A High-performance Current-mode Precision Full-wave Rectifier based on BiCMOS-CCCDBAs

Phamorn Silapan  
Electric and Industrial Program, Faculty of Industrial Technology, Uttaradit Rajabhat University, Muang, Uttaradit, THAILAND  
phamorn@mail.uru.ac.th

Winai Jaikla  
Electric and Electronic Program, Faculty of Industrial Technology, Suan Sunandha Rajabhat University, Dusit, Bangkok, THAILAND  
jnai2004@yahoo.com

Montree Siriruchyanun  
Department of Teacher Training in Electrical Engineering, Faculty of Technical Education, King Mongkut’s University of Technology North Bangkok, Bangkok, THAILAND  
mts@kmutnb.ac.th

Abstract - This article introduces a novel version for implementing current-mode precision full-wave rectifier. The features of the proposed circuit are that: it can rectify and amplify current signal with controllable output magnitude via an input bias current; the output current is free from temperature variation. In addition, direction of the output current signal can be arbitrarily controlled by controlled current in the circuit to be either positive or negative without changing circuit topology, which differs from the previous literatures. Circuit description merely consists of 3 BiCMOS CCCDBAs, without any passive component. The performances of the proposed circuit are investigated through PSPICE. They show that the proposed circuit can function as a current-mode precision full-wave rectifier, where input current range from -240 μA to 240 μA can be achieved at ±1.5V power supplies. The maximum power consumption is 11.8mW. In addition, the highest frequency is restricted at up to megahertz range.

I. INTRODUCTION

A precision rectifier is extensively used in signal processing circuits, for instance, in an AC to DC converter, in a signal polarity detector, in a peak signal detector, in an amplitude demodulation circuit, and in an automatic gain control system [1-2]. Basically, a voltage-mode precision rectifier employs an operational amplifier and a diode [3]. The output signal confronts a zero crossing distortion due to characteristic of the diode [4]. This problem has been subsequently solved by proposing the novel circuit without a diode [5]. In addition, the precision rectifiers are modified to use other active elements to achieve wider frequency response, for example, current conveyor [6] and current feedback operational amplifier [7]. Since a low-voltage operating circuit becomes necessary as in portable and battery-powered equipment, the current-mode technique is ideally suited for this purpose more than the voltage-mode one. Presently, there is a growing interest in synthesizing the current-mode circuits because of more their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry and lower power consumption [8-9]. From our investigations, there are seen that the previous literatures have proposed the current-mode precision rectifiers [10-12]. Unfortunately, the output magnitude of those proposed circuits can not be adjusted. Consequently, they require a proper amplifier to achieve appropriate level of output signal. Furthermore, in case of opposite polarity of output signal is required, it must be unavoidably changed the circuit topology or added a current inverter. This makes the circuit more complicated. Some of them employ a number of passive elements, which is not suitable for realizing into an integrated circuit [13]. The operations of all mentioned circuits, moreover, are dependent on temperature.

The purpose of this paper is to introduce a novel current-mode precision rectifier, whose output magnitude and polarity are electronically controllable without changing a circuit topology or adding any more circuit. It can be applied in an automatic control via a microprocessor. The circuit construction consists of 3 CCCDBAs. The PSPICE simulation results are also shown. They confirm that the proposed circuit provides a wide range of input current, temperature-insensitive, wide range of frequencies and controllability of the output magnitude and polarity via an input bias current and controlled current, respectively.
II. CIRCUIT CONFIGURATION

A. Basic Concept of CCCDBA

CCCDBA properties are similar to the conventional CDBA, except that input voltages of CCCDBA are not zero and the CCCDBA has finite input resistances \( R_p \) and \( R_n \) at the \( p \) and \( n \) input terminals, respectively. These parasitic resistances are equal and can be controlled by the bias current \( B_I \) by

\[
R_i = \frac{V_T}{2I_B},
\]

where \( V_T \) is the thermal voltage. The symbol and the equivalent circuit of the CCCDBA are illustrated in Fig. 1(a) and (b), respectively.

\[
\begin{bmatrix}
V_p \\
V_n \\
I_p \\
I_n \\
V_x \\
I_x
\end{bmatrix} =
\begin{bmatrix}
R_p & 0 & 0 & 0 & I_p \\
0 & R_n & 0 & 0 & I_n \\
1 & -1 & 0 & 0 & V_x \\
0 & 0 & 1 & 0 & I_x
\end{bmatrix}
\begin{bmatrix}
I_p \\
I_n \\
I_x
\end{bmatrix}.
\]

(1)

\[
I_{Z2} = \frac{V_r}{2I_B},
\]

where

\[
i_f = \frac{I_c I_n}{2I_B}
\]

(2)

\[
I_{Z3} = \frac{I_c I_n}{2I_B}
\]

(3)

Consequently, the output current can be found to be

\[
I_O = I_{Z2} + I_{Z3} = -\frac{I_c}{2I_B}I_n.
\]

(4)

It can be seen from Eq. (8) that the circuit in Fig. 2 can perform as a precision current-mode full-wave rectifier whose output magnitude and polarity can be controlled via controlled current \( I_c \) and \( I_B \), which is theoretically temperature independent.

B. The proposed precision current-mode full-wave rectifier

Fig. 2 displays the proposed current-mode full-wave rectifier circuit. Considering the circuit in Fig. 1 and using the BiCMOS CCCDBA properties described in section A, we will receive

\[
V_{p2} = V_{p3} = V_{w1} = -R_{w1}I_{n1} = -\frac{I_c V_T}{4I_B}.
\]

(3)

The output currents of the CCCDBA3 and CCCDBA3 can be respectively found to be

\[
I_{Z2} = \frac{V_r}{2I_B},
\]

(4)

and

\[
I_{Z3} = \frac{I_c I_n}{2I_B}
\]

(5)

From Eqs. (3-5), we can receive following equations for output currents

\[
I_{Z2} = \begin{cases} \frac{I_c I_n}{2I_B} & \text{if } I_n > 0 \\ 0 & \text{if } I_n < 0 \end{cases}
\]

(6)

\[
I_{Z3} = \begin{cases} 0 & \text{if } I_n > 0 \\ -\frac{I_c I_n}{2I_B} & \text{if } I_n < 0 \end{cases}
\]

(7)

III. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examinations. In this work, the high-performance BiCMOS CCCDBA [14] was used for implementation of the proposed rectifier to achieve more precision. The circuit description of the CCCDBA is depicted in Fig. 3. The PNP and NPN transistors employed in the proposed circuit in Fig. 3 were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [15]. The PMOS and NMOS transistors were simulated by using the parameters of a 0.35μm TSMC CMOS technology [16] with ±1.5V power supplies and \( I_o \) was set to 150 μA. The aspect transistor ratios of PMOS and NMOS are listed in Table I. The output current responses for different input frequencies are also shown in Fig. 4. It is confirmed that the proposed circuit can rectify when frequency is up to megahertz range without disturbing magnitude of the output current. Fig. 5 depicts DC transfer characteristics, where \( I_{n1} = 5μA \). It can be seen that the proposed circuit offers a wide-range of input current to be a rectifier. Additionally, its output current direction can be controlled by \( I_c \).

<table>
<thead>
<tr>
<th>CMOS Transistors</th>
<th>W(μm) / L(μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M5, M14-M17, M18-M19</td>
<td>5/0.5</td>
</tr>
<tr>
<td>M6-M7</td>
<td>8/1.5</td>
</tr>
<tr>
<td>M8-M11</td>
<td>15/0.5</td>
</tr>
<tr>
<td>M12-M13</td>
<td>20/0.5</td>
</tr>
<tr>
<td>M20-M21</td>
<td>10/0.5</td>
</tr>
</tbody>
</table>

Fig. 6 shows the output current versus temperature variations to 27°C, 50°C and 100°C. It is clearly observed that
the output current is almost not dependent on the temperature, this is due to temperature compensation in the proposed rectifier, as explained earlier. The results shown in Figs. 7(a) and 7(b) are results of the output current variations, where when \( I_{in} = 20 \mu A \), \( I_{hi} = 5 \mu A \), \( I_{ci} = \pm 10 \mu A, \pm 20 \mu A \) and \( \pm 30 \mu A \). It insists that the magnitude of output current can be electronically controlled. In addition, polarity of the output current depends on the direction of \( I_C \).

Fig. 8 represents plots of the magnitude output current owing to controlled current \( (I_C) \) variations, it should be remarked that magnitude of the output current of the proposed rectifier can be electronically controlled by the controlled current for a wide-range. The maximum power consumption is 11.8mW.

![Figure 3. Circuit description of BiCMOS current controlled current differencing buffered amplifier](image)

**IV. CONCLUSIONS**

The novel current-mode precision rectifier, based on CCCDBAs, which can rectify an input current with electronic controllability of output magnitude, has been reported in this paper. Direction of the output current signal can be arbitrarily controlled by controlled current in the circuit to be either positive or negative without changing circuit topology, which differs from the previous literatures. Circuit description merely consists of a temperature-insensitive current amplifier using 3 CCCDBAs. The performances of the proposed circuit have been also investigated through PSPICE. They show that the proposed circuit can function as a current-mode precision full-wave rectifier, where input current range of \(-240 \mu A \) to \( 240 \mu A \) can be achieved at \( \pm 1.5V \) power supplies. The total
power consumption is 11.8mW. Furthermore, the highest frequency is restricted up to megahertz range. With claimed outstanding feature, it is very appropriate to develop the proposed circuit to be a part of a monolithic chip for working in a current-mode signal processing circuit/system.

References


