Current-mode multi-scroll chaos generator employing CCCII

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Current-mode multi-scroll chaos generator is introduced. It uses second generation current controlled current conveyor (CCCII) and produces current output chaotic signals. PSPICE simulations show that current-mode multi-scroll chaos generator can generate more scroll chaotic attractors with high frequency and low voltage.

Introduction: With increasing of chaotic signal applications, demand on chaos generator that is simple, low voltage and wider frequency range is increasing [1]. In order to improve the frequency characteristics of chaotic attractors, researchers have tried to use current-mode devices to implement high frequency chaos generators. The current-mode devices used for chaos generators mainly include operational transconductance amplifier [2, 3], current feedback operational amplifier [4, 5], or CCII etc., [6–8]. However, the existing chaos generators mostly provide voltage output chaotic signal rather than current output chaotic signal of wider dynamic range and band, hence it is difficult to generate high frequency chaotic attractors with many scrolls. Furthermore, the current signal is easy to design adders and integrators etc., so that current-mode chaotic circuit is more simple and effective [9].

We propose an efficient current-mode multi-scroll chaos generator employing CMOS second generation current controlled current conveyor (CCCII). PSPICE simulations show that the proposed current-mode chaos generator can generate more scroll chaotic attractors with high frequency. Centre of the spectrum is about 3.3 MHz.

Current-mode multi-scroll chaos generator: As shown in Fig. 1, the circuit includes three current integrators and current staircase sequence function employing CCCII. There is no passive resistance in main circuit. It is suitable for integrated circuit realisation.

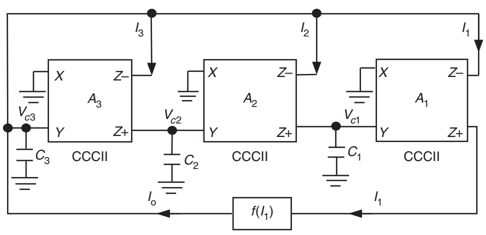

Fig. 1 *Current-mode chaos generator employing CCCII*

CCCII symbol is shown in Fig. 2. The ideal terminal characteristics of CCCII may be written as: $V_x = V_y$, $I_{z+} = I_x$, $I_{z-} = -I_x$, $I_y = 0$. I_b is the biasing current. It controls input resistance R_x of inverting terminal X.

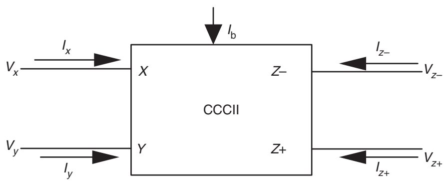

Fig. 2 *Symbol of CCCII*

Considering the main parasitic effect of CCCII is R_{xi} $(i = 1, 2, 3)$ [9], it is tunable by I_b. Thus the proposed current-mode multi-scroll chaos generator may be modelling in mathematics by the following equations:

$$\begin{cases} \dot{I}_1 = \dfrac{I_2}{C_1 \cdot R_{x1}} \\ \dot{I}_2 = \dfrac{I_3}{C_2 \cdot R_{x2}} \\ \dot{I}_3 = -\dfrac{I_1}{R_{x3} \cdot C_3} - \dfrac{I_2}{R_{x3} \cdot C_3} - \dfrac{I_3}{R_{x3} \cdot C_3} + \dfrac{f(I_1)}{C_3 \cdot R_{x3}} \end{cases} \tag{1}$$

Which are third-order non-linear differential equations including current state variables (I_1, I_2, I_3) and current staircase sequence function $f(I_1)$. The current staircase sequence function can be realised by employing CCCII, as shown in Fig. 3.

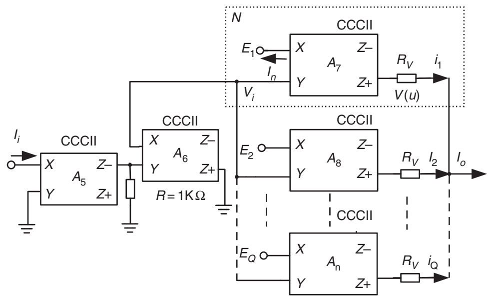

Fig. 3 *Current staircase sequence function circuit*

In Fig. 3, A_5 and A_6 realise I_i convert to V_i. The voltage gain of A_7 is: $V_{z+} = ZI_n = Z((I_i \cdot R - E_1)/R_x)$, where Z is trans-impedance gain of CCCII. Given the supply voltage, the saturation voltage $\pm|V_{sat}|$ of CCCII is determined. Thus, the output voltage of A_7 is:

$$V(u) = |V_{sat}|\mathrm{sign}(V_i - E_1) = |V_{sat}|\mathrm{sign}(I_i \cdot R - E_1) \tag{2}$$

The output current of A_7 is:

$$i_1 = \frac{V(u) - 0}{R_v} = \frac{|V_{sat}|\mathrm{sign}(I_i \cdot R - E_1)}{R_v} = S(I_i \cdot R - E_1) \tag{3}$$

Some basic cells are connected in parallel as shown in Fig. 3 to obtain the current staircase sequence function:

$$I_o = \sum_{j=1}^{Q} i_j = \sum_{j=1}^{Q} \frac{|V_{sat}|\mathrm{sign}(I_i \cdot R - E_j)}{R_v} \tag{4}$$

Set $R_1 = R_2 = R_3 = 1$ KΩ, $C_1 = C_2 = 100$ pF, $C_3 = 143$ pF, $x = I_1$, $y = I_2$, $z = I_3$, $t = R_1C_1\tau$, $dt = R_1C_1\, d\tau$, $a = C_1/C_3$, (1) can be written as:

$$\begin{cases} \dot{x} = y \\ \dot{y} = z \\ \dot{z} = -a \cdot (x + y + z - f(x)) \end{cases} \tag{5}$$

This is Jerk equations, where $a = 0.7$. Comparing (1)–(5), we can get: $f(x) = f(I_1)$. Which is current staircase sequence function, can denote as:

$$f_1(I_1) = \xi\left[\sum_{j=0}^{M} (\mathrm{sgn}(RI_1 + 2j\xi) + \mathrm{sgn}(RI_1 - 2j\xi)) - \mathrm{sgn}(RI_1)\right] \tag{6}$$

or

$$f_2(I_1) = \xi \sum_{j=0}^{N} [\mathrm{sgn}(RI_1 + \xi(2j+1)) + \mathrm{sgn}(RI_1 - \xi(2j+1))] \tag{7}$$

where M or N is integer. $\xi = E_1 = V_{sat}/R_v$. Considering $f(x) \in \{f_1(x), f_2(x)\}$, system (5) can generate $2(M+1)$ scroll or $2N+3$ scroll chaotic attractors.

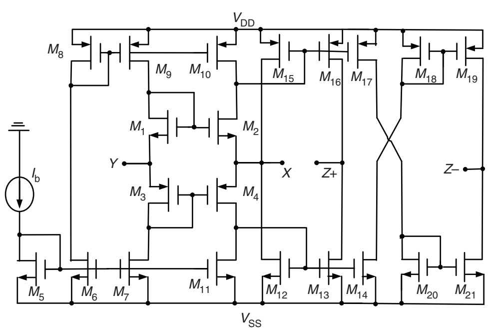

Fig. 4 *CMOS structure of CCCII*

PSPICE simulations: The contrivable CCCII is shown in transistor level in Fig. 4. We use TMSC 0.18 μm CMOS technology transistor models, set the supply voltage as ±1.5 V, $I_b = 100$ μA.

Taking $R_1 = R_2 = R_3 = 1$ kΩ, $C_1 = 100$ pF, $C_2 = 100$ pF, $C_2 = 143$ pF, simulation shows that $\pm|V_{sat}|$ is about ±1.5 V. Setting $R_v = 400$ kΩ, the parameters of current staircase sequence function for generating 20-scroll chaotic attractors are presented in Table 1.

Table 1: Parameters of current staircase sequence function for generating 20-scroll chaotic attractors

E_1	E_2/E_3	E_4/E_5	E_6/E_7	E_8/E_9
0	10 mV −10 mV	20 mV −20 mV	30 mV −30 mV	40 mV −40 mV
E_{10}/E_{11}	E_{12}/E_{13}	E_{14}/E_{15}	E_{16}/E_{17}	E_{18}/E_{19}
50 mV −50 mV	60 mV −60 mV	70 mV −70 mV	80 mV −80 mV	90 mV −90 mV

According to $I_1 = V_{c1}/R_{x1}$, $I_2 = V_{c2}/R_{x2}$, $I_3 = V_{c3}/R_{x3}$, $R_{x1} = R_{x2} = R_{x3}$, by scale transformation, the voltages (V_{c1}, V_{c2}, V_{c3}) satisfy Jerk equations too. PSPICE simulation is shown in Fig. 5. 20-scroll chaotic attractors are generated by the proposed current-mode chaos generator. However, at most 14-scroll chaotic attractors can be physically generated in one direction in the existing literature.

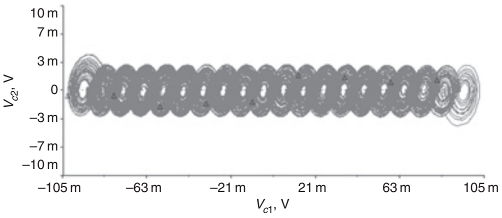

Fig. 5 *PSPICE simulation of 20-scroll chaotic attractors*

As shown in Fig. 6, the centre of chaos spectrum is about 3.3 MHz.

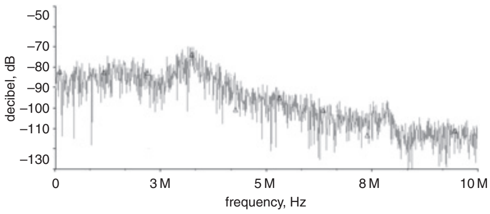

Fig. 6 *PSPICE simulation of chaos spectrum*

Conclusion: A current-mode multi-scroll chaos generator employing CCCII and produces current output chaotic signals is introduced. The proposed chaos generator is composed of current integrators and current staircase sequence function. PSPICE simulations are verified that the current-mode chaos generator can generate more scroll chaotic attractors with high frequency and low voltage.

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