TRANSLINEAR-C FUNCTION GENERATOR USING MOCCCIIS

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1. INTRODUCTION

Nowadays the second generation current controlled current conveyor (CCCII) has become a popular active device in the design of current mode (CM) analog circuits. It enjoys attractive realization features and a broad frequency range of operation without any external resistor. This class of circuits is referred to as translinear-C circuits. Many translinear-C current mode filters and oscillators have been reported in the technical literature [1–5]. Moreover, like filters and sinusoidal oscillators, triangular/square wave generators are also widely used in a wide range of applications in instrumentation and measurement systems, due to which a large number of triangular/square wave generators have been developed using a wide variety of active devices [6]. However, not much work is available in technical literature on good quality current mode function generators, especially on current mode translinear-C function generators.

In this paper, a novel and versatile translinear-C function generator (TCFG), using a multi-output current controlled current conveyors (MOCCCIIs) based band pass filter (BPF) as its basic building block, has been proposed. The basic building block, *i.e.*, the current mode BPF, is realized using three MOCCCIIs and two grounded capacitors. The TCFG is realized simply by providing a direct feedback from the output to the input of this BPF. The realized function generator uses only four MOCCCIIs and only four grounded capacitors. The versatility of the circuit justifies the use of the number of these devices. The realized function generator exhibits four phase sinusoidal quadrature current outputs and, a square and two opposite phase triangular output voltages. It also provides sufficiently wide range independent electronic control of its operating frequency, attractive sensitivity figures, and is compatible for monolithic implementation in contemporary IC technologies. The realized TCFG was designed and verified using PSPICE with excellent results.

Key words: current conveyors, current-mode circuits, function generators, oscillators

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2 . THE PROPOSED CIRCUIT

The electrical symbol of the MOCCCII used in the realization of the proposed circuits is shown in Figure 1. The port relations of this MOCCCII, can be given by the following matrix

$$\begin{bmatrix} Iy \\ Vx \\ Izi \\ Izi^- \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 1 & Rx & 0 & 0 \\ 0 & +1 & 0 & 0 \\ 0 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} Vy \\ Ix \\ Vzi \\ Vzi^- \end{bmatrix} \tag{1}$$

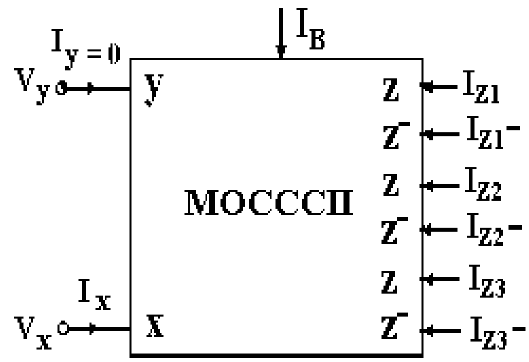

Figure 1. Electrical symbol of the MOCCCII

where, R_x is the parasitic resistance at the *x*-input terminal of the MOCCCII and i = 1,2,3. *Vzi* and *Vzi*⁻ are the voltages at *zi* and *zi*⁻ terminals, respectively. The band-pass filter used as the basic building block for the realization of the TCFG, was realized using three MOCCCIIs as shown in Figure 2. This band-pass filter is in fact a modified version of the current mode universal filter available in literature[7].

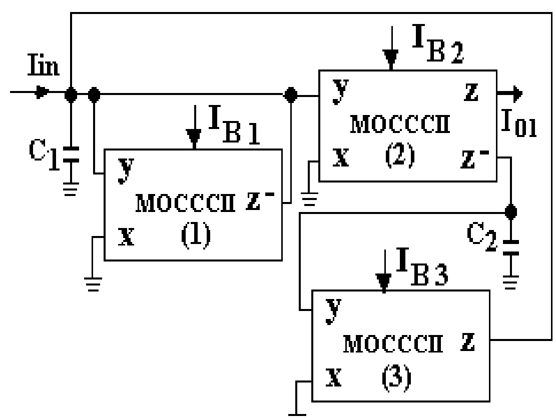

Figure 2. Current mode translinear-C band pass filter

Routine analysis yields the transfer gain of the current mode band-pass filter as follows:

$$\frac{I_{01}}{I_{in}} = \frac{s\frac{1}{R_{x2}C_1}}{s^2 + s\frac{1}{R_{x1}C_1} + \frac{1}{R_{x2}R_{x3}C_1C_2}} \tag{2}$$

where, R_{xi} [$= V_T / (2\, I_{Bi})$, i = 1,2,3, …] is the parasitic resistance at the *x*-input terminal of the MOCCCIIs, V_T is the thermal voltage and I_{Bi} is the bias current of the i^{th} MOCCCII, which is tunable over several decades. The TCFG is realized by providing a direct feedback from the output (I_{01}) to the input of the basic building block as shown in Figure 3. To obtain the various currents and voltages, additional appropriate output (z) terminals from the MOCCCIIs are included. It is to be noted that $I_{01} = -I_{02}$ and $I_{03} = -I_{04}$. The characteristic equation, from Figure 3 can be analyzed as,

$$s^2 + s\left[\frac{1}{R_{x1}C_1} - \frac{1}{R_{x2}C_1}\right] + \frac{1}{R_{x2}R_{x3}C_1C_2} = 0 \tag{3}$$

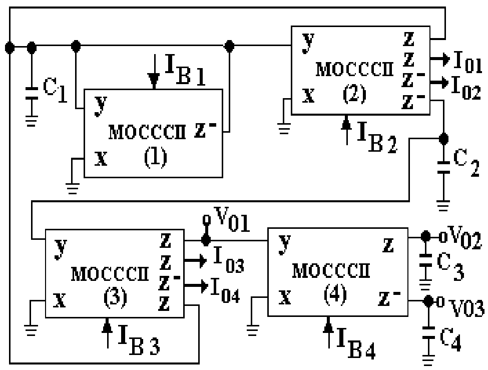

Figure 3. Translinear-C function generator (TCFG) circuit

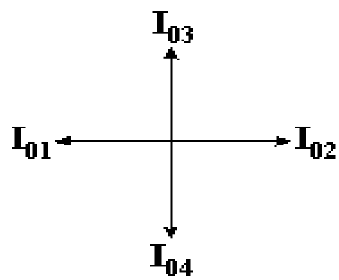

Figure 4. The phaser outputs of the TCFG

Equation (3) yields the condition and the frequency of oscillation(ω_o) respectively as

$$R_{x2} = R_{x1} \tag{4}$$

and

$$\omega_o = \left[\frac{1}{R_{x2}R_{x3}C_1C_2}\right]^{1/2} \tag{5}$$

Hence, with $I_{B1} = I_{B2} = I_{B3} = I_{B4} = I_B$, (5) reduces to

$$\omega_o = \frac{2I_B}{V_T}\left[\frac{1}{C_1C_2}\right]^{1/2} \quad . \tag{6}$$

It is clear from (6) that the frequency of oscillation ω_o can be tuned electronically over a wide range by varying the bias current I_B, which can easily be achieved by implementing all the MOCCCIIs on the same chip. It is to be noted that in such oscillators ω_o is temperature sensitive, hence temperature compensation of translinear current conveyors is essential under varying environmental conditions. This can be accomplished using the technique available in the literature [8].

From Figure 3, at oscillating frequency it can easily be shown that

$$I_{03} = j\, I_{02}, \quad I_{01} = -I_{02} \quad \text{and} \quad I_{03} = -I_{04} \tag{7}$$

which results in four quadrature outputs, as shown in the phaser diagram of Figure 4. It is clear from (7) that I_{01} and I_{02} are of equal magnitude while the magnitudes of I_{03} and I_{04} are equal.

Also, a square voltage is available at one of the output nodes (V_{01}) of the third MOCCCII because of the saturation effect caused by the flow of output current (I_{Z1}) of the node through its own high impedance. To obtain the triangular voltage outputs, an MOCCCII based voltage integrator is connected at this node of the third MOCCCII, as shown in Figure 3. The output current (I_{Z1}) at the third MOCCCII now flows through the high impedance which is a parallel combination of the output impedance of third MOCCCII and input impedance of the *Y*-terminal of the fourth MOCCCII. This maintains the voltage saturation at the node (V_{01}). The integration of this square wave voltage then provides the triangular voltage waveforms of the TCFG, as shown in Figure 3. Thus, the TCFG of Figure 3 provides the sinusoidal quadrature currents, square and triangular voltages, all of the same frequency.

3. SENSITIVITY ANALYSIS

The incremental sensitivity measure on the TCFG's frequency of oscillation was analyzed and given as follows:

$$S^{\omega_0}_{R_{xi},C_i} = -\frac{1}{2} \tag{8}$$

where i = 1,2,3,4. Equation (8) shows that the proposed function generator exhibits low sensitivity properties, *i.e*. less than unity in magnitude.

4. NON-IDEAL EFFECTS

Considering the non-idealities of the MOCCCIIs, the terminal equation (1) can be expressed as

$$\begin{bmatrix} Iy \\ Vx \\ Iz_i^+ \\ Iz_i^- \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ \beta_i & R_x & 0 & 0 \\ 0 & +\alpha_i & 0 & 0 \\ 0 & -\alpha_i & 0 & 0 \end{bmatrix} \begin{bmatrix} Vy \\ Ix \\ Vz_i^+ \\ Vz_i^- \end{bmatrix} \tag{9}$$

where, $\alpha_i = 1-\varepsilon_i$ and $\beta_i = 1-\varepsilon_v$; ε_i ($|\varepsilon_i| << 1$) and ε_v ($|\varepsilon_v| << 1$) represent the current and voltage tracking errors of the i^{th} conveyor, respectively. Taking the non-idealities of the MOCCCIIs into account, the characteristic equation of Figure 3 becomes

$$s^2 + \left[\frac{\beta_1}{Rx_1C_1} - \frac{\beta_2}{Rx_2C_1}\right]s + \frac{\alpha_2\alpha_3\beta_2\beta_3}{Rx_2Rx_3C_1C_2} = 0 \tag{10}$$

which gives the condition and the frequency of oscillation respectively as

$$\beta_1 R_{x2} = \beta_2 R_{x1} \tag{11}$$

and

$$\omega_o = \left[\frac{\alpha_2\alpha_3\beta_2\beta_3}{R_{x2}R_{x3}C_1C_2}\right]^{1/2} \tag{12}$$

Now, if all the MOCCCIIs have the same inequalities *i.e.*,

$$\alpha_1 = \alpha_2 = \alpha_3 = \alpha \ \ and \ \ \beta_1 = \beta_2 = \beta_3 = \beta \tag{13}$$

then, the condition and frequency of oscillation respectively can be written as

$$R_{x2} = R_{x1} \tag{14}$$

and

$$\omega_o = \alpha\beta\left[\frac{1}{R_{x2}R_{x3}C_1C_2}\right]^{1/2} . \tag{15}$$

Hence, with $I_{B1} = I_{B2} = I_{B3} = I_{B4} = I_B$, (15) reduces to

$$\omega_o = \frac{2I_B\alpha\beta}{V_T}\left[\frac{1}{C_1C_2}\right]^{1/2} . \tag{16}$$

From (14) it is clear that the condition of oscillation is not affected at all by the non-idealities but (16) shows that the frequency of oscillation is slightly affected by the tracking errors.

The parasitic resistance (R_x) at the *X*-terminals of the MOCCCIIs are already included in the design. The parasitic capacitances at the *X*-terminal of the MOCCCIIs will be ineffective as all the *X*-terminals in Figure 3 are grounded. The parasitic capacitances at *Y*-terminals and *Z*-terminals of the MOCCCIIs shall be merged with the external capacitances used at these terminals and reduce the actual capacitor values. However, the measured values of the parasitic resistances at input terminal–Y and output terminal-Z of the MOCCCIIs were found to be 200E+9 Ohms which are much higher than the impedances used in the design in the following section and thus their effects on the performance of the TCFG are insignificant.

5. SIMULATION RESULTS

The proposed oscillator circuit of Figure 3 was designed initially for an oscillating frequency, f_0= 122.46KHz using (6). The designed values were found as $C_1 = C_2 = C_3 = C_4$ = 100 pF. At room temperature of 27^0C, (6) yields I_B = 1 µA. The MOCCCII circuit used is obtained from the circuit available in technical literature [4]. The output waveforms obtained through PSPICE simulation are given in Figure 5 and Figure 6. It is clear from Figure 5, that I_{o1} and I_{o2} are of equal magnitudes while the magnitudes of I_{o3} and I_{o4} are equal as given in (7). The saturation voltage (V_{o1}), for ± 2.5V supply was measured and found to be ± 2.48V which is exhibited in Figure 6 as well. The TCFG was then tuned by varying the bias current I_B and results obtained are shown in Figure 7, which illustrates the electronic tuning of the frequency. Thus, the results of Figure 5 through Figure 7, justify the theory.

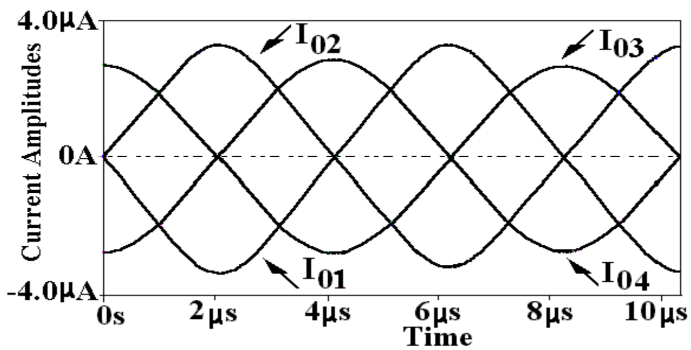

Figure 5. Four phase quadrature current output waveforms of the TCFG

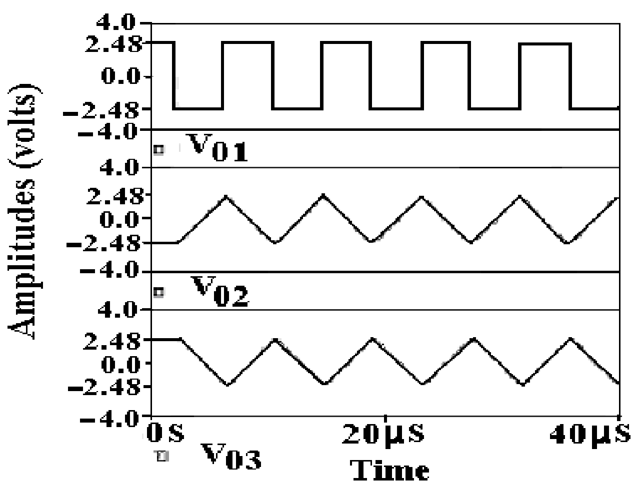

Figure 6. Various voltage output waveforms of the TCFG

Amplitude variation of the various currents with I_B were carried out and the observations given in Figure 8, indicate that the current amplitudes with each other remain almost equal throughout the entire tuning range. However, the amplitude of all the output currents rises together with the increment in the bias current.

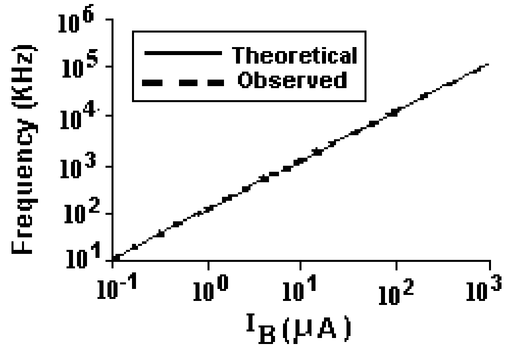

Figure 7. Frequency variation with bias current (I_B)

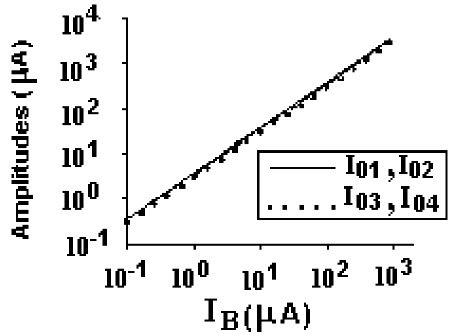

Figure 8. Variation of output currents with bias current (I_B)

6. CONCLUSION

A novel versatile translinear-C function generator is realized using a multi output current controlled second generation current conveyor (MOCCCIIs) based band-pass filter. The realized function generator uses only four MOCCCIIs and only four grounded capacitors. The circuit possesses attractive sensitivity performance and electronic frequency control over a wide range, and is compatible for monolithic implementation in contemporary IC technologies. The simulation results of the function generator verify the theory.

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