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Square Wave Generator with Voltage-Controlled Frequency Based on Universal Current Conveyor

***Abstract**. A novel square wave generator (relaxation oscillator) with controllable frequency is described. It employs two universal current conveyors (UCC) and grounded passive elements. The generator includes integrator with two integration capacitors that alternate in charging which results in linear and precise control of frequency by voltage. New implementation of UCC with attractive properties in CMOS 0.18 μm technology is also presented. Computer simulations in PSpice environment confirm the theoretical assumptions.*

***Streszczenie.** W artykule przedstawiono nowy generator fali prostokątnej o regulowanej częstotliwości, zbudowany na bazie dwóch przekaźników prądowych (UCC) oraz elementów pasywnych. Opisano także zastosowanie technologii CMOS 0,18um do przekaźników. Dokonano weryfikacji symulacyjnej w programie PSpice. (**Generator fali prostokątnej o napięciowym sterowaniu częstotliwością oparty na uniwersalnych przekaźnikach prądowych**).*

Keywords: Square Wave Generator, Relaxation Oscillators, Universal Current Conveyor.
Słowa kluczowe: generator fali prostokątnej, oscylator relaksacyjny, uniwersalny przekaźnik prądowy.

Introduction

Square waveform generators with controllable frequency are important circuits used in instrumentation and measurement, for instance for signal processing obtained from sensors [1 - 3]. They have better electromagnetic interference immunity, lower sensitivity and simpler structures compared to harmonic oscillators based on a linear positive feedback structure. Due to these properties, many relaxation oscillators have been published recently [2 - 11]. They employ various active elements and their topology usually consists of a Schmitt trigger (comparator with hysteresis) and an integrator in a closed loop.

Our paper presents a novel square wave generator with two current conveyors, only grounded passive elements and frequency that is linearly controlled by voltage. According to our survey of literature, a circuit with the above mentioned properties has not been published yet. Current conveyors have been chosen due to their wide bandwidth, high slew rate, better accuracy and high dynamic range with low supply voltage. Grounded passive elements are advantageous for integrated implementation.

Universal Current Conveyor

The Universal Current Conveyor (UCC) [12 - 14] has the symbol presented in Fig. 1.

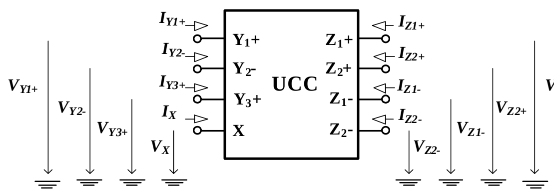

Fig. 1. Symbol of UCC

The input-output characteristics of the ideal UCC is described as:

$$\begin{pmatrix} V_X \\ I_{Y1+} \\ I_{Y2-} \\ I_{Y3+} \\ I_{Z1+,2+} \\ I_{Z1-,2-} \end{pmatrix} = \begin{pmatrix} 1 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1 \end{pmatrix} \cdot \begin{pmatrix} V_{Y1+} \\ V_{Y2-} \\ V_{Y3+} \\ I_X \end{pmatrix} \quad (1)$$

The new CMOS structure of the UCC is presented in Fig. 2 and transistors aspect ratios are given in Table 1. Fig. 3 shows the frequency dependence of the impedances of X, Z+ and Z- terminals with low frequency values 23 mΩ, 0.522 MΩ, and 0.867 MΩ, respectively.

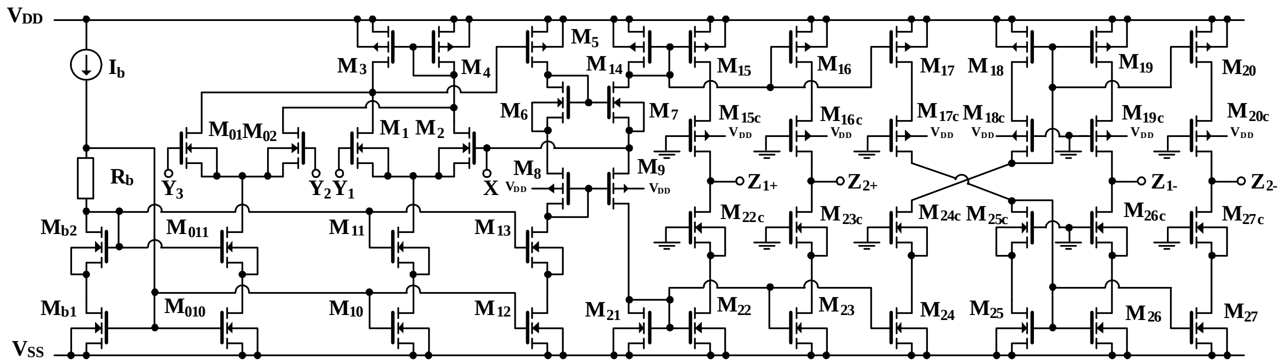

Fig. 2. CMOS implementation of UCC

Table 1. Component values and transistor aspect ratios from Fig. 2

UCC	W/L [µm/µm]
M_1, M_2, M_{01}, M_{02}	20/1
M_3, M_4	10/3
M_5	40/3
M_6, M_7	50/0.5
M_8, M_9	140/0.5
M_{10}, M_{11}, M_{010}, M_{011}	2/1
M_{12}, M_{13}	8/1
M_{14} - M_{20}	120/3
M_{15c} - M_{20c}	15/3
M_{21} - M_{27}	15/3
M_{22c} - M_{27c}	5/1
M_{b1}, M_{b2}	4/1
R_b= 1 kΩ, I_b = 50 µA, V_{DD} = $-V_{SS}$ = 2 V	

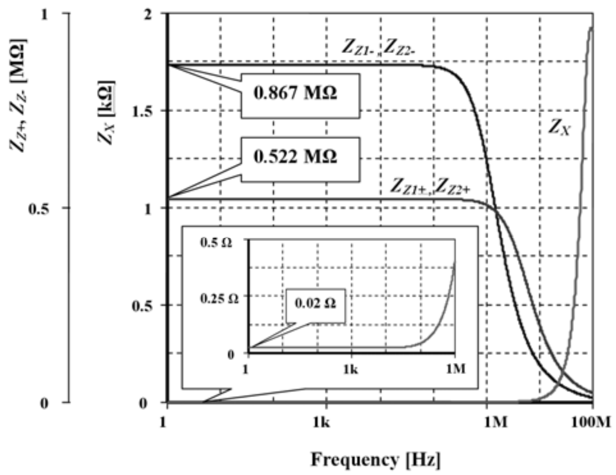

Fig. 3. Frequency dependence of the impedances of X, Z+ and Z- terminals

Fig. 4 shows the frequency responses of current and voltage gains where the -3dB bandwidths are as follows: V_X/V_{Y1}, V_X/V_{Y2}, V_X/V_{Y3}: 128 MHz, I_{Z+}/I_X: 22.2 MHz, and I_{Z-}/I_X: 14.5 MHz.

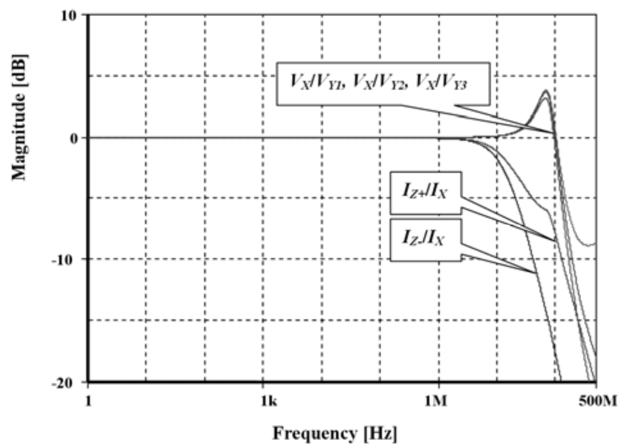

Fig. 4. Frequency responses of current and voltage gains

Square wave generator based on UCC

The designed square wave generator is shown in Fig. 5. The voltages in the circuit are referenced to ground.

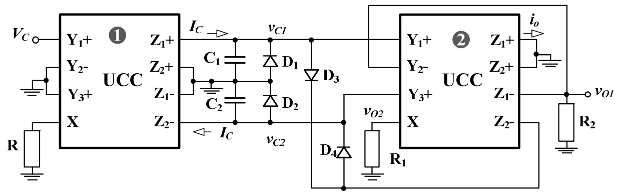

Fig. 5. Square wave generator based on UCC

The elements UCC (1), R, C_1 and C_2 form a voltage integrator. The voltage V_C controls the speed of charging the capacitors and also the frequency of the generated output signal. Providing the voltage V_C is positive, the capacitor C_1 charges to positive voltage and C_2 to negative. Discharging the capacitors is carried out by the Schmitt trigger (comparator with hysteresis) [11] which consists of UCC (2), R_1 and R_2. Its input voltage is the sum of v_{C1} and v_{C2}. The connection of terminals Z_1- and Y_2- provides a positive feedback in the circuit. It is necessary to select $R_2 > R_1$ to ensure the positive feedback with a loop-gain higher than unity. The input threshold levels are given as

$$V_{TH} = -V_{TL} = I_{XZ\max}(R_2 - R_1) \tag{2}$$

where I_{XZmax} is the lower value of the two currents I_{Xmax} and I_{Zmax} which are the maximum currents that can be supplied by UCC at pins X and Z_{1-} respectively. Relation (2) is exactly valid only for "ideally" limiting conveyor, which means that output current is constant outside a linear operation area. Most real conveyors do not start to limit suddenly at a certain value of input current, but they have rounded transfer characteristic at the transition between linear operation and limiting.

Fig. 6 shows the corresponding waveforms of the generator. It is seen from the waveforms that the circuit operates in two cycles. In one cycle the capacitor C_1 integrates the current I_C that is proportional to the input control voltage ($I_C = V_C/R$). In the same cycle the capacitor C_2 is charged by the saturation current of the Schmitt trigger flowing through the diode D_4. The voltage on C_2 quickly reaches the cut-in voltage V_D of the diode D_2. When the voltage ($v_{C1} + v_{C2}$) reaches V_{TH}, the Schmitt trigger changes its state and the second cycle begins. Here the output current of the Schmitt trigger is opposite, C_1 quickly discharges through D_3 to $-V_D$ and C_2 integrates the current I_C until the sum of v_{C1} and v_{C2} reaches V_{TL}. Utilization of two capacitors results in better frequency linearity and accuracy. Simple voltage-controlled relaxation oscillators have only one capacitor that integrates the current derived from the control voltage in one cycle and is discharged by Schmitt trigger in the second cycle. The discharging time does not depend on the control voltage and this brings error into the $V - f$ conversion. In our generator, the periods of both cycles are directly proportional to the control voltage. It should be noted that the output of the generator can be chosen also at pin X of UCC. This output is of low impedance. Moreover, a high-impedance current output at terminal Z_{1+} is also available.

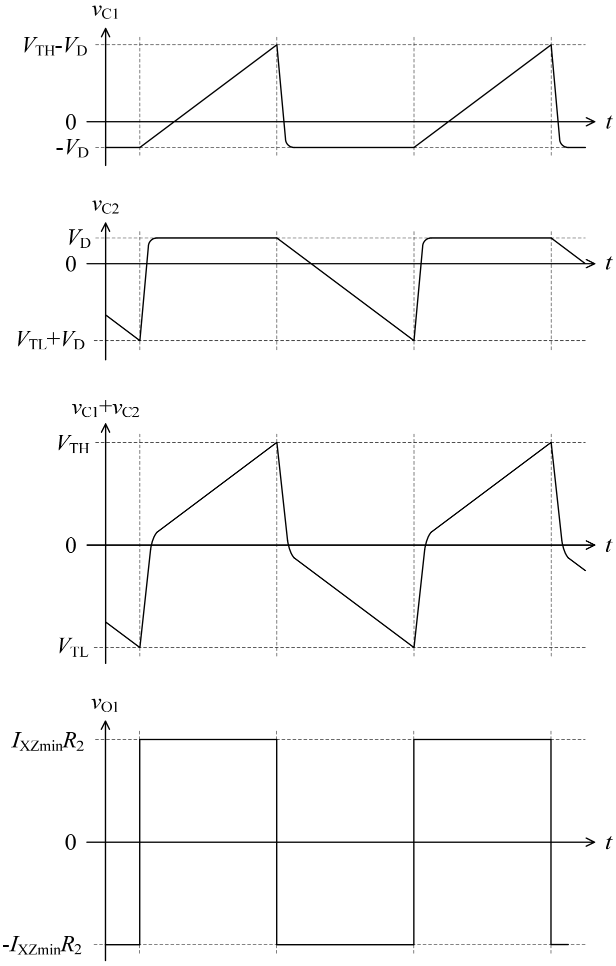

Fig. 6. Waveforms of the generator

The following relation can be derived for the maximum generated frequency

(3) $$f_{\mathrm{Gmax}} = \frac{I_{\mathrm{Zmax}}}{4CV_{TH}}\text{, where } C = C_1 = C_2$$

This ensures that the output current I_{Zmax} of the Schmitt trigger manages to discharge the capacitor to the cut-in voltage of the parallel diode during the time of one operating cycle at the maximum generator frequency f_{Gmax}. The frequency of the generated signal is

(4) $$f_{\mathrm{G}} = \frac{V_{\mathrm{C}}}{2RCV_{TH}}$$

Computer simulation

While computing numerical parameters of the circuit and performing its simulations we will consider the parameters of the conveyor described above. The maximum Z-terminal current of the conveyor is $I_{\mathrm{Zmax}} \approx$ 550 μA. The resistance R_2 will be chosen 1 kΩ which results in the amplitude of the output voltage v_{O1} of cca 0.55 V. This is below the maximum pin voltage of the conveyor and thus current (not voltage) limiting occurs at Z_{1-} terminal. If the resistance R_1 = 230 Ω, the Schmitt trigger threshold voltage is according to (2) $V_{\mathrm{TH}} \approx -V_{\mathrm{TL}} \approx$ 0.42 V. This value is approximate as described below the relation (2). The capacitances $C_1 = C_2$ were chosen 0.4 nF which allows maximum frequency $f_{\mathrm{Gmax}} \approx$ 812 kHz according to (3). Finally R = 10 kΩ and diodes were chosen BAT68 Schottky. Fig. 7 shows the waveforms of the capacitor and output voltages with V_{C} = 0.5 V. Dependency of generator frequency on control voltage is demonstrated in Fig. 8. The slight deviation from linearity is caused by the “non-ideally” limiting conveyor which was already discussed below the equation (2).

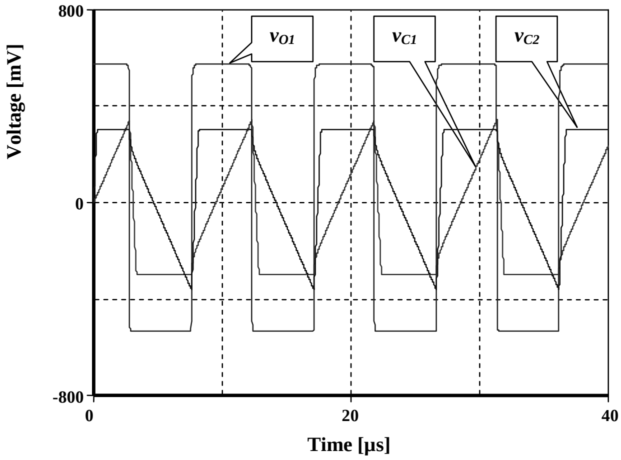

Fig. 7. Waveforms of the generator with V_{C} = 0.5V

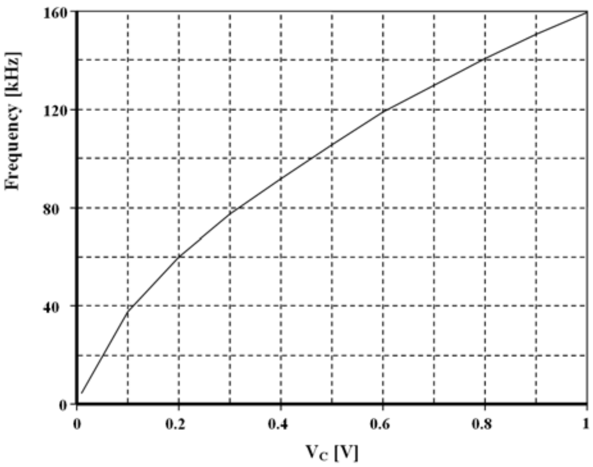

Fig. 8. Generated frequency versus control voltage

Conclusions

Relaxation oscillator employing two universal current conveyors and grounded passive elements has been proposed. Relations and recommendations for computing element parameters have been given. Frequency of generated signal is linearly controlled by voltage with a good accuracy and in a wide range.

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