Current-Controllable Square/Triangular Waveform Generators using Operational Transconductance Amplifier and Uniform Distributed RC

Atichaya Klungtong 1+, Supachai Klungtong, Virote Pirajnanchai and Paitoon Rakluea

1 Faculty of Engineering, Rajamangala University of Technology Thanyaburi, 12110, Thailand

Abstract. This article presents the square/triangular waveform generators circuit. Its scheme is principally composed of two operational transconductance amplifiers (OTAs) and single-layer uniform distributed RC (URC). The features of the proposed circuit are that, its output waveform width and height can be independently controlled by the OTAs bias currents, which is not dependent on power supply level and schematic is simple. In addition, characteristics of proposed square/triangular waveform generators circuit and its application are simulated by the PSpice program and they are in agreement with the theory.

Keywords: square/triangular waveform generator, operational transconductance amplifier, uniform distributed RC

1. Introduction

Square and triangular waveform generators with current-controllable frequency have a wide range of applications in signal processing, communication system, instrumentation and measurement system. Such generators can be easily realized by using an operational transconductance amplifier (OTA). Several topologies for waveform generators have been reported in the literature [1]-[4]. The design uses OTAs as switching element and controls the frequency by DC bias current. Typically, the pulse waveform generators are employed to implement such function. It is composed of voltage comparator, timing resistor and timing capacitors. The basic operation of this circuit is RC series network. With the provided voltage source, the capacitor is charged and discharged where the voltage across capacitor rises and falls exponentially. When the charged voltage reaches an upper threshold level, it results in changing of the waveform state. The positive output waveform is then generated. The height of output waveform depends on the supply’s voltage whereas the waveform width is directly proportional to the RC time constant. However, it is interesting to mention about some disadvantages of the conventional waveform generators circuit. Firstly, the input waveform width has an effect on the operation of the circuit. Namely, most circuit requires the input waveform width to be either wider or narrower than the output waveform width. Secondly, the output pulse height of most circuit cannot be electronically adjusted which is important in some application.

In this paper, the square/triangular waveform generators circuit using operational transconductance amplifiers (OTAs) and single layer uniform distributed RC (URC) is presented where its output waveform width and height can be electronically tuned and frequency controls by any capacitance of URC circuit. The proposed circuit scheme is composed of two OTAs and one single layer URC. An OTA provides a highly linear electronic and a wide tunable range of the transconductance gain. The characteristics URC elements have several advantages over lumped RC network. The structure of distributed RC elements in thin-film technology is built using smaller high frequency. Distributed RC elements may have many form structure. [5] For instance, single layer capacitive, double layers capacitive and multi layer thin-film structure.
structure of the general URC consists of layers of conductors, resistive layer and dielectrics can be
sandwiched together in many permutations. The resistive or conductive layers may be contacted at various
points around their edges. Other advantages are applied to active filters. For instance single capacitive layer
URC [6] and double capacitive layers in the conjunction with amplifier in literatures [7], [8].

2. Circuit Description

2.1. Operational Transconductance Amplifier (OTA)

The operation transconductance amplifier (OTA) is a transconductance type device, which means that
the input voltage controls an output current by means of the device transconductance, labelled \( g_m \). This
makes the OTA voltage-controlled current source (VCCS), which is in contrast to the conventional op-amp,
which is a voltage-controlled voltage source (VCVS). What is important and useful about the OTA’s
transconductance parameter is that it is controlled by an external current, the amplifier bias current, \( IB \), so
that one obtains \( g_m = \frac{I_B}{2V_T} \), where \( V_T \) is the thermal voltage (26mv) [9]. From this externally controlled
transconductance, the output current as a function of the applied voltage difference between the two input
pins, labelled \( V_1 \) and \( V_2 \), is given by

\[
I_o = g_m (V_1 - V_2)
\]

Clearly, an output voltage can be derived from this current by simply driving a resistive load. The port
relation of OTA as shown in Fig. 1(a) and equivalent circuit of the ideal OTA is shown in Fig. 1(b).

\[
\begin{align*}
I_o &= g_m (V_1 - V_2) \\
\text{(a)} & \quad \text{(b)}
\end{align*}
\]

2.2. Grounded Uniformly Distributed RC (URC)

A grounded URC is a symmetric two-port linear element characterized by resistance per-unit length \( R_0 \)
in \( \Omega/m \), its capacitance per-unit length \( C_0 \) in F/m and its total length \( L \). It is symbolically represented by the
T network of Fig.2. The total resistance and capacitance URC are \( R=R_0L \) and \( C=C_0L \), respectively. The time
constant \( \tau \) is defined as.

\[
\tau = R_0 C_0 L^2 = RC
\]

and is a measure of the propagation delay along the body of the URC. For frequencies much smaller than \( 1/\tau \)
the URC behaves like a lumped RC element. The URC accepts all two port descriptions; in particular, if \( Z_0 \)
is its driving impedance and \( Z_m \) is its transimpedance, we have

\[
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix} =
\begin{bmatrix}
Z_0 & Z_m \\
Z_m & Z_0
\end{bmatrix}
\begin{bmatrix}
I_1 \\
I_2
\end{bmatrix}
\]

and is a measure of the propagation delay along the body of the URC. For frequencies much smaller than \( 1/\tau \)
the URC behaves like a lumped RC element. The URC accepts all two port descriptions; in particular, if \( Z_0 \)
is its driving impedance and \( Z_m \) is its transimpedance, we have

\[
\begin{bmatrix}
V_1 \\
V_2
\end{bmatrix} =
\begin{bmatrix}
Z_0 & Z_m \\
Z_m & Z_0
\end{bmatrix}
\begin{bmatrix}
I_1 \\
I_2
\end{bmatrix}
\]

Fig. 2: (a) A Uniformly Distributed RC section, (b) are symbolic and its equivalent lumped T network
The two linear equations (3), relating the four variables \( V_1, I_1, V_2 \) and \( I_2 \) of the two-port, are independent. Two URCs are called commensurate [10] if they equal time constants. Pairs of commensurate URC have been used widely in past works.

### 2.3. Waveforms Generator

The proposed circuit has been modified from astable multivibrator circuit [10]-[12] which is shown in Fig.3 (a). The operation of this circuit is thus first given. It is assumed that the realization of the circuit based on CMOS transistors. Basically, the OTA serves as an adjustable resistor, which is controlled by bias current \( (I_B) \), where the Op-Amp, the capacitor \( C \) and the resisters \( R_1, R_2 \) construct an inverting Schmitt trigger circuit. Based on periodic charge/discharge operation of the capacitor, the triangular wave \( V_C(t) \) and the square wave \( V_O(t) \) are then generated as illustrated in Fig.3(b) where the oscillated frequency is given by

\[
f = \frac{g_m}{4kC} \quad \text{where} \quad k = \frac{R_1}{R_1 + R_2}
\]

As shown in Fig.3 (b), \( V_{OH} \) and \( V_{OL} \) represent positive and negative saturate voltages of \( V_O(t) \), respectively, whereas \( V_{IH} \) and \( V_{IL} \) are respectively positive and negative threshold voltage of the Op-Amp non-inverting node.

![Circuit Diagram](image)

**Fig. 3:** (a) Basic pulse generator circuit, (b) Circuit’s signal

### 3. Waveform Generators Proposed Circuit

Based on the circuit illustrated in Fig. 3(a), it is applied for proposed square/triangular waveform generators. The circuit modified by replacing the Op-Amp with the OTA2, URC and modifies the circuit structure as shown in Fig.4 (a). When the OTA2 is in saturation mode, the peak to peak amplitude of output signal is given by

\[
V_{O1}(t)_{pp} = 2I_{B1}Z_0
\]

\[
V_{O2}(t)_{pp} = 2I_{B2}Z_m
\]

Implying that the amplitude can be electronically adjusted by the bias current \( I_{B1} \) and \( I_{B2} \). In addition, the frequency can controllable by the parameters of passive element value URC. The input signal \( V_{2OTA1}(t) \) and \( V_{1OTA1}(t) \) are fed into the output node of the OTA2 and capacitance node of the URC, respectively. At the initial state, the inverting node of the OTA2 is connected to the ground. It causes the output voltage \( V_{O1}(t) \) to be \( +I_{B1}Z_0 \). Let us consider the OTA2, \( V_{O2}(t) \) is equal to \( +I_{B2}Z_m \). When the positive rising edge of the input signal is present and maximum voltage level is greater than \( V_{O1}(t) \), \( V_{O2}(t) \) then changes to negative saturate voltage \( -I_{B2}Z_m \) causing \( V_{O1}(t) \) converts to negative saturate voltage \( -I_{B1}Z_0 \). With the negative voltage level of \( V_{O1}(t) \), resulting in discharging process of URC capacitance by \( I_{B1} \). The voltage across URC capacitance. \( V_{URC}(t) \) is thus linearly decreased. When \( V_{URC}(t) \) reaches to voltage level that is less than \( -I_{B2}Z_m \), \( V_{O1}(t) \) and \( V_{O2}(t) \) are again converted to positive voltage \( +I_{B1}Z_0 \) and \( +I_{B2}Z_m \), respectively. The described circuit operation is illustrated by timing diagram given in Fig.4 (b). The output pulse width of the proposed circuit is

209
\[ T = C_0 R_0 L^2 \sqrt{\frac{I_{B_2}}{I_{B_1}}} \]  \hspace{1cm} (7)

where its height is defined by

\[ V_{O1}(t)_{pp} = 2I_{B1}Z_0 \]  \hspace{1cm} (8)

Both (7) and (9) express that the waveform’s width and height of this circuit are electrically tunable which are adjusted by the bias current \( I_{B1} \) and/or \( I_{B2} \), respectively. As can be seen, the advantage of the proposed scheme is focused on the ability of electronically control.

4. Simulation Results

The proposed square/triangular waveform generators of Fig. 4 (a) was simulated with PSpice using the LM13700 OTA simplified model, and The URC is approximated by the ladder lumped RC elements of 10 sections, The proposed circuit using two OTA and one URC. A typical output triangular waveform obtained from the simulation of the circuit (with the total capacitance \( C=400nF \) and the total resistance \( R=2M\Omega \)) are shown in Fig.5 along with the square wave generated at the output of the astable multivibrator. The frequency of the waveforms in this case found to be 0.8 kHz. This result is in good agreement with the frequency 0.8 kHz calculate using the derived analytical formula given by (7)

![Fig. 5: (a) Output signal waveform generator \( V_{O2}(t) \), (b) Square waveform generator output signal \( V_{O1}(t) \), Triangular waveform generator differential output signal \( V_{O1}(t) \) and \( V_{O2}(t) \)](image)

Next, the ability of electrically amplitude control and pulse width control is demonstrated in Fig. 6. For pulse width adjustment, \( I_{B1} \) and \( I_{B2} \) are varied as shown the x-axis.
5. Conclusion

In this paper, a new square/triangular waveform generators using operational transconductance amplifiers (OTA) and uniform distributed RC (URC) with independent control of frequency and amplitude has been presented. It is shown that the simulation results confirm well with the theoretical analysis that matches very closely. This Circuit can be expected to find wider applications in many applied electronics circuit, communications circuit, instrumentation, and signal processing applications.

6. References


Fig. 6: Variation of time period at $V_{01}(t)$ for variation in bias current