CA3080 And LT1228 Based Linear Voltage Controlled Square-Triangular Wave Oscillator

Himanshu Shekhar[*1], Aashiya[*2], Neha[*3], Rahul Kumar[*4]

[*1]Department of Electronics and Communication Engineering, Netaji Subhas University of Technology, Delhi, India
[*2]Department of Electronics and Communication Engineering, Netaji Subhas University of Technology, Delhi, India
[*3]Department of Electronics and Communication Engineering, Netaji Subhas University of Technology, Delhi, India
[*4]Department of Electronics and Communication Engineering, Netaji Subhas University of Technology, Delhi, India

ABSTRACT

This paper presents the design and realization of a square/triangular waveform generator based on current-mode design principles using the LT1228 integrated circuit, which internally combines an operational transconductance amplifier (OTA) with a current feedback amplifier (CFA) and a current-mode integrator. The proposed circuit overcomes the limitations of conventional voltage-mode waveform generators, which rely on RC networks and comparators, by utilizing OTAs, a CFA, and an op-amp for both integration and Schmitt trigger functions. The Schmitt trigger, configured using the LT1228 in its saturation region, provides a stable square waveform with electronically adjustable hysteresis through the bias current. The amplitude and duty cycle of the generated waveforms are independently tunable by controlling the input voltages and reference voltage (Vref), offering a flexible and compact solution for voltage and power applications. Experimental results confirm the circuit's capability to generate waveforms at approximately 10.42 kHz, with duty cycles of 90%, 50%, and 10% by adjusting Vref from -1.6V to 1.6V. The design operates efficiently at ±1V supply, making it ideal for integration into sensor interfaces, waveform generators, modulators, and analog signal processing circuits.

Keywords: Current-mode integrator, LT1228, Schmitt trigger, Square/triangular wave generator, Duty cycle control

I. INTRODUCTION

Square/triangular wave generators are widely used in instrumentation, pulse width modulators, capacitive/resistive sensors interface, digital capacitance/impedance measurements, measurement equipment, sensor interfaces, communication modules, and the feedback control circuits of power converters and modulator circuits. Such generators can be easily realized by using an operational transconductance amplifier (OTA) as a switching current source to charge and discharge a grounded timing capacitor, followed by a Schmitt trigger [1]. The design uses OTAs as a switching element and controls the frequency by DC bias current. Typically, the pulse waveform generators are employed to implement such functions. It comprises a voltage comparator, a timing resistor, and timing capacitors. The basic operation of this circuit is the RC series network. With the provided voltage source, the capacitor is charged and discharged, where the voltage across the capacitor rises and falls exponentially. When the charged voltage reaches an upper threshold level, it results in a change of the waveform state. The positive output waveform is then generated. The height of the output waveform depends on the supply's voltage, whereas the waveform width is directly proportional to the RC time constant. An OTA provides a highly linear electronic and a wide tunable range of the transconductance gain.

Many triangular and square wave generators consist of a Schmitt trigger with a lossy integrator that provides only a square wave. In addition, the frequency cannot be tuned by the electronic method, and the duty cycle cannot be adjusted. Additionally, the frequency control is nonlinear. Thus, it is not easy to control.

Until now, many researchers have presented studies focused on using Operational Transconductance Amplifiers (OTAs) to synthesize various electronic circuits. Waveform generators are fundamental building blocks for numerous electronic systems. For this work, we studied multiple OTA-based waveform generator circuits to understand their architecture and control mechanisms. The first circuit, from [2], employs a single Dual-Output OTA (DO-OTA) to generate square and triangular waveforms. The OTA functions as a comparator with current-controlled transconductance, and the oscillation characteristics are tuned using an external bias current. It offers a compact configuration with control over frequency and duty cycle. Although a compact architecture is achieved using a single DO-OTA, the frequency and duty cycle are not independently controllable, and accurate waveform symmetry depends heavily on matched component values and bias currents. The second circuit [3], utilizes multiple OTAs and passive components. It enables independent control of frequency and amplitude via separate bias currents, providing high linearity and a wide tuning range suitable for applications requiring precise waveform shaping; however, this comes at the cost of increased circuit complexity, power consumption, and area due to the use of multiple OTAs and resistors. Now we propose an improved square/triangular wave generator circuit based on current-mode design principles in which the oscillation amplitude and duty cycle can be independently controlled by input voltages and reference voltage (Vref), offering a flexible and compact solution for voltage and power applications. Experimental results confirm the circuit's capability to generate waveforms at approximately 10.42 kHz, with duty cycles of 90%, 50%, and 10% by adjusting Vref from -1.6V to 1.6V. Our proposed circuit effectively overcomes the limitations identified in previously reported OTA-based designs by offering wide range operation, and full electronic tunability of both duty cycle and amplitude.

II.METHODOLOGY

A Schmitt Trigger is a comparator circuit with hysteresis, widely used in digital and analog systems to convert a noisy or slowly varying input signal into a clean, fast-transitioning digital output. Unlike a standard comparator, the Schmitt Trigger introduces two distinct threshold voltages, the upper threshold and the lower threshold which define when the output switches from high to low or vice versa. This hysteresis behavior effectively eliminates unwanted output toggling caused by noise or small fluctuations in the input signal near the switching threshold.

In practical applications, Schmitt Triggers are valuable for debouncing mechanical switches, waveform shaping, and generating square waves from analog inputs. In oscillator circuits, they often serve as essential building blocks to ensure clean and stable transitions, especially when integrated with RC networks or used as feedback components.

An integrator circuit, typically implemented using an operational amplifier (op-amp) or an Operational Transconductance amplifier (OTA), performs the mathematical integration of its input signal. When a constant or square wave voltage is applied at the input, the output of the integrator becomes a linearly ramping waveform, essentially a triangular wave if the input is a square wave. This occurs because integration of a constant value (like the high or low level of a square wave) results in a steadily increasing or decreasing voltage over time. As the input alternates between high and low states, the output alternates between positive and negative slopes, producing a continuous triangular waveform.

In OTA-based implementations of the Schmitt Trigger and integrator circuits, the control voltage or bias current can be used to linearly vary the key parameters of operation[1]. For the Schmitt Trigger, the hysteresis window defined by its upper and lower threshold voltages can be modulated by adjusting the OTA's transconductance (g_m), which itself is a linear function of the control voltage. This feature allows the threshold levels to be dynamically tuned in real time, making the circuit adaptable to varying input conditions or noise environments. Similarly, in an OTA-based integrator, the rate of change of the output voltage, or the slope of the triangular waveform generated in response to a square wave input, is directly proportional to g_m and inversely proportional to the integrating capacitor. By controlling g_m through a voltage or current source, the integration rate can be linearly adjusted, allowing precise control over the frequency or amplitude characteristics of the output waveform. This linear voltage control enhances the flexibility and functionality of analog signal processing blocks, particularly in applications like waveform generation, modulation, and adaptive filtering.

Schmitt Trigger using LT1228 [4]

LT1228 is the combination of the operational transconductance amplifier (OTA) and current feedback amplifier (CFA). This IC has several advantageous features such as electronic controllability, wide bandwidth, high voltage input impedance, high current output impedance, and a wide range of applications etc.

The LT1228 is an off-the-shelf IC using BJT technology. It implements the current-gain control with an operational transconductance amplifier (Voltage Differencing to Current), whose gain is a direct variation to an externally biased current. The output current is converted to a voltage by an external resistor.

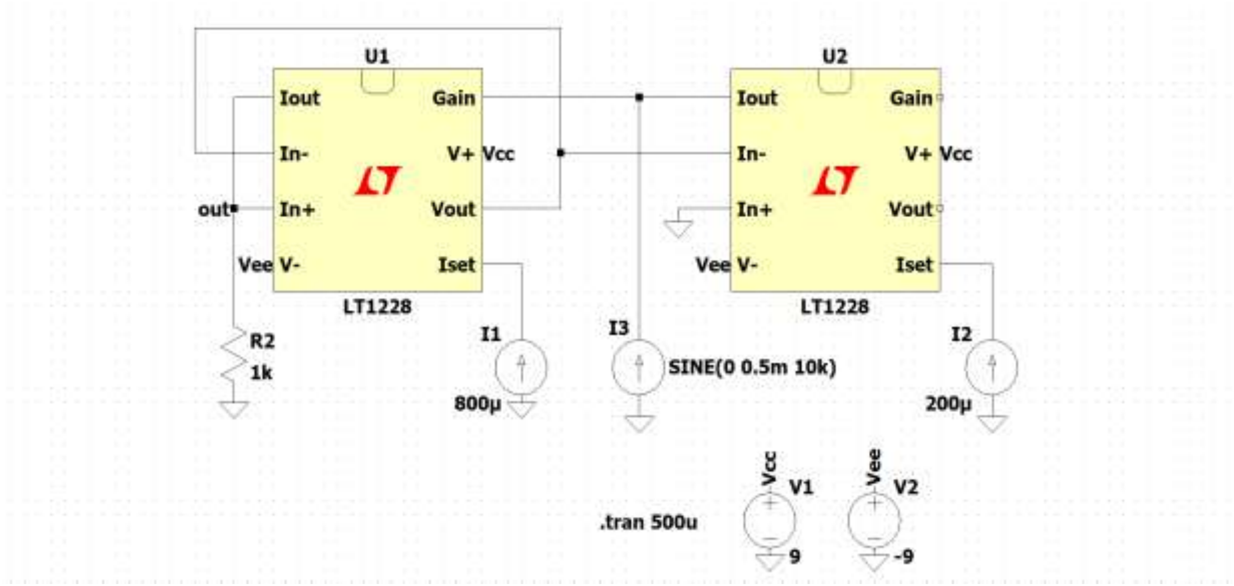


Figure 1: The Schmitt trigger using LT1228.[4]

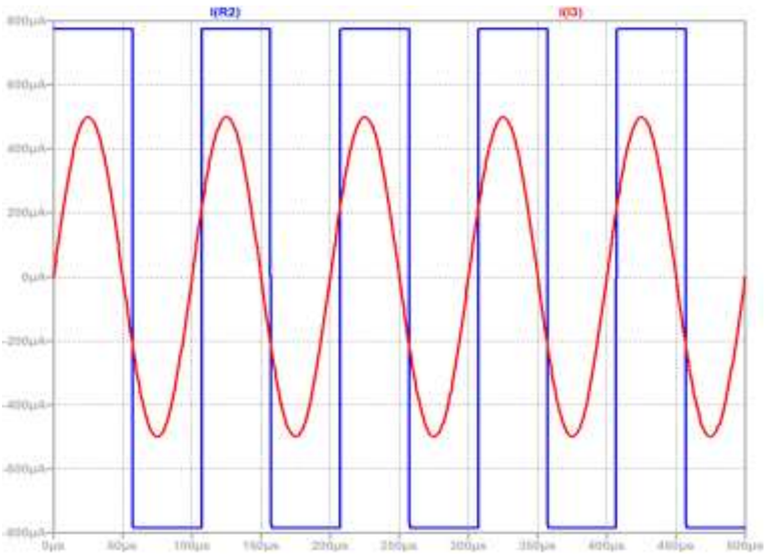


Figure 2:. The waveform of Schmitt trigger using LT1228s.

When Schmitt trigger uses the LT1228's saturation mode, which has both internal OTA and CFA. The OTA operates in the saturation region if the input voltage differencing $(V_+ - V_-)$ more than 150 mV or less than -150mV. Then output current found as

$$I_y = I_B \quad if \; V_+ - V_- \geq 150mV$$

$$I_y = -I_B \quad if \; V_+ - V_- \leq 150mV \qquad \text{....1}$$

Hence, output current can be obtained as

$$I_{out} = -I_{B1} \; if \; I_{in} \geq I_{HL}$$

$$I_{out} = I_{B1} \; if \; I_{in} \leq I_{HL} \qquad ....3$$

Where I_{HL} and I_{LH} are high and low hysteresis currents

$$I_{HL} = I_{B2} \; and \; I_{LH} = -I_{B2} \qquad ....4$$

Using equation 4 above, I_{0ut} can be calculated as

$$I_{out} = -I_{B1} \; if \; I_{in} \geq I_{B2}$$

$$I_{out} = I_{B1} \; if \; I_{in} \leq -I_{B2} \qquad ....5$$

In a Schmitt Trigger configuration using the LT1228, the OTA section functions as a voltage comparator with controllable hysteresis, where the threshold levels are linearly adjusted through the bias current. By varying this current, the transconductance (g_m) of the OTA changes, enabling real-time control over the hysteresis window. The output current is converted to voltage using an external resistor, and positive feedback is applied to achieve the desired switching behavior. This voltage-controlled approach makes the circuit highly adaptable for noise filtering, signal conditioning, and waveform shaping in analog systems.

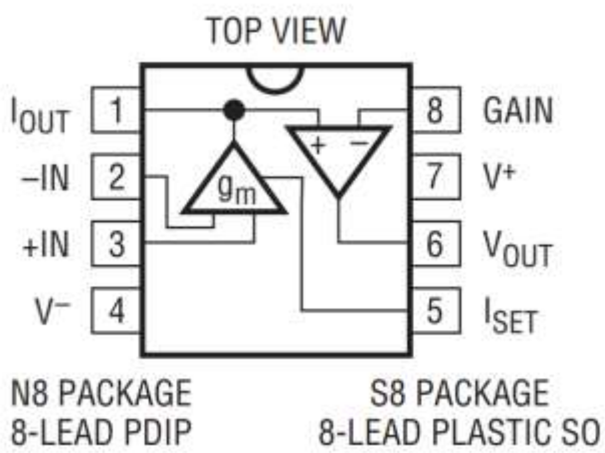


Figure 3: Pin Configuration of LT1228 [5]

After testing LT1228, it's found that output current of OTAs is

$$I_y = I_B tanh\left(\frac{V_+ - V_-}{3.87V_T}\right) \qquad .....6$$

Where V_- and V_+ are voltages at pins 2 and 3, V_T denote the thermal voltage. I_B is the bias current of terminal 5. The hyperbolic tangent is as

$$tanhx = x - \frac{x^3}{3} + \frac{2x^5}{15} - \frac{17x^7}{315} \; + ... \qquad .....7$$

If $x \ll 1$, then tanh≈ x and its first order approximation can be driven as

$$tanh\left(\frac{V_+ - V_-}{3.87V_T}\right) = \frac{V_+ - V_-}{3.87V_T} \qquad .....8$$

$$I_y = \frac{I_B(V_+ - V_-)}{3.87V_T} \qquad .....9$$

Finally when $\frac{I_B}{3.87V_T} = g_m$ and V_T=26mV then

$$I_y = 10 I_B (V_+ - V_-) \quad .....10$$

III.CIRCUIT DESCRIPTION AND OPERATION

The proposed square/triangular wave generator comprises 2 main parts, as illustrated in the flow diagram of Fig. 3. Current-mode Schmitt trigger is employed to change a triangular wave to a square wave, which is fed back as an input signal to the current-mode integrator. As briefly explained, the current-mode square wave can be achieved at the output of the Schmitt trigger while the current-mode triangular wave can be obtained at the output of the integrator. We propose to adopt this methodology in our Square-triangular wave generator circuit, where the two LT1228 ICs would comprise the Schmitt trigger[5] and the CA3080 OTA with a capacitor and a resistor would act as an integrator to this.

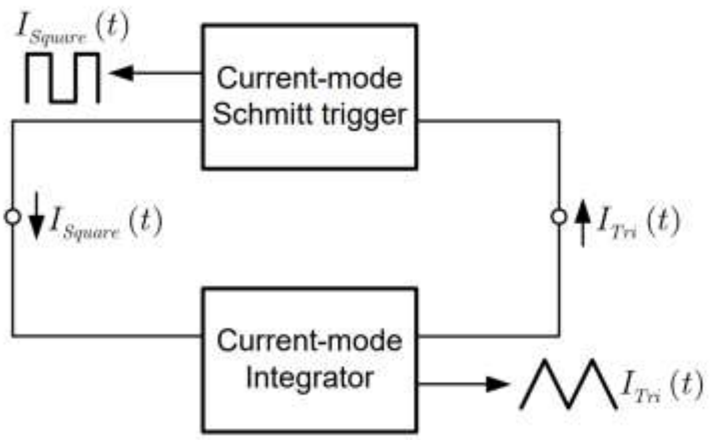


Figure 4: Principle for the Square-triangular wave generator.[6]

The LT1228 based Schmitt trigger would provide us with a stable square waveform when a triangular waveform is fed as input. The triangular waveform is to be generated by the current-mode integrator that is made using a CA3080 OTA and along with a resistor R and a capacitor C. This current-mode integrator [7] is supposed to take a square waveform current, integrate it and give out a triangular waveform as its output. Fig. 4 shows the proposed circuit for the square-triangular wave generator.

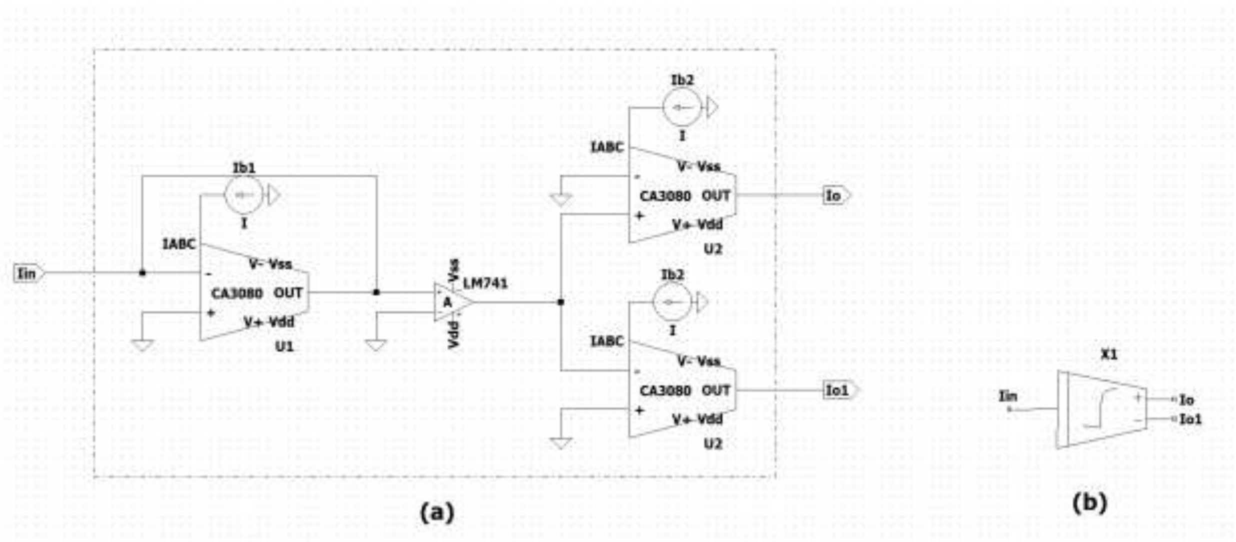


Figure 5: Current-mode integrator[7] (a) circuit implementation (b) symbolic representation

The open-loop gain $A_{OA}(s)$ of an Operational Amplifier is

$$A_{OA}(s) = \frac{A_o W_a}{s+w_a} \equiv \frac{B}{s} \qquad ....11$$

Where w_a is the 3-dB Bandwidth

The current transfer function of the current-mode integrator is as below, where B represents the gain-bandwidth product of OA, g_{m1} *and* g_{m2} are the transconductance gains of OTAs,

$$\frac{I_o(s)}{I_{in}(s)} = \frac{B}{s}\left[\frac{g_{m2}}{g_{m1}}\right] = \frac{B}{s}A_G \qquad ....12$$

In the above equation A_G(integrator gain) is the ratio between g_{m2} and g_{m1}

$$\frac{I_o(s)}{I_{in}(s)} = \frac{B}{s}\left[\frac{I_{B2}}{I_{B1}}\right] = \frac{B}{s}A_G \qquad ....13$$

Where $g_{m1} = \frac{I_{B1}}{2V_T}$ and $g_{m2} = \frac{I_{B2}}{2V_T}$

A_G is the current gain, that is the current ratio between the bias current 162 and ft1. In this case, the temperature dependence of the transconductance gains g,1 and g.2 of the bipolar OTAs are compensated.

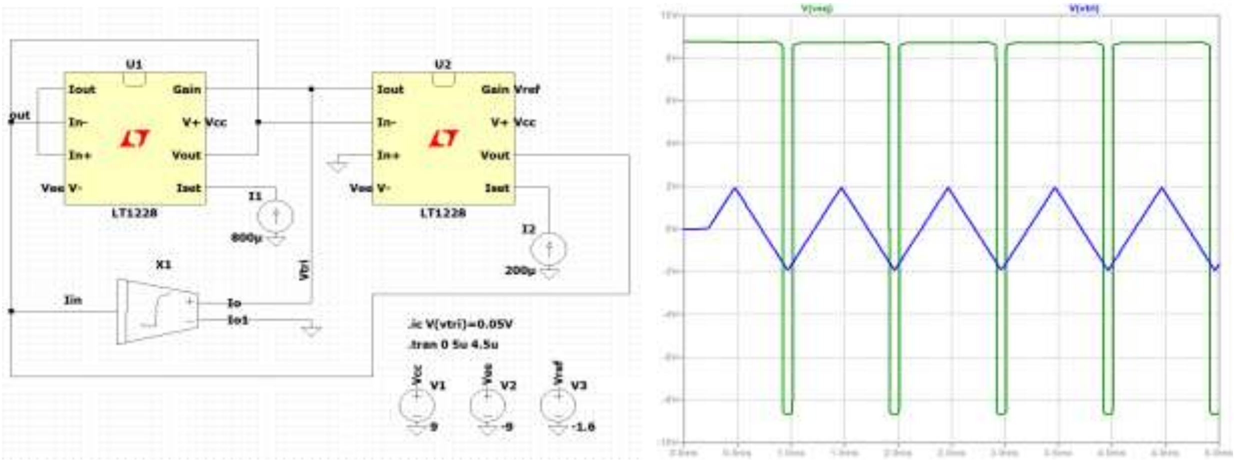
Proposed LT1228 and current-mode integrator based square/triangular waveform generator

In this proposed circuit, Fig. 6, the circuit is designed and implemented using a current-mode integrator [7] and LT1228 operational transconductance amplifiers (OTAs) based on Fig. 4 principle of the square/ triangular wave generator.

The current-mode integrator serves as the core element for integrating the input current signal, converting it into a voltage (in the internal loop), and producing an output current that is the time integral of the input current where the integrator consists of two OTAs and an internally compensated current-mode integrator block, in which current mode Schmitt trigger is employed to change a triangular wave to a square wave, which is fed back as input signal to current-mode integrator. As briefly explained, the current-mode square wave can be achieved at the output of the Schmitt trigger, while the current-mode triangular wave can be obtained at the output of the integrator, without requiring any passive components, while the LT1228 devices are configured to perform the transconductance functions necessary for current-mode integration. This integrator eliminates the need for passive components like resistors and capacitors, enabling a compact and fully active design suitable for IC implementation. By adjusting the bias currents of the integrator, the gain can be electronically tuned, providing flexibility for various signal processing applications such as waveform generation and filtering. The generated waveforms, as shown in the simulation results, confirm the expected triangular and square waveforms, indicating the successful integration of the current-mode integrator configuration with practical components.

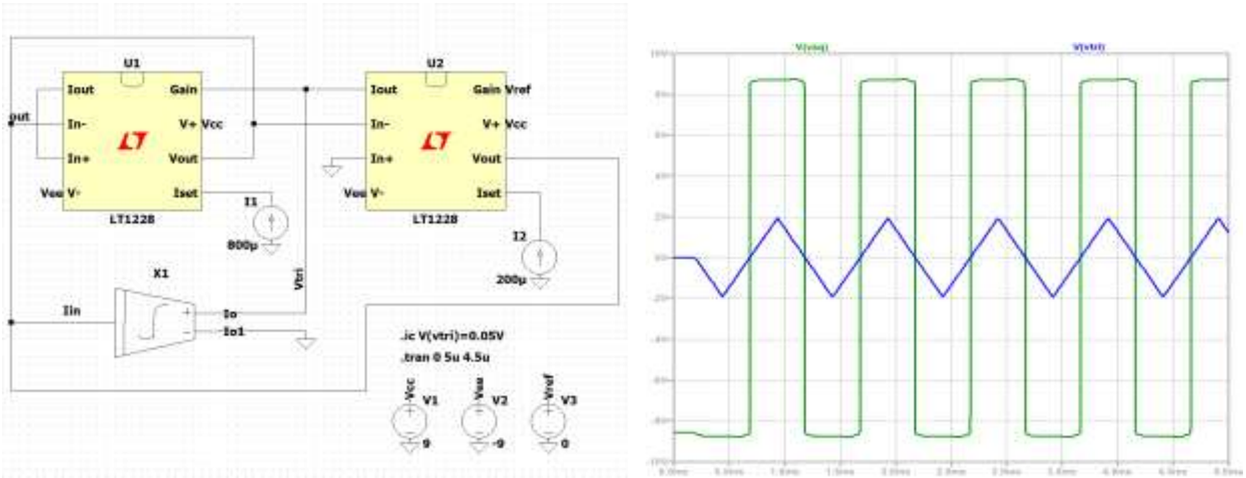
By adjusting the reference voltage (Vref), the upper and lower threshold voltages of the Schmitt trigger change, which alters the switching points of the square wave. As a result, the duty cycle of the output waveform can be modulated without affecting the frequency. Simulation results demonstrate that increasing Vref reduces the high-time duration of the square wave, and decreasing Vref extends it, offering a reliable means of duty-cycle control through a simple voltage input.

For the simulation of fig.6, the reference voltage (Vref) is set to 0V. The triangular waveform crosses the Schmitt trigger thresholds roughly midway in each cycle, producing a nearly 50% duty cycle in the square wave output. This results in a balanced high and low time, characteristic of symmetric square wave generation. Here, in Fig. 7, Vref is increased, raising the upper threshold. This causes the output square wave to stay low longer and switch high for a shorter interval. As a result, the duty cycle becomes less than 50%. This is useful when a short pulse is needed relative to the period. Also, for the simulation of Fig. 8, Vref is reduced, lowering the switching thresholds. The comparator now toggles high sooner and stays high longer, resulting in a high duty cycle, well above 50%. The waveform is high for a longer portion of each cycle, useful for applications needing extended “on” time.



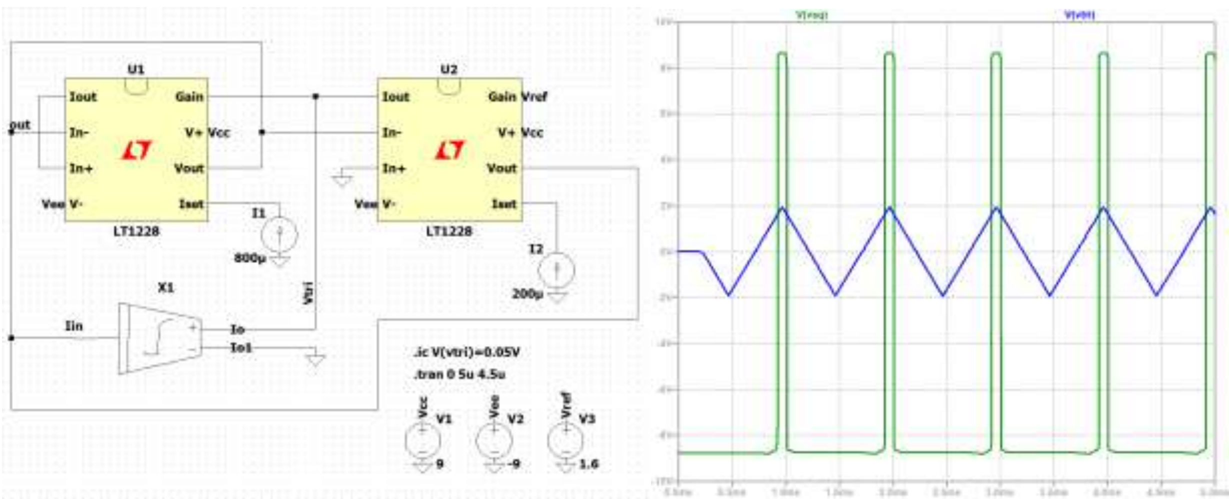
(a) (b)

Figure 6 : (a) Proposed LT1228 and current-mode integrator based square/triangular waveform generator for Vref= -1.6V. (b) The voltage waveforms with triangular and rectangular wave at a frequency of 10.42 kHz giving 90% Duty Cycle



(a) (b)

Figure 7 : (a) Proposed LT1228 and current-mode integrator based square/triangular waveform generator for Vref=0V. (b) The voltage waveforms with triangular and rectangular wave at a frequency of 10.42 kHz giving 50% Duty Cycle



(a) (b)

Figure 8: (a) Proposed LT1228 and current-mode integrator based square/triangular waveform generator for Vref=1.6V. (b) The voltage waveforms with triangular and rectangular wave at a frequency of 10.42 kHz giving 10% Duty Cycle

IV. Experimental Results

This section shows the experimental results to ensure the efficiency of the triangular/square wave generator using LT1228s. In the experiment I_{set1} = 800 µA, I_{set2} = 200 µA, ±9 V supply voltage was used. The two LT1228s are connected to form a Schmitt trigger, thus giving out a square waveform. Designing the frequency and duty cycles of the proposed circuit are 10 kHz, 90%, 50%, and 10%, which are obtained when Vref is varied as -1.6V, 0V, and 1.6V. The amplitude of triangular and square waves, respectively, are 1.71V and 8.70V. Fig. 6 (b), Fig. 7 (b) and Fig. 8 (b), display the triangular and square waves with the frequency of 10.42 kHz when Vref is varied -1.6V, 0V, and 1.6V. It is the amplitude of the triangular signal, which is controlled by the input current I_{set2} and the amplitude of the square signal is controlled linearly on the supply voltages Vcc and Vee as shown in Fig. 9.

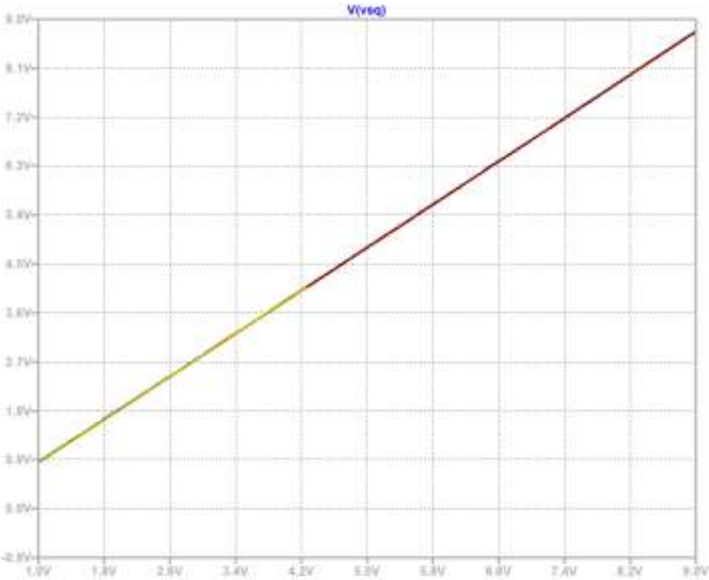


Figure 9: Amplitude of the square signal on varying the supply voltages Vcc from 1V to 9V with an increment of +0.1V and Vee from -1V to -9V, with an increment of -0.1V.

V. References

[1] Won-Sup Chung, Hoon Kim, Hyeong-Woo Cha and Hee-Jun Kim, "Triangular/Square-Wave Generator With Independently Controllable Frequency and Amplitude", *IEEE Transactions on Instrumentation and Measurement*, vol. 54, no. 1, February 2005.
[2] Yu-Kang Lo, Hung-Chun Chien and Huang-Jen Chiu, "Tunable Waveform Generators Using Single Dual-Current Output OTAs", *Journal of Circuits, Systems, and Computers,* vol. 17, no. 6, 2008.
[3] Rajeev Kumar Ranjan, Kaushik Mazumdar, Ratnadeep Pal, Satish Chandra, "Generation of square and triangular wave with independently controllable frequency and amplitude using OTAs only and its application in PWM", Analog Integr Circ Sig Process (2017).
[4] Pharmon Silapan, Pawich Choykhuntod, Rapeepan Kaewon and Winai Jaikla, "Duty-Cycle Electronically Tunable Triangular/Square Wave Generator Using LT1228 Commercially Available ICs for Capacitive Sensor Interfacing", June 2022.
[5] Linear Technology "LT1228- 100MHz Current Feedback Amplifier with DC Gain Control".
[6] Montree Siripruchyanun, "A Novel Simple Current-mode Square/Triangular Wave Generator with Electronic Controllability", King Mongkut's University of Technology, North Bangkok, Thailand.
[7] Katesuda Klahan, Worapong Tangsrirat, Wanlop Surakampontorn.Teerasilapa Dumawipata, "Current-Mode Integrator using OA and OTAs and Its Applications", *Thammasat Int. J. Sc. Tech*, vol. 8, no. 2, April-June 2003.