Voltage-Controlled Square/Triangular Wave Generator with Current Conveyors and Switching Diodes

Martin Janecek, David Kubanek, and Kamil Vrba

***Abstract*—A novel relaxation oscillator based on integrating the diode-switched currents and Schmitt trigger is presented. It is derived from a known circuit with operational amplifiers where these active elements were replaced by current conveyors. The circuit employs only grounded resistances and capacitance and is suitable for high frequency square and triangular signal generation. Its frequency can be linearly and accurately controlled by voltage that is applied to a high-impedance input. Computer simulation with a model of a manufactured conveyor prototype verifies theoretical assumptions.**

***Keywords*—Current conveyor, Relaxation oscillator, Schmitt trigger, VCO, Voltage-controlled oscillator.**

I. INTRODUCTION

Square waveform generators with controllable frequency are widely used circuits in the fields of instrumentation and measurement. They serve as interfaces for signal processing from sensors [1], [2], [3], as they offer better electromagnetic interference immunity, lower sensitivity, and simpler structures compared to harmonic oscillators based on a linear positive feedback structure. Due to these advantages, many relaxation oscillators have been published recently [2] – [11]. The topology of relaxation oscillator usually consists of a Schmitt trigger and an integrator in a closed loop. Designers employed various active elements in these blocks. Initially mostly operational amplifiers were used, later operational transconductance amplifiers, current conveyors, current feedback operational amplifiers etc.

Our paper presents a novel square/triangular wave generator with current conveyors, only grounded resistances and integration capacitance. This makes the circuit attractive for integrated implementation. High-impedance voltage input is used to accurate, linear, and wideband control of oscillation frequency. The generator is a modification of an opamp-based circuit where the active elements were appropriately replaced by current conveyors. Thanks to conveyors the circuit can operate with wider bandwidth, higher slew rate, better accuracy, and higher dynamic range with low supply voltage.

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II. GENERATOR CIRCUIT

A. *Original Circuit with Opamps*

The generator designed in this paper is based on the circuit shown in Fig. 1.

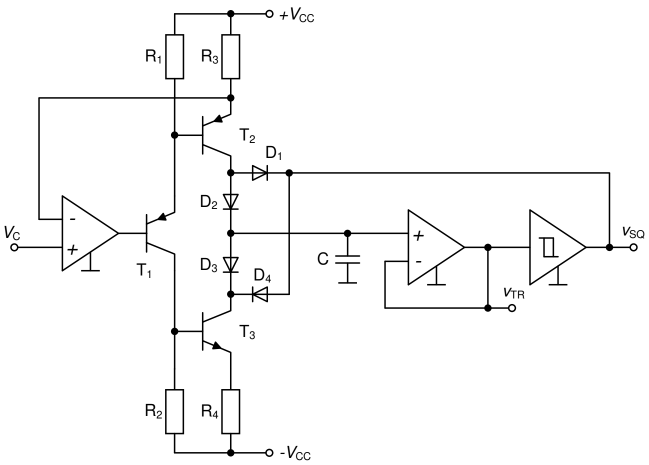

Fig. 1. Generator with operational amplifiers and transistors

It is a well known structure of relaxation oscillator where the capacitor C is periodically charged and discharged by a constant current that alternates its polarity. Magnitude of this current is directly proportional to the control voltage V_C and this current is generated in the left part of the circuit (from the capacitor C). The control voltage regulates the speed of charging the capacitor and also the frequency of the generated output signal. If it is valid $R_3 = R_4$, the collector currents of the transistors T_2 and T_3 are equal and are flowing down in the schematic (providing that the control voltage is positive). The diodes D_1 to D_4 ensure switching the T_2 and T_3 collector currents in the following way: if the hysteresis comparator output is low, D_1 is open and drains the entire T_2 collector current into the comparator output. Thus no current flows through D_2. In this period C is being discharged by the T_3 collector current via D_3. If the capacitor voltage reaches negative threshold of the comparator, the output of comparator changes to high. In this case D_2 leads the entire T_2 collector current into the capacitor which is being charged until its voltage reaches the positive threshold of the comparator. D_4 is open and no current flows through D_3. The voltage at v_{TR} output has a triangular waveform and voltage at v_{SQ} output a square waveform.

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B. Current Conveyors Employed

Before we introduce the novel generator circuit, we present the current conveyors CCII+/- and UCC [12] that are employed in the circuit solution. Their symbols and terminal specification are shown in Fig. 2. The following relations are valid for the voltages and currents in Fig. 1:

UCC:
$I_{Y1+} = I_{Y2-} = I_{Y3+} = 0$, $V_X = V_{Y1+} - V_{Y2-} + V_{Y3+}$, $I_{Z1+} = -I_{Z1-} = I_{Z2+} = -I_{Z2-} = I_X$.

CCII+/–:
$I_Y = 0$, $V_X = V_Y$, $I_{Z+} = -I_{Z-} = I_X$.

These two conveyors are included in the integrated circuit UCC-N1B [13] whose samples were manufactured in the ON Semiconductor Design Centre Brno, Czech Republic. The proposed generator can be realized with only one UCC-N1B circuit.

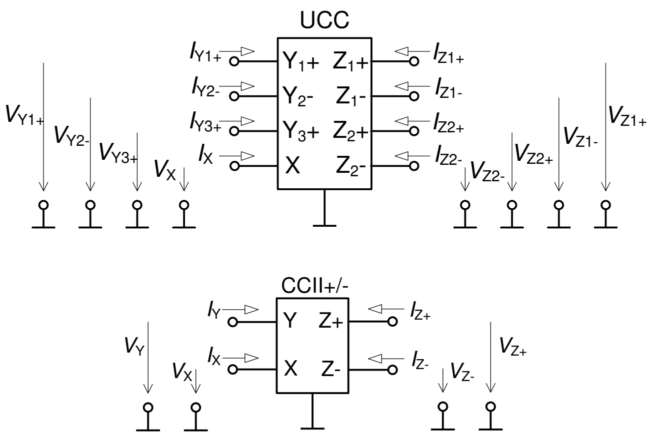


Fig. 2. UCC and CCII+/- symbols and their terminal specification

C. Oscillator with Current Conveyors

The proposed square/triangular wave oscillator is shown in Fig. 3.

As apparent, the transistor current source was replaced by CCII+/- which converts the input control voltage V_C to currents with opposite directions at Z+ and Z- outputs. The method of switching currents by the four diodes remained unchanged and works in the same way as described above.

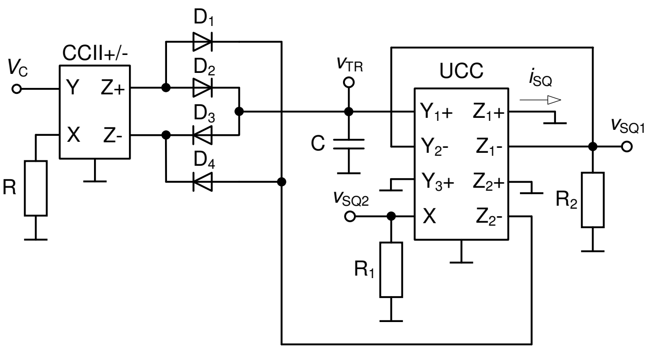


Fig. 3. Square/triangular wave generator

The slight difference is that cathode of D_1 and anode of D_4 are connected to current output of hysteresis comparator (Schmitt trigger) [11] which consists of UCC, R_1, and R_2. The Z_1- Y_2- connection provides a positive feedback in the comparator. 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 of the comparator are given as

$$V_{TH} = -V_{TL} = I_{XZ\max}(R_2 - R_1), \quad (1)$$

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. The Schmitt trigger can be also designed using simple CCIIs as it was shown in [14], however, two active elements have to be used.

The triangular output voltage (v_{TR}) is taken directly from the capacitor C. Two voltage outputs (v_{SQ1} and v_{SQ2}) offer mutually inverted square waveforms. These outputs can be loaded only with very high impedance, otherwise a voltage buffer must be connected. A current output (i_{SQ}) is also available, which can be loaded by arbitrary impedance without affecting the circuit performance.

The frequency of the generated signal is

$$f_G = \frac{V_C}{2RC(V_{TH} - V_{TL})} = \frac{V_C}{4RCI_{XZ\max}(R_2 - R_1)}. \quad (2)$$

III. Computer Simulation

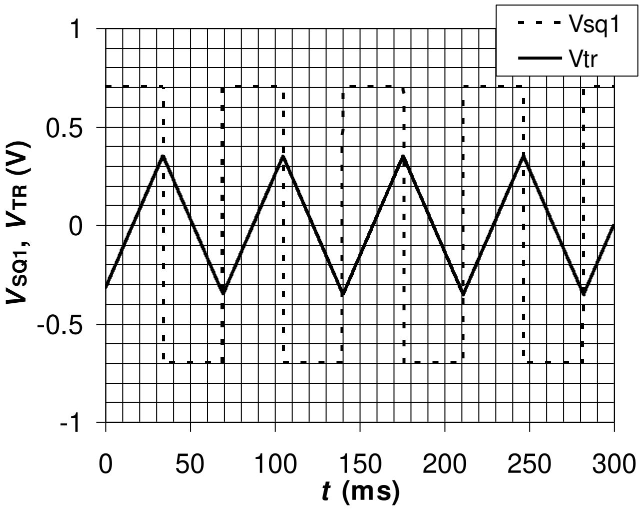
While computing numerical parameters of the circuit and performing its simulations we will consider the real parameters of the UCC-N1B prototype. The maximum X and Z terminal currents of the conveyor are the same, namely $I_{Xmax} = I_{Zmax} = I_{XZmax} = 0.7$ mA. The resistance R_2 will be chosen 1 kΩ which results in the amplitude of the output voltage v_{SQ1} of 0.7 V. If the resistance $R_1 = 500$ Ω, the Schmitt trigger threshold voltage is according to (1) $V_{TH} = -V_{TL} = 0.35$ V. The resistance R was chosen 1 kΩ and diodes BAT68 Schottky.

Figs. 4 a) and b) show the waveforms of the generator with $V_C = 0.1$ V, $C = 5$ nF, (theoretical frequency $f_G = 14.3$ kHz), and $V_C = 0.7$ V, $C = 200$ pF, (theoretical frequency $f_G = 2.5$ MHz), respectively.

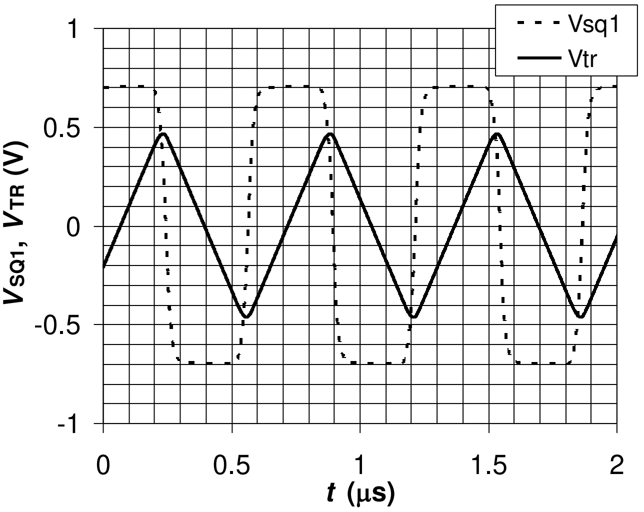
Fig. 4 a) shows the behaviour of the circuit at low frequency. Here the influence of conveyor non-idealities is very small and the waveforms are almost ideal. Distortion is apparent in Fig. 4 b) where the simulated frequency is about 1.5 MHz, which differs from the theoretical value, but the waveforms still maintain their shape.

Dependency of frequency on control voltage for three values of capacitance C is demonstrated in Fig. 5.

The simulated frequency corresponds very well with the ideal one computed by (2) at frequencies below 100 kHz. Above this frequency the error increases but the dependency is still nearly linear.



a)



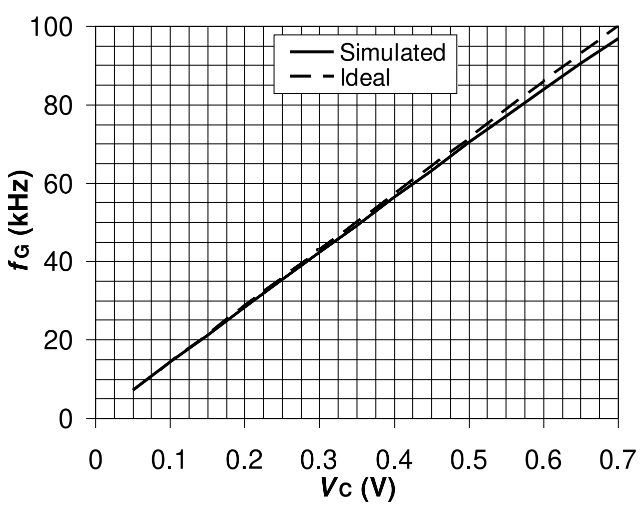
b)

Fig. 4. Simulated waveforms of the generator; a) V_C = 0.1 V, C = 5 nF; b) V_C = 0.7 V, C = 200 pF

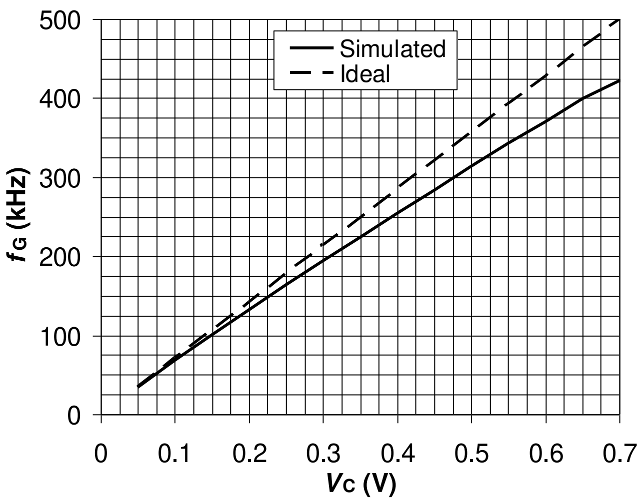
IV. Conclusion

Relaxation oscillator with two current conveyors according to a classic circuit with operational amplifiers has been designed. It employs only grounded passive elements, which is advantageous for integrated implementation. The circuit features with voltage triangular-wave output and both voltage and current square-wave output.

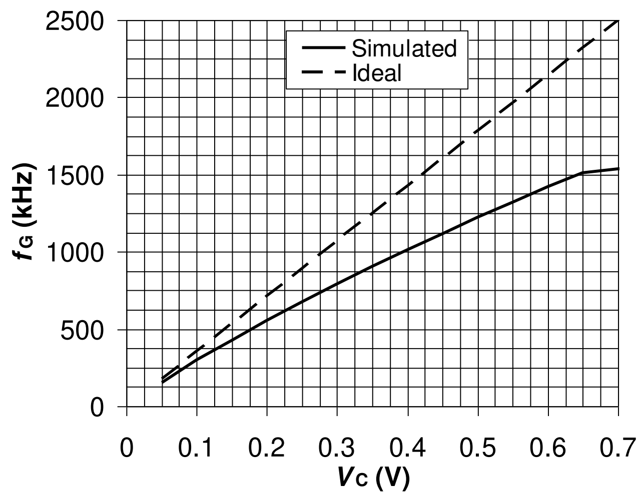
The generated frequency is directly proportional to the control voltage and the relation for evaluating the generated frequency depending on the control voltage and element values has been given. The circuit functionality has been verified by computer simulations with a PSpice model of manufactured sample of universal current conveyor UCC-N1B. Thanks to the high-speed conveyors and diodes the circuit is suitable for generating high frequency signals. The generated frequency agrees with theoretical assumptions up to about 100 kHz and linearity of the frequency setting is maintained up to units of megahertz. The future work in this area will continue with practical implementation of the proposed circuit and modifications improving the accuracy of the generated frequency according to the control voltage.



a)



b)



c)

Fig. 5. Generated frequency vs control voltage for three capacitances a) C = 5 nF, b) C = 1 nF, c) C = 200 pF

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