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Electronically Tunable Sinusoidal Oscillator Using Only Single Current-Controlled Current Conveyor Trans-Conductance Amplifier

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ABSTRACT- This work presents a wide frequency range sinusoidal oscillator design that relies on only one active component, a current-controlled current conveyor trans-conductance amplifier, and a few passive components. It just employs two grounded and non-floating capacitors and one resistor to complete the procedure. This design has the advantage of allowing the oscillation frequency and condition to be adjusted not only electronically, but also separately, without affecting the values of any passive components. To verify the functionality and usefulness of the developed sinusoidal oscillator circuit, ORCAD PSPICE simulations are done using 0.18um process parameters for complementary metal oxide semiconductor technology. The obtained results demonstrate its application to a wide range of frequency generation without the need for additional components, hence validating the theoretical expectation.

Keywords: Current mode, current conveyor, sinusoidal oscillator, transconductance amplifier, frequency of oscillation.

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1. INTRODUCTION

This sinusoidal oscillator uses the current conveyor transconductance amplifier (CCTA), which was initially developed in 2005 [1]. Since then, other studies [2-8] have offered a variety of implementation choices for the CCTA block based on bipolar junction transistor (BJT), complementary metal oxide semiconductor (CMOS), or bipolar complementary metal-oxide semiconductor (BiCMOS) technology. This device's versatility has resulted in its ongoing recognition, as indicated by the numerous analog circuit functions that have been built using it [5-12]. To demonstrate its usefulness, the literature proposed multifunction filters [5], direct frequency modulator [6], shadow universal filters [8], memcapacitor emulator [9], differentiator and integrator [10], PID Controller [11], squaring and square-rooting circuits [12], and oscillator [14-25] using CCTA.

This CCTA block is simply constructed by connecting the output of a second-generation current conveyor (CCII) to the input of a trans-conductance amplifier that has both positive and negative polarities available at its output terminal. Because CCTA contains CCII and an operational trans-conductance amplifier (OTA), it possesses the characteristics of both the current conveyor and the transconductance amplifier. This is the reason for its relatively high slew rate and wider dynamic range. Furthermore, it offers a wider bandwidth and consumes less power than similar devices. Because of these qualities, CCTA is appropriate for a variety of analog signal generation and processing applications.

The sinusoidal oscillator is an essential part of every modern electronic or communication system. The majority of sinusoidal oscillator circuits reported so far have either a higher number of floating or grounded passive components or more than one active element. Because there are more elements, the size expands and so takes up more space on the chip. In most situations, the available work fails to offer electronic controllability to their critical parameters, and even when it does, independent control over oscillation state and frequency is frequently missing.

The suggested sinusoidal oscillator consists of an innovative current-controlled CCTA (CCCCTA), two grounded capacitors, and a single grounded resistor. In this proposed design, the frequency (FO) and condition (CO) of the oscillation can both be independently controlled and it is appropriate for integration due to the utilization of all grounded as well as the smallest number of active components. This circuit is validated using the PSPICE model of the CCCCTA with dual-mode outputs.

Our work is provided in the following format: *Section 2* discusses the fundamentals of current-controlled CCTA, including its features and transistor-level implementation, as described in [7]. *Section 3* explores the suggested CCCCTA-based sinusoidal oscillator, while *Section 4* examines the simulation results, performance comparison, and discussion. *Section 5* contains closing remarks as well as prospects.

2. CURRENT CONTROLLED CCTA

The fundamental symbol for the CCTA element and a model illustrating its behavior are depicted in *figures 1(a)* and *(b)*. The input stage of the CCTA includes a CCII module that is further connected with an OTA. Output current obtained at the ‘*z*’ terminal of the conveyer is passed to an outside load to convert it into a voltage at the same terminal. This voltage then serves as the input of the operational trans-conductance amplifier and according to the value of potential obtained at the input terminal, the trans-conductance amplifier provides a dual output current at its output terminals with both positive and negative polarities.

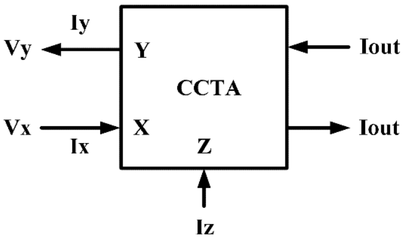


Figure 1(a): Symbolic depiction of basic CCTA

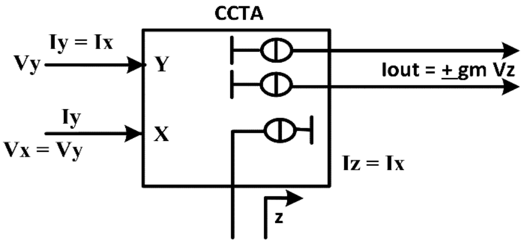


Figure 1(b): Behavioral depiction of basic CCTA

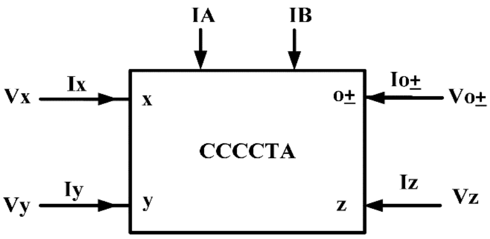


Figure 2(a): Basic block of CCCCTA

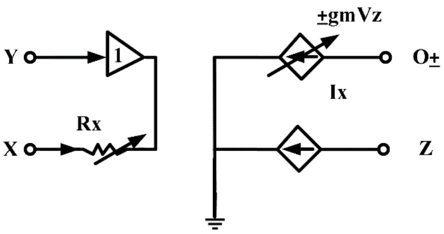


Figure 2(b): Equivalent behavioral representation of CCCCTA

Figure 2(a) and *(b)* represent the basic block of this current-controlled CCTA and its equivalent circuit depicting its behavior. The following matrix describes the property and hence the basic functionality of the CCCCTA:

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \\ I_{out\pm} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & \mathrm{R_X} & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & \pm \mathrm{g_m} & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \\ V_{out\pm} \end{bmatrix} \tag{1}$$

where g_m is the trans-conductance and R_X is the parasitic resistance of CCCCTA. The value of both can be set and changed easily just by changing the value of the input bias current I_B and I_A respectively.

Many authors have proposed the structure of CCTA, which is summarized in [13]. Most of these circuits consist of BJT-based structures of CCTA or BiCMOS-based. The CMOS implementation of the conventional CCCCTA [7] is depicted in *figure 3*. This circuit implementation has a mixed trans-linear loop (M_1-M_4) which is DC-biased with the help of current mirrors (M_5-M_7 and M_{10}-M_{11}). Transistors (M_8-M_9 and M_{12}-M_{13}) transfer the intermediate output at the z-terminal, which is generated, from the x-terminal current. Transistors (M_{14}-M_{17}) create the OTA section. This OTA's transconductance gain can be adjusted using I_{B2}.

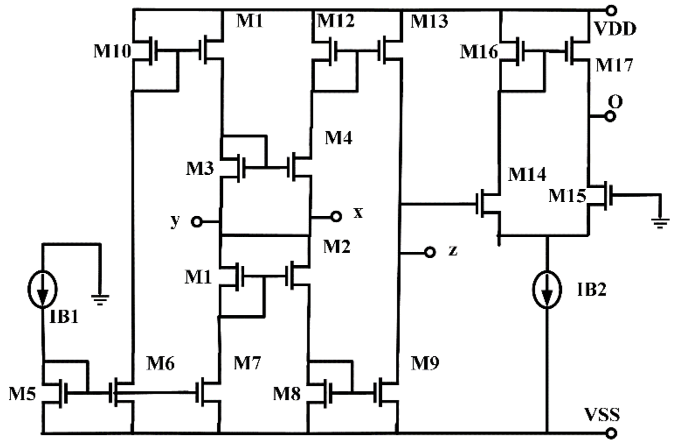


Figure 3: CMOS-based CCCCTA structure [7]

Many researchers have suggested the design of a sinusoidal oscillator using basic active elements like CCII, CCTA, current differential trans-conductance amplifier (CDTA), and operational trans-resistance amplifier (OTRA), etc. to date [5-6, 14-25]. The implementations using CCTA are generally based on existing BJT-based CCTA or BICMOS. MOS-based current-controlled CCTA design was also used to implement a sinusoidal oscillator with the current tuning capability [14], but it lacks features as it has only a single output terminal that can provide only one polarity. A BiCMOS-based implementation of the oscillator was offered in [15], while [16] presented a CCII-based single resistance-controlled oscillator with five passive components in total with tunability given by only one passive resistor. A single resistance-controlled oscillator with five passive components that was based on OTRA and was not electrically controllable was described in [17]. Four passive components and two CCII were used in the sinusoidal oscillator design in [18], while a total of three CDTA elements with three passive components were used in [19]. Four passive components are utilized in the OTRA-based design that was proposed in [20], whereas six passive components are employed in [21]. The VDCC-based sinusoidal oscillator proposed in [22] and the VCII-based sinusoidal oscillator proposed in [23] both included a significant number of passive components, whereas the CCTA-based oscillator proposed in [24] is incapable of providing independent electronic tuning and cannot be used to generate a wide range of frequencies. In contrast to previous investigations, the proposed design incorporates only one CCCCTA and three grounded passive components, which is a substantial reduction in complexity. A comparable number of components are employed in [25], but it does not provide the broad range of frequency that we provide in the present research. Furthermore, FO can be electronically shifted by adjusting the bias current I_B.

3. PROPOSED DESIGN

In the proposed design as shown in *figure 4*, dual current outputs are available and both can be utilized. This CCCCTA structure is a modified version of [7] with the first half portion implementing the current conveyor section in the same manner as the previous one, but it also includes a z-copy terminal that can include more functionality in the circuit. Further, a dual OTA structure is used here to provide output currents in both directions along with z-copy terminal z_c.

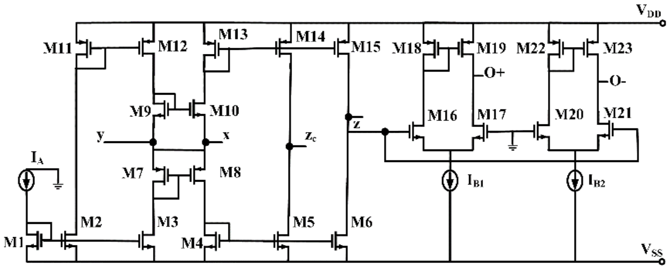


Figure 4: Proposed CCCCTA implementation using CMOS

Current I_A is passed via the current mirror section transistor M_1 and M_2-M_3 and then a set of transistor pairs M_{11}-M_{12} are used for the current biasing of the circuit. Transistors M_7, M_8, and M_9, M_{10} form the buffer section of the conveyor such that the same voltage is produced at the x-terminal as that provided at the y-terminal. Then the current mirror action of transistors M_{13}, M_{14}, and M_4, M_5 copies the current at terminal '*x*' that appears at terminal '*z*'. The same current is obtained at the z-copy terminal due to the transistors M_{15} and M_6. M_{16} to M_{19} and M_{20} to M_{23} follow the trans-conductance amplifier action and produce an output of both polarities at the output terminals. The current I_{B1} and I_{B2} biases the two OTAs of the structure and control its trans-conductance.

The dimensions of all the transistors used to design this CCCCTA are mentioned in *table 1*. The dimensions are taken such that the transistor sizes do not vary a lot and hence area will be minimized during chip fabrication and its floor planning. With a supply voltage of 1 volt and transistor sizes listed in Table 1, the transconductance for this CCTA's OTA section is 510 µS, with a 3-dB bandwidth of 286 MHz.

Table 1. Aspect ratios of the transistors used in the design

Transistors	W/L Ratio (µm)
M_1-M_6, M_9-M_{10}, M_{16}-M_{17}, and M_{20}-M_{21}P-R interval	12/1
M_7-M_8, and M_{11}-M_{15}, M_{18}-M_{19}, and M_{22}-M_{23}	10/1

To find the input impedance at the '*x*' terminal in *figure 4*, a current source I_i can be applied at the same, and then using simple mathematical analysis, the input resistance is found as:

$$R_x = \frac{1}{(g_{m10} + g_{m8})} - \frac{I_A}{I_i\,(g_{m10} + g_{m8})}\left(\frac{g_{m8}}{g_{m7}} - \frac{g_{m10}}{g_{m9}}\right) \tag{2}$$

where I_A is the current used for biasing the transistors and I_i is the applied input current. It indicates that the parasitic resistance is a function of the I_A and hence by varying its value R_x can be changed accordingly. This equation can further be simplified by taking the value of trans-conductance, such that $g_{m8} = g_{m10} = g_{mA}$ and $g_{m7} = g_{m9}$, then the *equation (2)* reduces to:

$$R_x = \frac{1}{2\,g_{mA}} \tag{3}$$

This means that the input resistance R_x can be adjusted and modified solely using the input bias current I_A, as the device's g_m is directly proportional to the square root of the current I_A that passes through it.

The output current of each OTA for the configuration depicted in *figure 4* to the input voltage appearing at one of its terminals (V_z) and another terminal grounded is derived as:

$$I_o = \left(\frac{g_{m19}}{g_{m18}} + \frac{(g_{m17}\,g_{m18} - g_{m16}\,g_{m19})}{g_{m18}\,(g_{m16}+g_{m17})}\right) g_{m16}\,V_z - I_B \left(\frac{(g_{m17}\,g_{m18} - g_{m16}\,g_{m19})}{g_{m18}\,(g_{m16}+g_{m17})}\right) \tag{4}$$

By setting, $g_{m16} = g_{m17} = g_{mB}$ and $g_{m18} = g_{m19}$, the *equation (3)* of output current can be simplified as:

$$I_o = g_{mB}\,V_z \tag{5}$$

where, $g_{mB} \propto \sqrt{I_B}$ with $I_B = I_{B1} = I_{B2}$

This indicates that the output current varies and can be increased for the same potential at the z-terminal by raising the bias current's value.

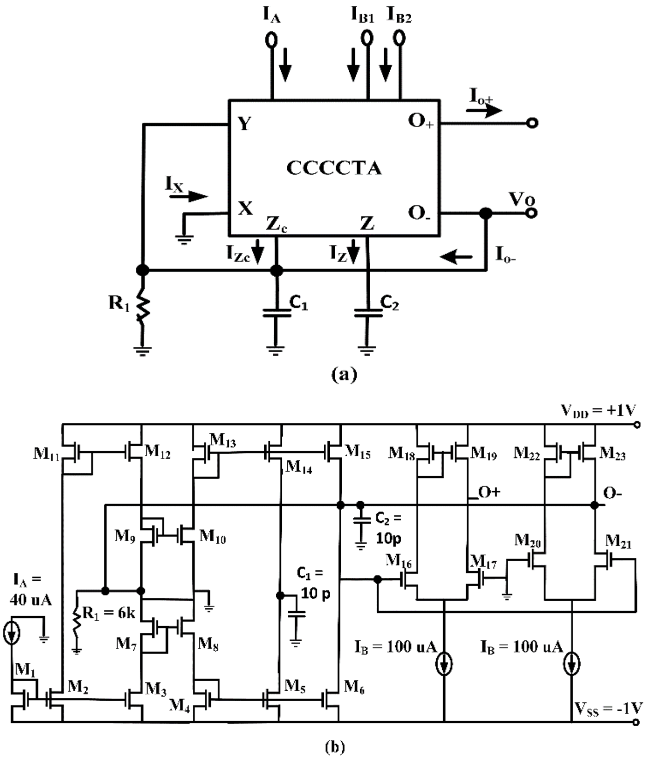
Figure 5(a) shows the schematic block of the proposed sinusoidal oscillator based on this CCCCTA structure while *Figure 5(b)* shows its transistor level circuit used for simulation. It has one CCCCTA element, one resistor R_1, and two capacitors C_1 and C_2. On applying basic nodal analysis at the output port, and using the basic properties of the device as mentioned in section 2, the following characteristic equation is obtained:

$$R_1 R_x C_1 C_2\, s^2 + (R_x C_2 - R_1 C_2)s + g_m R_1 = 0 \tag{6}$$

On solving this equation, the CO and the FO (ω_o) are gained as:

$$\text{CO: } R_1 \geq R_x \text{ and FO: } \omega_o = \sqrt{\frac{g_m}{R_x C_1 C_2}} \qquad (7)$$

By suitably choosing the value of resistor R_1 in the circuit, the oscillations can be obtained easily satisfying the oscillation condition. *Equation (3)* confirms that the biasing current I_A can be utilized to electronically set up and modify the CO without adjusting any passive components in the target circuit. In addition, as mentioned after *equation (5)*, it is clear that g_m value can be changed by way of changing the bias current I_B, and hence by varying the same, the frequency ω_o can be controlled electronically without changing the component values and also without changing the condition of oscillation.



(a)

(b)

Figure 5: Proposed CCCCTA-based sinusoidal oscillator

4. RESULTS AND DISCUSSION

The CCCCTA-based sinusoidal oscillator was simulated using the 0.18-µm CMOS technology parameters from ORCAD PSPICE 17.2. Initially, capacitors C_1 and C_2 were set to 10 pF each. The biasing currents are set to I_A = 40 µA and I_B = 100 µA with a supply voltage of ±1 volt. To ensure oscillation as well as sufficient output signal gain, R_1 is chosen as 6 kΩ, which is substantially higher than R_x (1.8 kΩ). *Figure 6 (a)* displays the oscillations obtained, whereas *figure 6 (b)* illustrates the frequency spectrum. The frequency measured is 4.3 MHz, which is much closer to the theoretical value obtained through calculation.

The frequency obtained at the output terminal varies by varying the bias current I_B. This was tested by providing different values to the bias current. For a bias current of 100 µA, the frequency ω_o is 3.5 MHz, while for a bias current of 150 µA, the frequency ω_o is 4.3 MHz, and for a bias current of 200 µA, the frequency ω_o is 4.9 MHz. It verifies the design and confirms the generation of the sinusoidal waveforms of different frequencies electronically by varying the value of bias current. *Figure 7 (a)* presents the oscillator waveform for a bias current of 100 µA, 150 µA, and 200 µA respectively. *Figure 7 (b)* presents the frequency obtained from the corresponding waveforms. The results again approve the theoretical calculations.

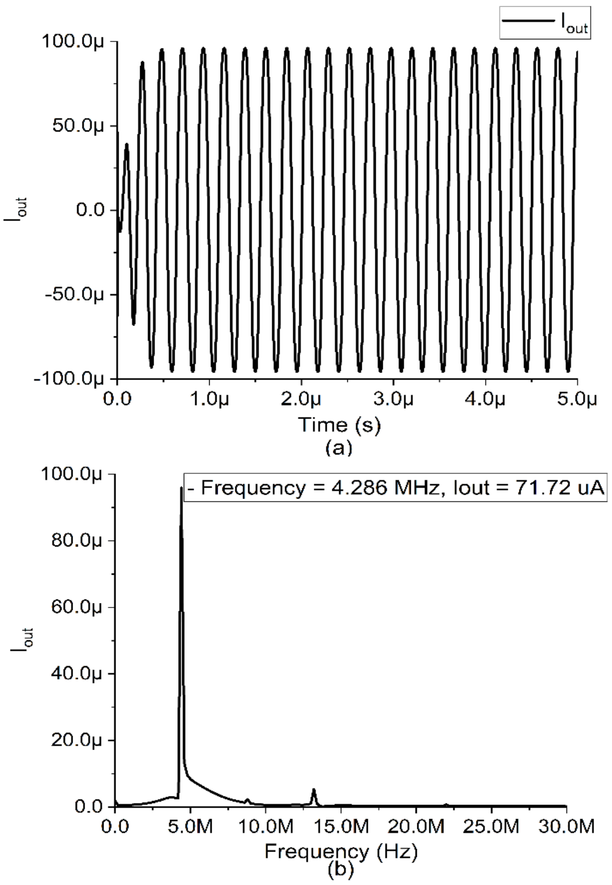


Figure 6: (a) and (b) Single CCCCTA-based sinusoidal oscillator waveform with a constant bias current and its frequency spectrum

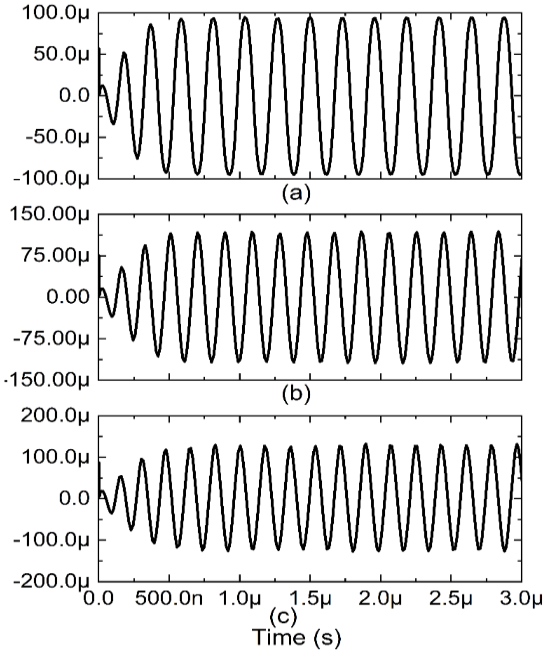


Figure 7: (a) Single CCCCTA based sinusoidal oscillator waveform with variation in biasing current I_B

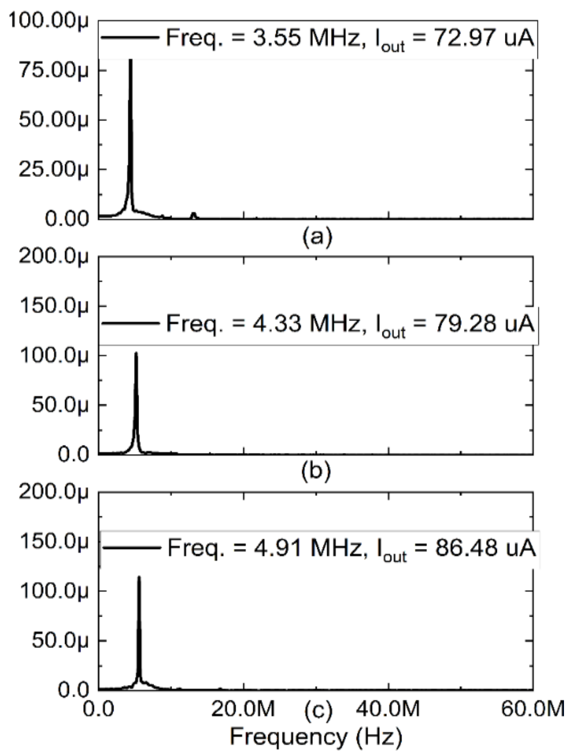
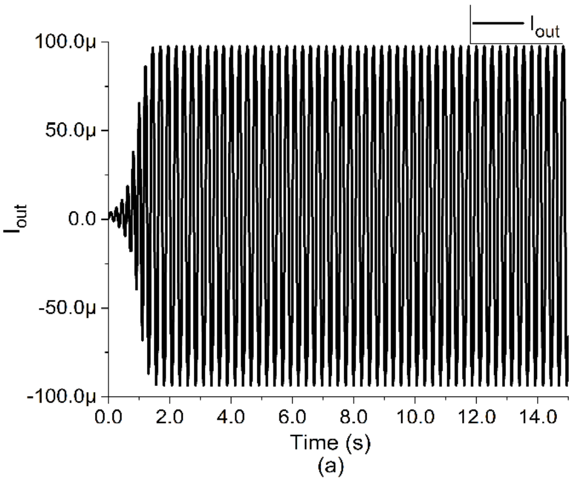


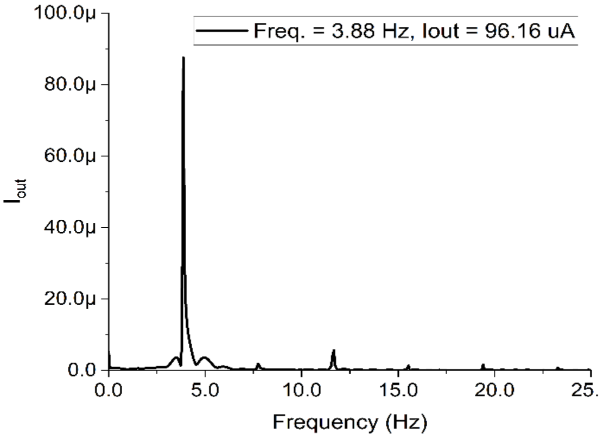
Figure 7: (b) Single CCCCTA-based sinusoidal oscillator frequency spectrum with variation in biasing current I_B

The circuit was simulated again to check its utility at a higher as well as lower frequency. Biasing currents and other values were kept the same while the capacitor values were taken as 0.1 pF for both the capacitors C_1 and C_2. The frequency obtained at the output terminal was 60 MHz for this case which again varies by varying the bias current I_B.

Further, keeping other terms constant and only setting values of both the capacitors at 10uF provide the oscillation with a low-frequency value of 3.8 Hz only which is again shown in *figure 8 (a)* along with its frequency spectrum in *figure 8 (b)*. It proves the utility of this sinusoidal oscillator for a wide frequency range of applications.



(a)



(b)

Figure 8: (a) and (b) Single CCCCTA based sinusoidal oscillator waveform with its spectrum in the lower frequency range

Figure 9(a) shows the frequency range achieved by setting capacitors C_1 and C_2 to specific values and changing the bias current while keeping all other parameters constant. *Figure 9(b)* illustrates the frequency range that can be achieved by setting the bias current to a fixed value and altering the values of capacitors C_1 and C_2 while keeping all other parameters constant.

Results show that the frequency can be generated from a few Hz to several MHz range with the same circuit without any modification. For high-frequency generation C_1 and C_2 can be kept in the pF range and for low-frequency applications, they can be kept in the range of µF, and then further tuning is possible just by varying the OTA bias current I_B. It provides great flexibility to use this design for a very wide frequency range and hence proves its ability to be used in a large number of application areas.

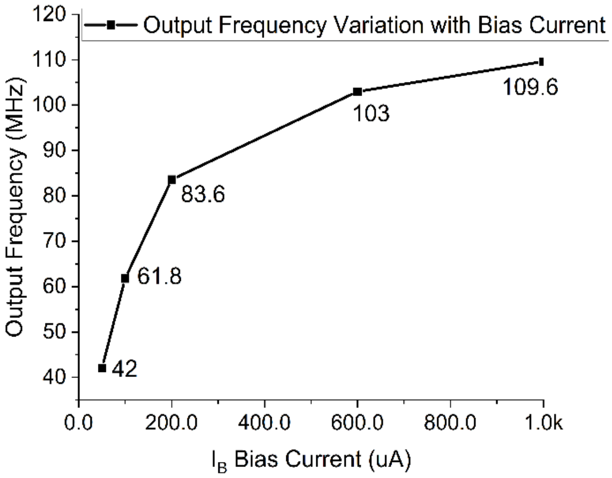


Figure 9: (a) Variation of the output frequency with respect to the bias current I_B with C_1=C_2= 0.1 pF

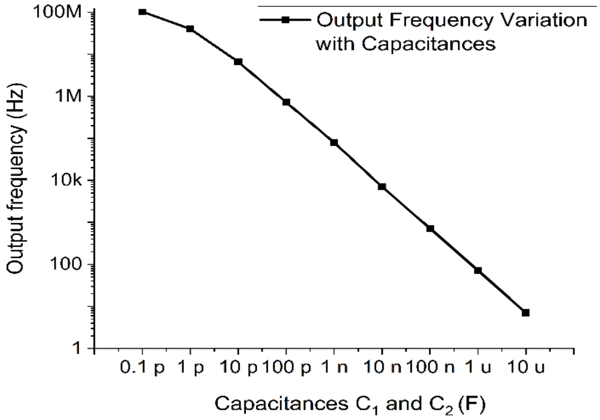


Figure 9: (b) Variation of the output frequency with respect to the capacitance values, with the I_B fixed at 600 µA

Table 2 compares the proposed sinusoidal oscillator to the one currently in use. It can be observed that in most cases, either electronic tuning is not possible or if possible, then not independently controlled for CO and FO. In addition, the number of passive components used are either more or not grounded. Further, the MOS technology implementation provides comparatively less power consumption and the proposed design considers the minimum area requirement for integrated circuit fabrication.

Table 2. Comparison between the proposed and existing sinusoidal oscillators.

Ref.	**Analog building Block (ABB)**	**Total Number of ABB**	**Total Number of passive Components**	**All grounded components**	**Technology**	**Supply voltages (V)**	**Electronic tuning of output current**	**FO and CO Independently Adjustable**	**O/p frequency range (Hz)**
[5]	DXCCTA	1	3	No	0.18 µm TSMC CMOS	±1.25	Yes	Yes	28.6 M maximum
[6]	CCTA	1	4	Yes	PSPICE simulation	±5	Yes	No	0.1 - 1.1 M
[14]	CCCCTA	1	3	Yes	0.25 µm TSMC CMOS	±1.25	Yes	No	15.40 M
[15]	CCCCTA	1	3	Yes	0.35-µm BiCMOS	±1	Yes	Yes	556 k
[16]	CCII	1	5	No	Experimental IC PA 630a	±1	No	No	5 - 16 k
[17]	OTRA	1	5	No	MIETEC 1.2 µ MOS	±5	No	Yes	1.592 - 4 M
[18]	CCII	2	4	No	PR100N and NR100N for the PNP and NPN	±5	No	No	5 - 30 k
[19]	CDTA	3	3	No	PSPICE simulation	±2.5	No	No	3.4 M
[20]	OTRA	1	4	No	CMOS gpdk 180 nm	±1.8	No	No	13 k - 2.4 M
[21]	OTRA	1	6	No	0.18 µm CMOS	±0.9	No	No	15.92 M
[22]	VDCC	2	3	Yes	0.18 µm CMOS	±0.9	Yes	Yes	913 k – 1.1 M
[23]	VCII	2	6	Yes	0.18 µm CMOS	--	No	Yes	500k - 1.4 M
[24]	CCTA	1	2	Yes	0.18 µm CMOS	±1.25	Yes	No	2.8 M
[25]	CCCCTA	1	3	Yes	0.18 µm CMOS	±5	No	Yes	20 k - 346.8 k
[Proposed work]	CCCCTA	1	3	Yes	0.18 µm CMOS	±1	Yes	Yes	2 - 109 M

5. CONCLUSIONS

A simple design of a sinusoidal oscillator using only a single CCTA as its active element in current mode is developed. Because of the CCTA's current-controlled capabilities, passive resistance at the input terminal is eliminated, and electronic modification becomes possible. Furthermore, creating a sinusoidal oscillator with fewer and all grounded passive components allows for its implementation and application in integrated circuits. Another distinguishing characteristic of this device is that the input current controlling feature can be used to establish the oscillation condition and the OTA biasing current can be used to set the oscillation frequency, making it beneficial to regulate both parameters separately. The simulation results confirm that varying the biasing current value can readily change the generated frequency. Additional simulation results demonstrate that this design may be used over a wide frequency range, making it appropriate for usage in a variety of application areas. As a result, the proposed wide-range oscillator is likely to be used in a variety of analog signal processing applications.

This research can be expanded in the future to create a multiphase oscillator. Furthermore, we have currently constructed a sinusoidal oscillator, which can be used in various applications where sinusoidal oscillations are required at the input terminals.

6. ACKNOWLEDGMENTS

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