NEW QUARTZ CRYSTAL OSCILLATORS USING THE CURRENT-FEEDBACK OPERATIONAL AMPLIFIER

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New crystal oscillators using the current-feedback operational-amplifier (CFOA) are presented. Each circuit uses one CFOA, a crystal and, at most, five externally connected passive elements. Experimental results are included.

Keywords: Oscillators; Current-feedback operational amplifier

INTRODUCTION

Quartz crystal oscillators built around various discrete and integrated-circuit active elements are available in the literature [1, 2]. Of particular interest here are crystal oscillators built around the second-generation current-conveyor (CCII) [3–5]. Because the CCII minimally degrades the quartz crystal performance, CCII-based crystal oscillators enjoy good frequency stability and are, therefore, very attractive [3].

On the other hand, the current-feedback operational-amplifier (CFOA) is a four-terminal device which is equivalent to a CCII plus an output voltage buffer and, thus, it can easily drive external loads. Moreover, the CFOA enjoys wide bandwidth which is relatively

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independent of the closed-loop gain and very high slew rate. Thus, the use of CFOA in realizing crystal oscillators will be attractive.

To the authors knowledge, the use of CFOA is designing crystal oscillators has not yet been reported in the literature. It is, therefore, the purpose of this letter to present a number of CFOA-based crystal oscillators.

PROPOSED CIRCUITS

Consider the oscillator structures shown in Figure 1. Assuming ideal CFOA with $i_z = i_x$, $i_y = 0$, $v_x = v_y$, $v_o = v_z$ routine analysis yields the characteristic equation given by

$$(Y_1 + Y_2)Y_4 + Y_2Y_3 = 0 \quad (1a)$$

for the oscillator structure of Figure 1(a), and

$$(Y_1 + Y_2)Y_4 - Y_2Y_3 = 0 \quad (1b)$$

for the oscillator structure of Figure 1(b).

Using the crystal equivalent circuit shown in Figure 2, the admittance Y_3 can be expressed as

$$Y_3 = \frac{r + sL_1 + 1/sC_1 + 1/sC_0}{r/sC_0 + L_1/C_0 + 1/s^2C_1C_0} \quad (2)$$

FIGURE 1 Proposed crystal oscillator structures.

FIGURE 2 Electrical equivalent circuit of quartz crystal.

where r is the crystal internal resistance, L_1 is the crystal internal inductance, C_1 is the crystal internal capacitance, and C_0 is the electrostatic capacitance between the two parallel plates of the crystal.

Combining Eqs. (1) and (2), new CFOA-based crystal oscillators can be obtained, from the oscillator structures of Figure 1, using various combinations of the admittances Y_1 , Y_2 and Y_4 . Following are two examples:

Example 1 In Figure 1(a), if $Y_1 = 1/R$, $Y_2 = 1/R + sC_2$ and $Y_4 = 1/R + sC_4$, then Eq. (1a) reduces to

$$\begin{aligned}
 & s^4 L_1 C_2 \left(\frac{C_4}{C_0} + 1 \right) + s^3 \left(\frac{L_1}{R} \left(\frac{C_2}{C_0} + \frac{2C_4}{C_0} + 1 \right) + C_2 r \left(\frac{C_4}{C_0} + 1 \right) \right) \\
 & + s^2 \left(\frac{C_2}{C_0} \left(\frac{C_4}{C_1} + \frac{r}{R} + 1 \right) + \frac{2C_4 r}{C_0 R} + 2 \frac{L_1}{R^2 C_0} + \frac{r}{R} + \frac{C_2}{C_1} \right) \\
 & + s \left(\frac{1}{C_0 R} \left(\frac{C_2}{C_1} + \frac{2C_4}{C_1} + 2 \frac{r}{R} + 1 \right) + \frac{1}{C_1 R} \right) + 2 \frac{1}{R^2 C_1 C_0} = 0 \quad (3)
 \end{aligned}$$

Equation (3) is a fourth-order polynomial in s . Following a procedure similar to that described in [6], by disregarding the s^4 term and substituting for s^3 the term

$$s^3 = -s\omega_p^2 \quad (4)$$

Equation (3) reduces to a second-order polynomial in s . Equating the real and imaginary parts, of this second-order polynomial to zero,

yields

$$\omega_p^2 = \frac{(1/C_0 R)((C_2/C_1) + 2(C_4/C_1) + 2(r/R) + 1) + (1/RC_1)}{(L_1/R)((C_2/C_0) + 2(C_4/C_0) + 1) + C_2 r((C_4/C_0) + 1)} \quad (5)$$

and

$$\omega_n^2 = \frac{2/(R^2 C_1 C_0)}{(C_2/C_0)((C_4/C_1) + (r/R) + 1) + 2(C_4/C_0)(r/R) + 2(L_1/R^2 C_0) + (C_2/C_1)} \quad (6)$$

With $C_1 \ll C_0$, $r \ll R$, Eqs. (5) and (6) can be approximated by

$$\omega_p^2 \cong \frac{1}{L_1 C_1} \quad (7)$$

and

$$\omega_n^2 \cong \frac{1}{L_1 C_1} \quad (8)$$

From (7) and (8) it obvious than ω_p and ω_n are approximately equal and thus, the circuit can oscillate at a frequency approximately given by the series-resonance frequency of the crystal.

Example 2 In Figure 1(b), if $Y_1 = 1/R$, $Y_2 = 1/R + sC_2$ and $Y_4 = 1/R + sC_4$, then Eq. (1b) reduces to

$$\begin{aligned} & s^4 L_1 C_2 \left(\frac{C_4}{C_0} - 1 \right) + s^3 \left(\frac{L_1}{R} \left(\frac{C_2}{C_0} + \frac{2C_4}{C_0} - 1 \right) + C_2 r \left(\frac{C_4}{C_0} - 1 \right) \right) \\ & + s^2 \left(\frac{C_2}{C_0} \left(\frac{C_4}{C_1} + \frac{r}{R} - 1 \right) + \frac{2C_4}{C_0} \frac{r}{R} + 2 \frac{L_1}{R^2 C_0} - \frac{r}{R} - \frac{C_2}{C_1} \right) \\ & + s \left(\frac{1}{C_0 R} \left(\frac{C_2}{C_1} + \frac{2C_4}{C_1} + 2 \frac{r}{R} - 1 \right) - \frac{1}{C_1 R} \right) + 2 \frac{1}{R^2 C_1 C_0} = 0 \end{aligned} \quad (9)$$

Equation (9) is a fourth-order polynomial in s . Following similar procedure as in the previous example, it is easy to, show that

$$\omega_p^2 = \frac{(1/C_0 R)((C_2/C_1) + 2(C_4/C_1) + 2(r/R) - 1) - (1/RC_1)}{(L_1/R)((C_2/C_0) + 2(C_4/C_0) - 1) + C_2 r((C_4/C_0) - 1)} \quad (10)$$

and

$$\omega_n^2 = \frac{2/(R^2 C_1 C_0)}{(C_2/C_0)((C_4/C_1) + (r/R) - 1) + 2(C_4/C_0)(r/R) + 2(L_1/R^2 C_0) - (C_2/C_1)} \quad (11)$$

With $C_1 \ll C_0, r \ll R$, Eqs. (10) and (11) can be approximated by Eqs. (7) and (8) respectively. Thus, the circuit can oscillate at a frequency approximately equal to the series-resonance frequency of the crystal.

EXPERIMENTAL RESULTS

The proposed circuits of Figure 1 were tested using the AD844 CFOA and different crystals. A typical output waveform obtained from the circuit of Figure 1(a) with $R = 10\text{k}\Omega$ and 20 MHz crystal is shown in Figure 3. Only three externally connected equal resistances were used. No external capacitances were connected. In fact the parasitic

FIGURE 3 Typical output waveform obtained from the oscillator structure of Figure 1(a) with: $Y_1 = 1/R$, $Y_2 = 1/R + s C_1$, $Y_4 = 1/R + s C_2$, $R = 10\text{ K}\Omega$, $C_y \cong 3\text{ pF}$, $C_z \cong 4.5\text{ pF}$ $f = 20\text{ MHz}$.

capacitances $C_y \cong 3 \text{ pF}$ and $C_z \cong 4.5 \text{ pF}$ at terminals y and z of the CFOA were exploited to advantage. It appears that the experimental results are in excellent agreement with the theory presented.

CONCLUSION

New CFOA-based crystal oscillators have been presented. Each circuit uses one CFOA, a crystal and, at most, five externally connected passive elements. In both circuits the output can be taken from a low impedance outlet, thus avoiding the degradation in the crystal performance resulting from external loading effects. The circuit of Figure 1(b) is a "single-pin" oscillator and, therefore, may be more attractive than that of Figure 1(a).

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