Current-mode biquad filter using CNTFET-based ZC-CITA

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A CNTFET-based z-copy current inverting trans-conductance amplifier (ZC-CITA) has been proposed. The proposed model uses 28 CNTFET-based transistors, 3 current sources and it uses supply voltages of ±2V with 32 nm technology mode. This paper also introduces the validity of ZC-CITA showing its application as biquad filter which has not been designed yet with an added advantage of power reduction. The result has been verified using HSPICE.

**Keywords:** Carbon nanotube field effect transistor (CNTFET), Carbon nanotube (CNT), Low power, Current inverting transconductance amplifier (CITA), Biquad filter

1 Introduction

Current mode and voltage mode are the active building blocks which are used in designing of analog signal processing circuit in recent past years due to their dynamic properties like large dynamic range, low power consumption, less area, high bandwidth\(^1\),\(^2\). A number of active building block is available in literature as current mode and voltage mode circuits such as current conveyor, current differencing buffered amplifier (CDBA), operational transconductance amplifier (OTA), current inverting transconductance amplifier (CITA)\(^3\),\(^4\), current operational amplifier (COA) and have been brought in as a response to these demands. In this paper, a new CNTFET based current-mode circuit structures for “Z-copy current inverting transconductance amplifier (ZC-CITA)” has proposed that were recommended as multipurpose current mode analog building blocks by Biolek\(^6\). It has been observed that there is an improvement in universal CDTA with the addition of Z-copy current, i.e., current \(I_z\). A traditional current mirror and the third generation current conveyor circuit are commonly used to achieve z-copy output current\(^7\). The main aim of the paper is to enhance the performance like transconductance, power dissipation of CITA by using CNTFET. The internal structure of ZC-CITA is taken from the structure of\(^8\) by grounding the p-terminal. The generalised block diagram of ZC-CITA is given in Fig. 1.

The port relation of CITA is given by these equations:

\[ V_n = 0 \]  \hspace{1cm} \text{... (1)}

\[ I_z = -I_n \]  \hspace{1cm} \text{... (2)}

\[ I_x = \pm g_m v_z \]  \hspace{1cm} \text{... (3)}

2 Proposed CNTFET Based ZC-CITA

The CNTFET based ZC-CITA is shown in Fig. 2 in which we use 28 CNTFET MOSFETs (M1-M18, M19- M28 are identical Table 1). The output current \((I_x)\) of the proposed ZC-CITA can be calculated as:

\[ I_x = g_{m16} v_{g16} - g_{m21} v_{g21} \]  \hspace{1cm} \text{... (4)}

**Table 1 — CNTFET based transistor dimensions.**

<table>
<thead>
<tr>
<th>Transistor</th>
<th>Diameter (nm)</th>
<th>Inter-pitch (nm)</th>
<th>Number of tubes</th>
<th>Channel length</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M18</td>
<td>1.5</td>
<td>20</td>
<td>6</td>
<td>32</td>
</tr>
<tr>
<td>M19-M24</td>
<td>1.5</td>
<td>20</td>
<td>5</td>
<td>32</td>
</tr>
<tr>
<td>M25-M28</td>
<td>1.5</td>
<td>20</td>
<td>6</td>
<td>32</td>
</tr>
</tbody>
</table>

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The power supply voltage is taken as $V_{dd} = -V_{ss} = 2V$ and the bias current $I_{b1}$ and $I_{b2}$ which is equal to 85 µA. Hence for finding the different values of transconductance we can vary the $I_{b3}$ from 10 µA to 1 mA, where we have take the value of $I_{b3} = 200$ µA and we get inverted current shown in block diagram of ZC-CITA. Where transconductance ($g_m$) at $I_{b3} = 200$ µA is 226.1 µA/V is shown in Fig. 3. This transconductance can be varies with the change in value of $I_{b3}$ and the power dissipation is 441.5 µW and the DC current and input-output transfer characteristics are shown in Fig. 4 and Fig. 5, respectively.

The CNTFET based z-copy use MOSFET which are having identical channel size and 32 nm technology node considered oxide thickness is 4 nm and supply voltage of ±2 V. The HFO$_2$ is taken as...
gate oxide which has dielectric constant of 16, whereas the mean free path is 200 nm and doping of 12.5 nm. The channel length ratio will depend on count of carbon nanotube used in p and n type MOSFET. The parameter of general CNTFET is shown in Table 2. The port resistance (input and output resistance) with respect to pitch and number of tubes are shown in Fig. 6 and Fig. 7, respectively.

CNTFET layout diagram is shown in Fig. 8. In CNTFET, single wall carbon nanotube (SWCNT) was used in parallel combination which results in merging of channel. However source and drain terminals are heavily doped whereas channel is kept undoped.

In CNTFET-based ZC-CITA the finest parameters related to structure are estimated as:

Count of tubes (N): Individual Nanotube based transistor will not be able to cope up with the performance as compared with CMOS so that to increase the performance of the circuit, count of CNT has to increase and used in the form of array which is calculated as:

\[ W = (N - 1) * S + D_{cnt} \]  

Inter-CNT Pitch (S): The distance between the two adjacent Nanotube forming centre is called inter CNT pitch, denoted by S.

\[ V_{th} = \frac{av\pi}{\sqrt{3qD_{cnt}}} \]  

Diameter of CNT (D_{cnt}): Diameter of the CNT is directly related to threshold voltage and the parameter of Chirality of tube (m,n) which is calculated as:

\[ D_{cnt} = \frac{A\sqrt{(n^2 + m^2 + mn)}}{\pi} \]  

3 Proposed CNTFET ZC-CITA Based CM Biquad Filter

The proposed design of biquad filter circuit consists of two capacitor and a ZC-CITA block which has three outputs I_{o1}, I_{o2}, I_{o3}, shown in Fig. 9.

From I_{o1}, I_{o2}, I_{o3}, I_{o4} we can get the transfer functions corresponding to which we get the desired

<table>
<thead>
<tr>
<th>CNTFET parameters</th>
<th>Considered values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work function (CNT)</td>
<td>4.5 eV</td>
</tr>
<tr>
<td>Mean Free path: Intrinsic CNT</td>
<td>200 nm</td>
</tr>
<tr>
<td>Gate oxide</td>
<td>HFO₂</td>
</tr>
<tr>
<td>Dielectric constant</td>
<td>16</td>
</tr>
<tr>
<td>Power supply</td>
<td>±2V</td>
</tr>
<tr>
<td>Mean free path: Doped CNT</td>
<td>12.5 nm</td>
</tr>
<tr>
<td>Physical channel length (L_{ch})</td>
<td>32 nm</td>
</tr>
<tr>
<td>Oxide thickness (T_{ox})</td>
<td>4 nm</td>
</tr>
<tr>
<td>Pitch</td>
<td>20 nm</td>
</tr>
<tr>
<td>Chirality of tube (m,n)</td>
<td>19,0</td>
</tr>
</tbody>
</table>
response of low pass, high pass, band pass and band reject filter. After routine circuit analysis technique we find the transfer functions as:

\[
\frac{I_{o3}}{I_{in}} = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_1C_2 + g_1g_2} \quad \ldots (8)
\]

\[
\frac{I_{o2}}{I_{in}} = \frac{g_1g_2}{s^2C_1C_2 + sC_1C_2 + g_1g_2} \quad \ldots (9)
\]

\[
\frac{I_{o1}}{I_{in}} = \frac{SC_2g_1}{s^2C_1C_2 + sC_1C_2 + g_1g_2} \quad \ldots (10)
\]

\[
\frac{I_{o4}}{I_{in}} = \frac{s^2C_1C_2 + g_1g_2}{s^2C_1C_2 + sC_1C_2 + g_1g_2} \quad \ldots (11)
\]

The filter natural frequency \(\omega_0\) and the quality factor \(Q_0\) is calculated as:

\[
\omega_0 = \sqrt{\frac{g_1g_2}{C_1C_2}} \quad \ldots (12)
\]

\[
Q_0 = \frac{\omega_0C_1}{C_1C_2} \quad \ldots (13)
\]

4 Results

The proposed biquad is simulated using HSPICE with component value at \(C_1=3 \text{ nF}\) and \(C_2=6 \text{ nF}\). The frequency response of proposed biquad is shown in Fig. 10. This CNTFET based ZC-CITA Circuit uses less power consumption and biquad use less number of components, i.e., only two capacitors. From a single circuit we can derive low pass, high pass, band pass and band reject filters as shown in Fig. 10.

5 Conclusions

This paper presents ZC-CITA based on CNTFET and its application as biquad filter which has not been designed yet and utilizes fewer number of components i.e. only two capacitors having higher transconductance and low power consumption. This paper present ZC-CITA based on CNTFET which gives better performance as compare to CMOS structure. The result has been verified using HSPICE at 32 nm technology node Input-output characteristics, transconductance, DC transfer characteristics and input-output resistance has also been successfully verified. The improvement in the circuit is also verified with biquad filter of 10 k as cut-off frequency.

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