

An Improved Triangular/Square-Wave VCO Using OTAs

Jin-Woong Jeong*, Chang-Su Won*, Won-Sup Chung*★

Abstract

An improved triangular/square-wave VCO using OTAs is presented. It consists of two OTAs, a timing capacitor, and a resistor. A prototype circuit built with commercially available components exhibits less than 0.01% nonlinearity in its current-to-frequency transfer characteristic from 0.2 to 14 kHz and 450 ppm/°C temperature coefficient of frequency over -20°C to 40°C.

Key words: Triangular/square-wave generator, Voltage-controlled oscillator(VCO), Current-controlled oscillator, Schmitt trigger, Operational transconductance amplifier(OTA),

1. Introduction

Triangular/square-wave voltage-controlled oscillators (VCOs) have a wide range of applications in instrumentation and communication systems. Such VCOs with wide sweep capability can easily be 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]–[3]. These realizations require a high-performance voltage comparator to form a Schmitt trigger and hence the resulting VCOs become complex and expensive. In this paper, a new scheme is presented where the Schmitt trigger is implemented with another OTA

instead of the conventional voltage comparator. Since the OTA exhibits the simpler configuration than the voltage comparator, the proposed VCO features a simple configuration. It, however, retains the wide sweep capability and good linearity of voltage to frequency.

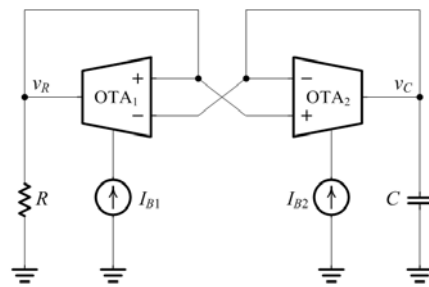


Fig. 1. Circuit diagram of the proposed VCO.

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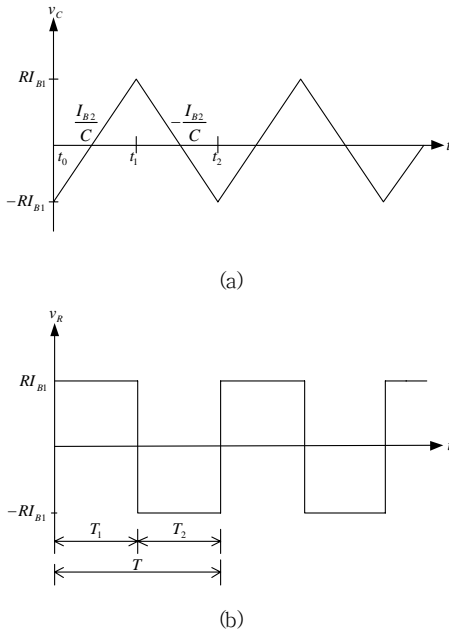


Fig. 2 Output waveforms of the VCO.

II. Circuit Description

The proposed VCO is shown in Fig. 1. OTA₁ and the resistor R form a current-controllable Schmitt trigger whose threshold voltage is proportional to the bias current I_{B1} . OTA₂ and the timing capacitor C form an integrator whose time constant is proportional to the bias current I_{B2} . The waveforms associated with the circuit is shown in Fig. 2.

To see how the VCO operates, let the output of the Schmitt trigger be at its positive saturation level of $L_+ = RI_{B1}$. A current equal to I_{B2} will flow through the capacitor C , causing the output of the integrator to linearly increase with a slope of I_{B2}/C . This will continue until the integrator reaches the high threshold $V_{TH} = RI_{B1}$ of the Schmitt trigger, at which point the schmitt trigger will switch states, its output becoming negative and equal to $L_- = -RI_{B1}$. At this moment the current through C will reverse its direction. It follows that the integrator output will start to decrease linearly with a negative slope of equal to $-I_{B2}/C$. This will continue until the integrator output voltage reaches the low threshold voltage of the Schmitt trigger, $V_{TL} = -RI_{B1}$. At this point the Schmitt trigger switches,

its output becomes positive ($L_+ = RI_{B1}$), the current through C reverses direction, and the output of integrator starts to increase linearly, beginning a new cycle.

From the above description it is easy to derive an expression for the period of the square and triangular waveforms. During the interval T_1 we have, from Fig. 2(a),

$$\frac{RI_{B1} - (-RI_{B1})}{T_1} = \frac{I_{B2}}{C} \quad (1)$$

from which we obtain

$$T_1 = 2CR \frac{I_{B1}}{I_{B2}} \quad (2)$$

Similarly, during T_2 we have

$$\frac{-RI_{B1} - (RI_{B1})}{T_2} = -\frac{I_{B2}}{C} \quad (3)$$

from which we obtain

$$T_2 = 2CR \frac{I_{B1}}{I_{B2}} \quad (4)$$

Equations (2) and (4) can be combined to obtain the period T of the output waves as

$$T = T_1 + T_2 = 4CR \frac{I_{B1}}{I_{B2}} \quad (5)$$

from which we obtain the oscillation frequency given by

$$f = \frac{1}{4CR} \frac{I_{B2}}{I_{B1}} \quad (6)$$

III. Experimental Results

The VCO shown in Fig. 1 was built with LM13600 OTAs and a polystyrene capacitor of 1 nF. The resistor used was $R = 100 \text{ k}\Omega$ and its tolerance is 0.5%. A simple current mirror and a resistor were used for producing a current source. The bias current I_{B1} was set to $10 \mu\text{A}$ for convenience and all measurement were performed at supply voltages of $\pm 5 \text{ V}$. The oscillation frequency against bias current I_{B2} was measured over the bias current range of $1\text{--}50 \mu\text{A}$. For comparison, the conventional VCO in [3] was also investigated. The results are plotted in Fig. 3. It appears that the linearity error of the proposed VCO is less than 0.01 % while that of the conventional VCO is less than 0.02 %. The nonlinearity is mainly caused by the switching delay of the OTA₂. The linearity

improvement of the proposed VCO is achieved by connecting the inverting input terminal of OTA_2 to its output terminal, thereby the net input voltage of OTA_2 at switching moments becomes about two time larger than the conventional case. The larger

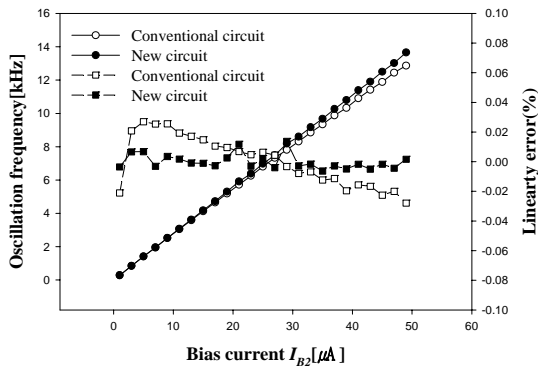


Fig. 3. Measured oscillation frequency against bias current I_{B2}

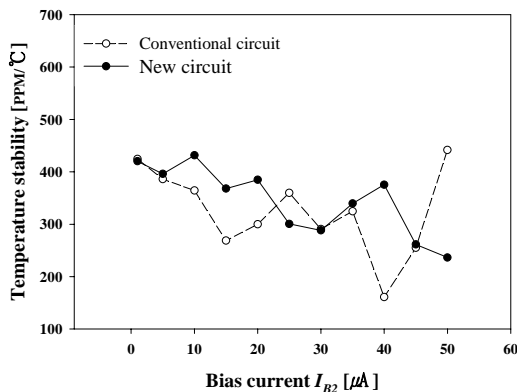


Fig. 4. Measured temperature stability against temperature. the input voltage of OTA_2 becomes, the faster OTA_2 saturates. This results in reducing the switching delay of OTA_2 . Fig. 4 shows the temperature stability of the output frequency measured over a temperature range from -20 °C to 40 °C. The temperature stability is maintained to within 450 ppm/°C over the frequency range of 0.2 – 14 kHz. Fig. 5 shows the oscillation frequency changes due to the power-supply voltage changes when $I_{B2} = 10$ μ A. It indicates that the proposed

VCO is less sensitive than the conventional one to the power-supply changes.

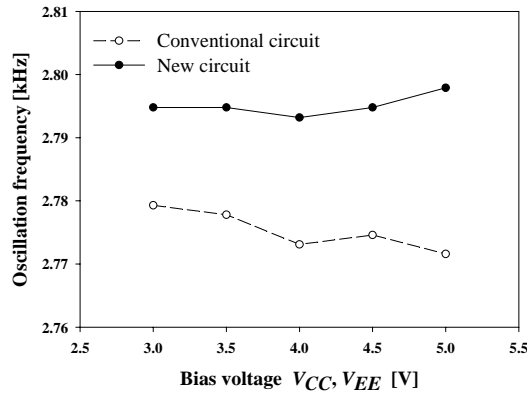


Fig. 5. Oscillation frequency changes due to the supply-supply voltage changes when $I_{B2} = 10$ μ A.

IV. Conclusion

An improved triangular/square-wave VCO using OTAs has been described. It features a simple configuration. An additional feature is the linear and wide controllability of frequency by a dc current, because of these properties the proposed VCO is expected to find wide applications in communication and instrumentation systems.

References

- [1] J. W. Haslett, "Current-switching linear VCO." *Electron. Lett.*, vol. 25, pp. 139–140, Jan. 1989.
- [2] W.-S. Chung, H.-W. Cha and K.-H. Kim, "Temperature-stable VCO based on operational transconductance amplifiers," *Electron. Lett.*, vol. 26, pp. 1900–1901, Oct. 1990.
- [3] *National Operational Amplifiers Databook*; pp. 1–631–1–648, National Semiconductor Corp, Santa Clara CA 1995.

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