the 45nm CMOS technology. The circuit uses ±0.45V DC supply and 10uA of biasing current. Transient, AC and DC analysis are carried out using HSPICE tool. The simulation results indicate the correct operation of the CCCII± circuit up to 38 GHz. A current mode universal filter is then implemented that employs CMOS-based CCCII± and capacitors. The filter can be configured to obtain three different outputs- low-pass, high-pass and band-pass and by further updates band reject and all pass filter can also be made. The HSPICE simulation results confirmed the suitability of the current-mode universal filter for operation in the 2.4 GHz band used by Wi-Fi standard. Thus the filter is suitable for the Wi-Fi applications. The CCCII± can be used as an active building block in the designing of various analog circuits such as oscillators, rectifiers, instrumentation amplifiers etc.

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