Abstract: The paper deals with a pair of current-mode sine-wave oscillator circuits. Both these circuits are implemented using positive second-generation current conveyors (CCII+). The principle of the first oscillator is based on a conventional Wien-bridge network. However, this implementation suffers from the use of a floating capacitor, which can be unacceptable in the case of on-chip integration. This drawback is solved in the second variant via a slight modification of the Wien-bridge network, which then allows the use of all capacitors grounded. The modified circuit version was manufactured by means of the so-called diamond transistors, which play the role of CCII+ active building blocks. The circuit behavior was analyzed theoretically, with particular emphasis on the identification of real effects and their elimination, and subsequently verified experimentally. The experimental results are included in the paper.

Keywords
Diamond transistor, Wien-bridge oscillator, current-mode, current conveyor.

1. Introduction
Sinusoidal oscillator is a basic and one of the most common applications in analog signal processing. There is a wide range of conceptions and various approaches in terms of principle and utilized active elements. In the case of current-mode (CM) regime, a current conveyor (CC) is frequently employed as the active element. For example, several oscillators are implemented using first-generation current conveyors CCI in [1], [2]. Rather than CCI, second-generation current conveyors, CCII, (usually of the positive type) are used in oscillator circuits [3]-[8]. The Wien-bridge oscillator (WBO) is a specific type. Two different WBOs using two CCII+ are reported in [6]. In addition to two CCII+, eight passive components are employed there. Another two papers, [7] and [8], are also focused on CCII+ based WBOs. All the WBOs published in [7] require a CCII+ with multiple Z-terminals for their operation (or for the explicit current output, if you like). Oscillator circuits in [8] employ CCII+ but the output signal is available only in the form of voltage. In addition, all the circuits published in [8] contain one floating capacitor. An economical version of the WBO employing one CFA (Current-Feedback Amplifier) and only four passive components with two capacitors grounded, is published in [9] and [10]. Owing to the CFA internal topology, these oscillators are of the CCII type, with buffered voltage outputs. Their key drawback consists in the impossibility of independent control of the oscillation frequency (OF) and oscillation condition (OC). The WBOs from [11] and [12] represent conventional oscillator structures employing one non-inverting voltage amplifier and the Wien bridge in a feedback loop. The amplifier is implemented by one CFA and two resistors. In spite of some important advantages of the CFA-based oscillators over their VFA (Voltage Feedback Amplifier) counterparts [11], these oscillators also provide only voltage outputs. CFA-based oscillators with explicit current outputs are proposed in [13] (Fig. 4). However, the load resistance affects the oscillator behavior.

The purpose of the present paper is to propose another two WBO realizations with explicit current outputs, each of them utilizing two CCII+ and six passive components (four resistors and two capacitors). The paper deals with two different explicit current-output WBO circuits. Both of them are based on the so-called diamond transistors (DT) [14]. DT is a part of the commercially available OPA860 integrated circuit. DT with emitter (E), base (B), and collector (C) terminals represents a CCII+ with terminals X, Y and Z (Fig. 1). DTs have successfully been employed in many applications such as advanced active building blocks. DTs were successfully used, for example, in [15] to implement ZC-CG-CDBA (Z Copy–Controlled Gain-Current Differencing Buffered Amplifier) or in [16] to implement CIBTA (Current Inverting Buffered Transconductance Amplifier), ZC-CITA (Z Copy-Current Inverting Transconductance Amplifier) in [17], and FB-VDBA (Fully Balanced-Voltage Differencing...
Buffered Amplifier) in [18]. A number of active elements and the methodology for constructing them using DTs were published in [19].

Fig. 1. Diamond transistor OPA860 as a CCII+.

2. Proposed Circuits

Fig. 2 shows a proposed CM oscillator using two CCII+s and a conventional Wien bridge network. Note that DT in the role of CCII+ together with the voltage buffer, operating between the base-emitter terminals of DT2, acts as a conventional CFA. From this point of view, resistors R2 and R4 adjust the gain of the non-inverting amplifier, which is a standard block of the WBO. However, due to the double use of two diamond transistors, not only voltage but also current output is available.

Fig. 2. CCII+ based Wien-bridge oscillator.

A potential drawback of this circuit consists in the floating capacitor C1, which can cause a problem in the case of integration on a chip. It can be overcome with the help of an idea from [13] and [20], where a derivation of Wien-bridge equivalent forms is described. A practical solution is achieved by interchanging complete impedances between two branches, namely a serial combination of R1 and C1 with R4. The resulting circuit shown in Fig. 3 is potentially suitable for on-chip integration since all capacitors are grounded, concurrently enabling explicit current output. Note that this oscillator resembles a topology published in [13] (in Fig. 4 (b) therein): In [13], CFA is used instead of DT1 and DT2. However, the output current is flowing from the z-terminal of the CFA to an external load, labeled as Rload in [13]. In Fig. 3, it would be represented by a connection of grounded resistor Rload to the node between the collector of DT1 and the base of DT2. In this way, the value of Rload would modify the amplifier gain and the oscillation condition. By contrast to this case, the topology in Fig. 3 does not suffer from this drawback; since the current output is available at the high-impedance collector node of DT2.

Fig. 3. Modified CCII+ based Wien-bridge oscillator with all capacitors grounded.

The characteristic equation (CE) is the same for both variants in Figs 2 and 3:

\[
0432143241143121 \quad s^2 C_1 R_1 R_2 + s(C R_2 C_2 + R_2 R_3 - C R_2 R_3) + R_4 = 0. \quad (1)
\]

The oscillation conditions (OC) and the oscillation frequency (OF) are as follows:

\[
\text{OC:} \quad \frac{R_2}{R_4} \geq \frac{R_1 + C_1}{C_2}, \quad (2)
\]

\[
\text{OF:} \quad \omega_b = \frac{1}{\sqrt{C_1 R_1 R_4}}. \quad (3)
\]

Under the conditions C1 = C2 and R1 = R3 = R, OC and OF can be simplified to the forms:

\[
\text{OC:} \quad \frac{R_2}{R_4} \geq 2, \quad (4)
\]

\[
\text{OF:} \quad \omega_b = \frac{1}{RC}. \quad (5)
\]

3. Analysis of Real Effects

In reality, both OC and OF differ from their ideal forms (2) and (3) due to non-ideal effects of the active devices used or due to imperfections of technological processes in the case of on-chip implementation.

As mentioned above, the second oscillator circuit was implemented using the OPA860 DTs for experimental purposes. Major real influences are described in the DT datasheet [14]. For simplicity, consider that the circuit will operate at a constant temperature and within the bandwidth of DTs used and thus the frequency and temperature dependence may not be analyzed. The parasitic capacitances and resistances of the collector and base terminals, Cc, Rc, and Cb, Rb, and the parasitic non-zero resistance of emitter terminal RE are the major non-idealities. A simple modeling of actual DT effects is shown in Fig. 4. Typical parameters according to [14] are RE = 54 kΩ, Cc = 2 pF, Rb = 445 kΩ, and Cb = 2.1 pF. Emitter input resistance RE depends on a bias current IADJ, which must be set via an external resistor RADJ (see [14]). A typical RE value is between 9 Ω and 11 Ω. The resistor RADJ = 330 Ω was used during all experiments, giving RE resistances of about 10 Ω.
The resulting model of the oscillator from Fig. 3 is shown in Fig. 5, where $R_Z$ is formed by a parallel combination of $R_{b1}$ and $R_{b2}$, and capacitor $C_Z$ represents a parallel connection of $C_{b1}$ and $C_{b2}$. The same situation is in the case of resistor $R_3' = R_4||R_{b1}$ and capacitor $C_3' = C_2||C_{b1}$. A proper choice of component values can cause that parasitic connections of $C_{b1}$ and $C_{b2}$ have a significant impact on the total coefficient value, but some of them can be neglected. If they are neglected, the simplified forms of the coefficients are as follows:

\[
\begin{align*}
 a_0 &= R_x R_y + R_x R_z + R_y R_z, \\
 a_1 &= C_2 R_x (R_x R_y + R_x R_z + R_y R_z) + \\
 &\quad + C_2 R_y (R_x R_y + R_x R_z + R_y R_z) + C_2 R_z (R_x R_y + R_x R_z + R_y R_z), \\
 a_2 &= C_2 C_3 R_y R_z (R_x + R_z) + C_2 C_3 R_y R_z R_x + \\
 &\quad + C_2 C_3 R_y R_z (R_x + R_z) + C_2 C_3 R_y R_z R_x + \\
 a_3 &= C_2 C_3 C_4 R_y R_z R_x (R_x + R_z + R_y R_z + R_y R_x).
\end{align*}
\]

The coefficients $a_0$ to $a_3$ of the CE are rather complex, composed of the summation of several terms. Some of them have a significant impact on the total coefficient value, but some of them are insubstantial and can be neglected. If they are neglected, the simplified forms of the coefficients are as follows:

\[
\begin{align*}
 a_0 &= R_x R_y + R_x R_z + R_y R_z, \\
 a_1 &= C_2 R_x (R_x R_y + R_x R_z + R_y R_z) + \\
 &\quad + C_2 R_y (R_x R_y + R_x R_z + R_y R_z) + C_2 R_z (R_x R_y + R_x R_z + R_y R_z). \\
 a_2 &= C_2 C_3 R_y R_z (R_x + R_z) + C_2 C_3 R_y R_z R_x + \\
 a_3 &= C_2 C_3 C_4 R_y R_z R_x (R_x + R_z + R_y R_z + R_y R_x).
\end{align*}
\]

The oscillation frequency can then be expressed as

\[
f_0' = \frac{f_0}{\sqrt{1 + \varepsilon}}
\]

where

\[
\varepsilon = \frac{C_Z R_x}{R_z} \left(1 + \frac{R_x}{R_y} + \frac{R_y}{R_z} + \frac{C_Z R_x}{R_z} - \frac{R_x}{R_z} \right).
\]

An error term $\varepsilon$, of zero value in the ideal case, is a small positive number in the real case, causing a decrease in the oscillation frequency, with $R_2$ and $C_2$ being the most prominent real effects. Their influence on the OF can be minimized by a proper choice of other component values.

### 4. Experimental Results

The modified WBO version in Fig. 3 was selected for experimental verification. Two OPA860 DTs were...
employed for circuit implementation. The following values of passive components were used: \( C_1 = C_2 = 1 \text{nF, } R_1 = R_2 = 100 \Omega, R_3 = 4.3 \text{k}\Omega, R_4 = 1 \text{k}\Omega, R_{ADJ} = 330 \Omega \).

According to (5), the corresponding theoretical \( f_0 \) value is 1.592 MHz.

### 4.1 Amplitude Stabilization

In order to perform a relevant measurement, the manufactured WBO was equipped with an automatic amplitude stabilization circuit as shown in Fig. 6. Such a circuit was simply implemented using one photoresistor-based optocoupler, one operational amplifier, and a few resistors. The photoresistor was connected in parallel to the base optocoupler, one operational amplifier, and a few resistors. The LED diode inside the optocoupler was excited by the generated signal after it had been amplified by a conventional inverting amplifier (see Fig. 6). A growing amplitude causes an increase in the LED light emission, causing a reduced resistance of the photoresistor and thus damping the amplitude. According to (4), the value of \( R_2 \) should be twice that of \( R_1 \) in the ideal case. The fixed value of \( R_2 \) was intentionally chosen more than twice as much (4.3x as mentioned above), since the oscillation condition is fulfilled by \( R_2 \) in parallel with the photoresistor.

In the ideal case, under the conditions \( C_1 = C_2 \) and \( R_1 = R_2 \), the \( R_2/R_4 \) ratio should be 2, as mentioned above. However, in reality, their ratio must be rather different. The required value can be determined from the OC, taking the real effects into consideration. According to (9), the required \( R_2/R_4 \) ratio is 2.11. In other words, the ratio of \( R_4 \) and photoresistor should be 2110 \( \Omega \) with \( R_4 = 1 \text{k}\Omega \). This value exactly corresponds with a simulation in the SNAP program [21], with the CE coefficients analyzed without any simplification.

The optocoupler is a low-speed device, responding to the mean value of the signal rather than to its instantaneous values. Due to this feature, the circuitry for amplitude control can be made up in such a simple way. However, for this reason it is impossible to use the same stabilization circuit for very low frequency oscillators when the optocoupler follows the instantaneous rather than the mean values.

### 4.2 Results Measured

The WBO output terminal (collector of \( DT_2 \)) was enhanced by an additional external resistor of 47 \( \Omega \) (Fig. 6). The current signal causes a voltage drop on this resistor, which can be subsequently used for measuring as well as for amplitude control.

The voltage signal was connected via the voltage buffer and additional 47\( \Omega \) matching resistor to an oscilloscope/spectrum analyzer.

Fig. 7 shows the waveform generated. The vertical axis is scaled such that 100 mV represents approximately 2 mA of the output current. The oscillation frequency measured was 1.433 MHz, which is about 10\% lower than the expected theoretical value 1.592 MHz. The THD measured was slightly lower than 0.25\%.

![Fig. 7. The steady-state waveform of the voltage measured.](image)

An analysis of the real influences revealed two main reasons for the difference between the measured and the theoretical oscillation frequency. It is a total parasitic impedance of the node where the collector of \( DT_1 \) is connected to the base of \( DT_2 \). According to [14], the concrete values are \( C_Z = 4.1 \text{pF} \) (\( C_Z = C_{c1}||C_{b2} \) and \( R_Z \) only 48 k\( \Omega \) \( R_Z = R_{c1}||R_{b2} \)). The value of the OF computed from (15) is 1.466 MHz, which is less than a 2.5\% deviation from the frequency measured. It proves that all the major real effects are properly modeled via (15).

The THD measured is on a relatively acceptable level. However, the actual THD value primarily depends on the linearity of CCIIs+, on the functionality of the amplitude stabilization circuit, and also on the \( R_3/R_1 \) and \( C_2/C_1 \) ratios as shown in [22]. Since the diamond transistor is not a linear device, the so-called degeneration resistor should be used in order to increase the linearity [14], [15]. That is why the actual THD value achievable with an on-chip WBO will be dependent on the above factors.

### 5. Conclusion

Two different versions of Wien-bridge type oscillators employing CCIIs+ and providing explicit current outputs were proposed in the paper. A method for overcoming the drawback of floating capacitors was shown and tested...
experimentally on the manufactured circuit. Positive second-generation current conveyors CCII+ were implemented by means of the OPA860 diamond transistors. Experimental results described in section 4 show a 10% decrease of measured oscillation frequency compared to its ideal theoretical value. A detailed analysis of real effects describes all the major influences and provides a formula for computing an approximate oscillation frequency, with a maximum error of less than 2.5%. A relatively low collector terminal resistance of the diamond transistor as well as its parasitic capacitance were indicated as the major factors causing the error in the oscillation frequency. To eliminate this error, a CCII+ with high output resistance and low parasitic capacitances should be used.

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References


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