A NEGATIVE PROPORTIONAL CHARACTERISTIC VCO USING CCIIS AND NAND RS-FLIP FLOP

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Abstract. This paper presents a method for realizing voltage controlled oscillator with negative proportional characteristic. The realization method based on the use of commercial available devices is utilized. The proposed oscillator comprises second-generation current conveyors and a NAND RS Flip Flop. The output frequency can be adjusted using negative and positive values of the control voltage without discontinuity. Experimental results verifying the performances of the proposed circuit are in close agreement with the calculated values.

Keywords: VCO, RS flip flop, Current conveyor, NAND gate

1. Introduction. A voltage controlled oscillator (VCO) is one of the most important circuit building blocks in measurement and communication systems. Its applications can be found in phase-locked loops, FM modulation, frequency synthesizers, timing recovery, and many others. The good VCO design dictates that the voltage to frequency curve is smooth (no discontinuities), monotonic, and linear. One fundamental method to realize the VCO is based on an op amp integrator in conjunction with an IC timer [1]. However, this approach has a complex structure. For the ease of hardware implementation and good capability of application, the VCO should be simple and small in size [2-4]. Nevertheless, the output frequency of each approach reported in the literature [2,3] can be adjusted by changing only positive control voltage. If we design the tunable VCO by adjusting both negative and positive values of control voltage without discontinuity, the advantages will be gained [4]. Moreover, there has been a strong motivation to realize versatile commercial VCO products in recent years. There are two types of voltage-frequency relation of VCO. One is positive slope characteristic and another is negative slope characteristic. This is due to the alternative support for customer’s preference.

The purpose of this paper is to present the similar VCO proposed in literature [4]. We develop this idea in the difference way to realize the negative proportional characteristic VCO using second-generation current conveyors (CCIIIs) and the NAND RS-Flip Flop. Since the concept of CCII has proven to be the universal active element to synthesize not only the sinusoidal oscillators [5,6] but also the VCOs [7,8]. The voltage-frequency relation of the proposed VCO can be linearly and continuously varied by negative and positive
values of the control voltage. Experimental results demonstrating the characteristics of the proposed oscillator are also included.

![Circuit symbol of the unity-gain CCII](image)

**Figure 1.** Circuit symbol of the unity-gain CCII

2. **Circuit Description.** Figure 1 shows the circuit symbol of the unity-gain CCII. Three port relations can be described by the following matrix equation

\[
\begin{bmatrix}
    i_y \\
    v_x \\
    i_z
\end{bmatrix} =
\begin{bmatrix}
    0 & 0 & 0 \\
    1 & 0 & 0 \\
    0 & \pm1 & 0
\end{bmatrix}
\begin{bmatrix}
    v_y \\
    i_x \\
    v_z
\end{bmatrix}
\]

(1)

From (1), the current at port Y is zero. The voltage at port Y is accurately transferred to port X. The current supplied to port X is conveyed to port Z, where it is supplied either positive polarity (in positive CCII or CCII+) or negative polarity (in negative CCII or CCII−).

![Proposed VCO with negative proportional characteristic](image)

**Figure 2.** Proposed VCO with negative proportional characteristic

The proposed VCO as shown in Figure 2 is based on the use of two identical negative CCIIIs in connection with the NAND RS-Flip Flop. The sequential operation of this VCO can be discussed as follows.

Considering at port X of each CCII−, the current \(i_{xj}\) is related to the reference voltage \(V_R\) and the control voltage \(V_C\) by

\[
i_{xj} = \frac{V_R - V_C}{R_j}
\]

(2)

When the diode \(D_j\) is turn on, the capacitor \(C_j\) will be discharged. On the other hand, the diode \(D_j\) is turn off, the capacitor \(C_j\) then charges to store the voltage at port Z as

\[
v_{zj} = \frac{1}{C_j} \int_{t_0}^{t} i_{Cj} d\tau = \frac{1}{C_j} \int_{t_0}^{t} i_{xj} d\tau
\]

(3)
Substituting (2) into (3), we have

\[ v_{zj} = \left( \frac{V_R - V_C}{R_j C_j} \right) (t - t_0) \]  

(4)

It should be noted that the reference voltage \( V_R \) and the control voltage \( V_C \) could easily adjust the voltage \( v_{zj} \) of each CCII\(^{−}\).

For initial conditions, we assume that the states of Flip Flop output signals \( O_1 \) and \( O_2 \) are set to high and low, respectively. The \( C_2 \) discharge lowers the voltage \( v_{z2} \) to approximately zero, then the signal \( \phi_2 \) is set to low. The \( C_1 \) charge simultaneously reaches the voltage \( v_{z1} \) to the threshold voltage of the Flip Flop (\( V_{TH} \)), the signal \( \phi_1 \) then is set to high. Based on the operation of RS-Flip Flop (\( F_1 - F_4 \)), the output signals \( O_1 \) and \( O_2 \) will be changed into the low and high states, respectively. Next, the diode \( D_1 \) will be turn on and the capacitor \( C_1 \) will be discharged. When the voltage \( v_{z1} \) decreases to approximately zero, the signal \( \phi_1 \) is set to low. On the other hand, the diode \( D_2 \) is turn off, and the capacitor \( C_2 \) is charged. When the voltage \( v_{z2} \) increases to the threshold voltage \( V_{TH} \), the signal \( \phi_2 \) will be set to high. The output signals \( O_1 \) and \( O_2 \) then are forced again to high and low, respectively.

From above discussion, the operation of the circuit as shown in Figure 2 is oscillation, which generates the tunable sawtooth and square waves. The output pulse width or the metastable time, \( t_w \), can be considered at the initial conditions. The metastable time \( t_w \) is the time period from the initial time (\( t_0 = 0 \) s) to the time at which the voltage \( v_{z1} \) reaches to the threshold voltage \( V_{TH} (v_{z1} = V_{TH}) \). From (4), the metastable time \( t_w \) can be approximated as

\[ t_W = \frac{R_1 C_1 V_{TH}}{V_R - V_C} \]  

(5)

Therefore, the oscillation frequency \( f_o \) can be given by

\[ f_o = \frac{V_R - V_C}{2R_1 C_1 V_{TH}} \]  

(6)

It is clearly seen that the oscillation frequency \( f_o \) is negative proportional to the control voltage \( V_C \) and can be generated even if the control voltage \( V_C \) is less than the reference voltage \( V_R \).

3. Experimental Results. The performances of the proposed VCO were studied through the experiment using commercial available devices as AD844 and 4011BE for CCII\(^{s}\)s and NAND gates, respectively. Since the device AD844 can operate only the positive CCII. To implement the negative CCII, we can do simply by connecting two positive CCII\(^{s}\)s together as shown in Figure 3. The power-supply voltages of the positive CCII\(^{s}\) and the gate \( F_j \) were set to \( +15/-15V \) and \( +15V/0V \), respectively. The resistor \( R_j \) was chosen as 10k\(\Omega\). The reference voltage \( V_R \) was set to 10V. The threshold voltage \( V_{TH} \) is about 8.5V.
Figure 4 shows the measured results of the signal $\phi_1$ and the oscillation output $O_1$, where the capacitor $C_j$ and the control voltage $V_C$ were set to 1nF and 5V, respectively. The oscillation frequency of about 29kHz is observed.

The plots of the measured and calculated frequencies against the control voltage to test the tunable frequency characteristic of the proposed circuit are shown in Figure 5. The changing control voltages were in the value range $-5\text{V}$ to $5\text{V}$ while the capacitor $C_j$ was chosen as 0.5nF, 1nF, and 5nF.

Figure 4. Measured results of the signal $\phi_1$ and the oscillation output $O_1$ (Upper trace: Signal $\phi_1$, Lower trace: Oscillation output $O_1$)

Figure 5. Plots of the frequency $f_o$ against the control voltage $V_C$

Figure 6 illustrates the measured results, where the control voltage signal was set to 2kHz sinusoidal, triangular, and square waveforms of peak amplitude $-5\text{V}/5\text{V}$. It shows that the output oscillation frequency of the proposed VCO closely follows the amplitude value of the changing control signal.
From experimental results, it is evident that the output oscillation frequency can be easily and linearly adjusted by changing negative and positive control voltage. Moreover, the measured results are closely agreed with the calculated values.
4. Conclusions. The negative proportional characteristic VCO based on the use of
CCIIs and RS Flip Flop has been described in this paper. Increasing control voltage
decreases the output oscillation frequency. Experimental results show that the proposed
VCO functions correctly and provides good performances. Furthermore, we are planning
to evaluate the ability of this VCO when it is applied to DC-DC converter.

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