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Realizations of single-resistance-controlled quadrature oscillators using GCFTA and UGVF

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This paper presents realizations of single-resistance-controlled-oscillators (SRCOs) using the recently proposed modern active building block (ABB), namely the generalized current follower transconductance amplifier (GCFTA) and unity-gain voltage-follower (UGVF). The SRCO is made using reduced number of components: one GCFTA and one UGVF as the active building blocks (ABBs), two resistors and two grounded capacitors. The circuit offers the advantage of non-interactive control of condition of oscillation (CO) and frequency of oscillation (FO) and enjoys low active and passive sensitivities. The circuit is also capable of providing two quadrature voltage outputs. PSPICE simulations have been carried out using the bipolar implementation of the circuits. The simulation results validate the theoretical analysis.

Keywords: analog circuits; single-resistance-controlled-oscillator (SRCO); generalized current follower transconductance amplifier (GCFTA); unity-gain voltage-follower (UGVF)

1.   Introduction

Generalized current follower transconductance amplifier (GCFTA) has been recently proposed by Herencsar *et al.* in 2008a and used in creating compact circuit structures for single-input multiple-output current-mode universal biquadratic filters (Herencsar *et al.* 2008a, Herencsar *et al.* 2008b, Herencsar *et al.* 2009b). GCFTA has close correspondence to another ABB, namely the current differencing transconductance amplifier (CDTA) proposed by Biolek in 2003. In fact, grounding any of the p or n terminals of the CDTA would create a GCFTA, since this would reduce the front-end current differencing unit of the CDTA to a positve/negative current follower. In a recently reported realization of sinusoidal oscillator using CDTA (Lahiri 2009), one of the p or n terminals of the used CDTAs are grounded. Hence, such realizations do not fully exploit the characteristics of CDTA and are more suitable to be implemented using GCFTA.

In this paper, a general GCFTA-based oscillator topology is reported from which two single-resistance-controlled oscillators (SRCOs) are derived. SRCOs find numerous applications in communication, control systems, signal processing, instrumentation and measurement systems and numerous catalogues on creating SRCOs

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based on different ABBs are available in the literature (Senani and Singh 1996, Liu and Tsay 1996, Gupta and Senani 1998, Gunes and Toker 2002, Bhaskar 2003, Bhaskar and Senani 2006, Tangsrirat and Surakampontorn 2009, Kilinc *et al.* 2006, Salama and Soliman 2000, Kumngern and Dejhan 2009). A survey of all these work indicates the use of single or multiple ABBs and at least five external passive components: three resistors and two capacitors, including floating capacitors in (Salama and Soliman 2000). On the contrary, the proposed SRCOs here employ one GCFTA, one unity-gain voltage-follower (UGVF), two resistors and two grounded capacitors. The proposed circuits offer the following advantages:

 (i) Non-interactive (independent) control of condition of oscillation (CO) and frequency of oscillation (FO).
 (ii) Low incremental active and passive sensitivities.
(iii) All external passive components are either grounded or virtually grounded. The use of grounded capacitors makes the circuit suitable for monolithic integration because grounded capacitor circuits can compensate for the stray capacitances at their nodes (Bhusan and Newcomb 1967, Soliman 2008).
(iv) Availability of two quadrature voltage outputs, which makes the circuit suitable to be used in quadrature mixers or other communication systems wherein there is a requirement of multiple sinusoids which are 90° phase shifted, e.g. quadrature mixers and single sideband modulators (Horowitz and Hill 1991, Khan and Khwaja 2000).

2.   Proposed oscillator circuits

The GCFTA element consists of an input current follower (positive or negative) that transfers the input current to the z terminal and a dual output transconductance amplifier (DO-OTA) stage, which is used to convert the voltage at the z terminal to dual output currents. The transconductance parameter g_m corresponds for the positive output and $-g_m$ for the negative output (Herencsar *et al.* 2009b). In general, the equations characterizing an ideal GCFTA are:

$$V_f = 0, \quad I_z = aI_f, \quad I_{x1} = b_1 g_m V_z, \quad I_{x2} = b_2 g_m V_z, \tag{1}$$

where $a, b_1, b_2 \in \{1, -1\}$. Hence, six types of CFTA variants can be defined, which are described in Table 1.

The circuit symbol of GCFTA is shown in Figure 1 and the bipolar implemen-

Table 1.   Types of CFTAs

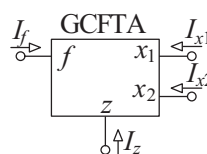| Type	a	b_1	b_2
CFTA+/+	1	1	1
CFTA+/−	1	1	−1
CFTA−/−	1	−1	−1
ICFTA+/+	−1	1	1
ICFTA+/−	−1	1	−1
ICFTA−/−	−1	−1	−1

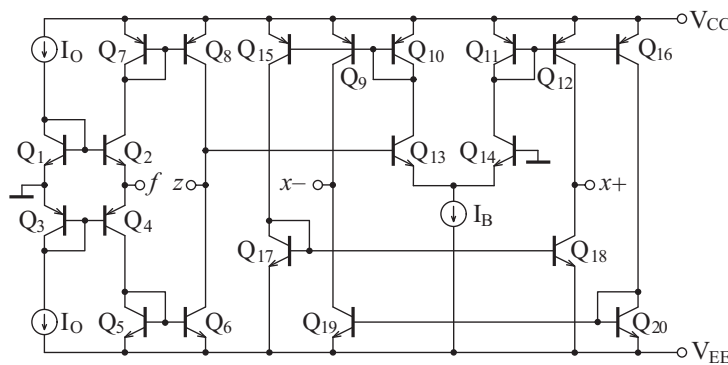Figure 1. Symbolic representation of GCFTA.

Figure 2. Bipolar implementation of CFTA+/−.

tation one of the variants, namely CFTA+/−, is shown in Figure 2. CFTA+/− can also be easily implemented using commercially available active components, viz. current follower amplifier (CFA) (e.g. AD844AN) and dual-output OTA (e.g. MAX435), as provided in (Herencsar *et al.* 2008a), where g_m denotes the transconductance of the OTA and is a function of the bias current.

2.1   *SRCO with quadrature voltage outputs*

The generalized configuration for realizing SRCOs using GCFTA and UGVF is shown in Figure 3. Using (1) and doing routine circuit analysis, the characteristic equation (CE) for the circuit topology can be found as:

$$s^2(C_1C_2R_1R_2) + sC_2R_2(1 - ab_1g_mR_1) - ab_2g_mR_1 = 0. \tag{2}$$

For the above equation to represent a valid CE for an oscillator, the following conditions should be simultaneously satisfied:

$$ab_1 = 1, \quad ab_2 = -1. \tag{3}$$

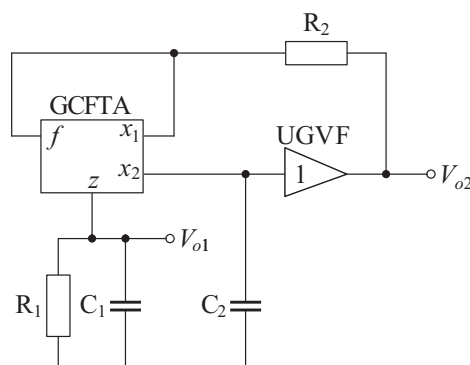Only two structures confirm these, as described in Table 2.

Figure 3.   The proposed generalized single-resistance-controlled quadrature oscillator using GCFTA and UGVF.

Table 2. Coefficients of GCFTA

variant	a	b_1	b_2
A	1	1	−1
B	−1	−1	1

From (2) and (3), it is clear that for both the structures A and B, the condition of oscillation (CO), i.e. the term with s has to be 0 (zero), is:

$$\text{CO:} \quad g_m R_1 = 1, \tag{4}$$

and the frequency of oscillation (FO) is:

$$\text{FO:} \quad f_o = \frac{1}{2\pi}\sqrt{\frac{g_m}{C_1 C_2 R_2}}. \tag{5}$$

It should be pointed out that although (4) defines the strict CO, however in practise $g_m R_1$ is made slightly more than unity for the start-up of oscillations. It is evident from (4) and (5) that the CO can be controlled independently of FO by changing R_1 and the FO can be controlled by means of resistor R_2. Therefore, the circuit truly describes a single-resistance controlled-oscillator (SRCO). The two quadrature voltage outputs of the general circuit topology as depicted in Figure 3, are related as:

$$V_{o1} = jb_2 k V_{o2}, \quad \text{where} \quad k = \frac{\omega_o C_2}{g_m}. \tag{6}$$

Clearly, for $k = 1$ the two quadrature voltages have equal amplitude.

2.2 *Non-ideal analysis and sensitivity study*

For a complete analysis, it is important to take into account the non-idealities of the GCFTA. Here, we provide the non-ideal analysis for variant A (i.e. the one using CFTA+/−). The model of the CFTA+/− including parasitic elements is shown in Figure 4. The non-ideal analysis for variant B can be carried on similar lines.

- $I_z = \alpha I_f$, where α represents the parasitic current gain, whose ideal value is unity. Similarly, the voltage transfer gain γ for the unity-gain voltage follower (buffer) differs slightly from its ideal value of unity because of the voltage tracking error.
- The parasitic resistance R_z and parasitic capacitance C_z appear between the high-impedance z terminal and ground. The stray/parasitic capacitance C_z is absorbed into the external capacitance C_1 as it appear in shunt with it. Also, since the value of R_z is in the order of MΩ, hence for an external resistor of value $R_1 \ll R_z$ connected at this terminal, $R_z \| R_1 \approx R_1$. Thus, the non-ideal effects of parasitic impedance at terminal z are reduced, if not completely eliminated.
- The parasitic resistance R_{x_2} and parasitic capacitance C_{x_2} appear between the
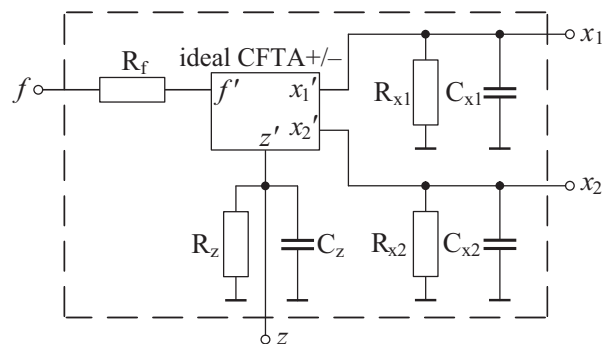

Figure 4. Model of the CFTA+/− including parasitic elements.

high-impedance x_2 terminal and ground. The parasitic capacitance can be absorbed in the external capacitance C_2, but the presence of parasitic resistance at terminal x_2 would change the type of the impedance, which should be of a purely capacitive character. A possible solution is to make the operating frequency $\omega_o > \frac{1}{R_{x_2}C_2}$.

- The parasitic resistance R_{x_1} and parasitic capacitance C_{x_1} appear between the high-impedance x_1 terminal and ground. To alleviate the effects of parasitic impedance at terminal x_1, the CFTA should be designed to have a very low input parasitic resistance at terminal f. Ideally, the value of input parasitic resistance at terminal f is zero and terminal f is virtually grounded. Thus, the parasitic impedance at terminal x_1 is connected between a virtual ground and a true ground.

Considering the first non-ideality and the parasitic capacitances at terminal z and x_2, the CO and FO of the proposed SRCO in Figure 3 get modified and are given as:

$$\text{CO:}\quad \alpha g_m R_1 = 1, \tag{7}$$

and

$$\text{FO:}\quad f_o = \frac{1}{2\pi}\sqrt{\frac{\alpha\gamma g_m}{(C_1 + C_z)(C_2 + C_{x_2})R_2}}. \tag{8}$$

The sensitivity study indicates that:

$$|S^{f_o}_{\alpha,\gamma,g_m,R_2}| = \frac{1}{2}, \tag{9}$$

$$S^{f_o}_{C_1} = -\frac{C_1}{2(C_1 + C_z)}, \tag{10}$$

$$S^{f_o}_{C_z} = -\frac{C_z}{2(C_1 + C_z)}, \tag{11}$$

$$S^{f_o}_{C_2} = -\frac{C_2}{2(C_2 + C_{x_2})}, \tag{12}$$

$$S^{f_o}_{C_{x_2}} = -\frac{C_{x_1}}{2(C_2 + C_{x_2})}. \tag{13}$$

It is evident from (9)–(13) that the magnitude values of all f_o sensitivities are less than unity and hence the proposed SRCO exhibits an attractive sensitivity performance. Also, both the CO and the FO in (7) and (8) are subject to process and temperature variations, to the presence of g_m term in the expressions. Similar tuning laws are also present in (Lahiri 2009) and (Jaikla *et al.* 2008). This should not be seen as a drawback for the FO, since the designer can control it using R_2. For the CO, a common practice is to make $R_1 > \frac{1}{g_m}$, so that even for any changes

in the right-hand side value (g_m) the inequality is satisfied and there is an appropriate start-up of the oscillations. For more accurate tuning, the external resistors could be replaced by non-linearity canceled MOSFETs (working in triode region) (Senani 1994). This shall provide electronic tuning properties via gate voltages to both the CO and FO and a voltage-controlled oscillator (VCO) is created.

3.   Simulation results

In order to confirm the above given theoretical analysis, the proposed CFTA-based SRCO (variant A) has been simulated with PSPICE simulation program. The bipolar implementation of the CFTA+/−, shown in Figure 2, and the bipolar implementation of the UGVF, presented in (Palumbo 1999) as output stage of CFA, has been used with the DC supply voltages of $+V_{CC} = -V_{EE} = 2$ V. In the design the transistor model parameters NR100N (NPN) and PR100N (PNP) of bipolar arrays ALA400 from AT&T were used (Frey 1993). Bias currents $I_O = 400$ μA have been chosen. The transconductance g_m of CFTA+/− can be set by current $I_B = 2g_m V_T$, where V_T is the thermal voltage (approximately 26mV at 27°C). The maximum values of terminal voltages and terminal currents of the CFTA+/− without producing significant distortion are computed as ±29.21 mV and ±16.81 mA, respectively, and the maximum value of terminal voltage of the UGVF without producing significant distortion is in the full scale of the supply voltage (in this case ±2 V). The DC current gain of the CFTA+/− $\alpha \cong 0.9852$ with bandwidth $f_\alpha \cong 135.225$ MHz and the transconductance $g_m \cong 0.9894$ mS (at $I_B = 52$ μA) with the bandwidth $f_{g_m} \cong 31.469$ MHz. The DC voltage gain of the UGVF $\gamma \cong 0.9992$ with bandwidth $f_\gamma \cong 3.971$ GHz.

The proposed circuit was designed using the following component values: $C_1 = C_2 = 10$ nF, $R_2 = 1$ kΩ, and $g_m = 1$ mS ($I_B = 52$ μA). The value of R_1 is kept slightly more than 1 kΩ to start the oscillations. The simulated output waveforms for V_{o1} and V_{o2} at steady stage are shown in Figure 5. It is evident from Figure 5 that the proposed circuit provides nearly equal sinusoidal waves and which is in accordance with (5). The offset (about 12 mV) of the V_{o2} is caused by the simple structure of the UGVF used (Palumbo 1999) that does not enable suppress this parameter. Figure 6 shows the frequency spectrum of the output waveforms and the value of total harmonic distortion (THD) at both the outputs are 1.67%. The results are summarized in Table 3. The variation of FO with resistor R_2 without affecting the CO is shown in Figure 7 and it is seen that the simulated values exhibit a close correspondence with the theoretical predictions.
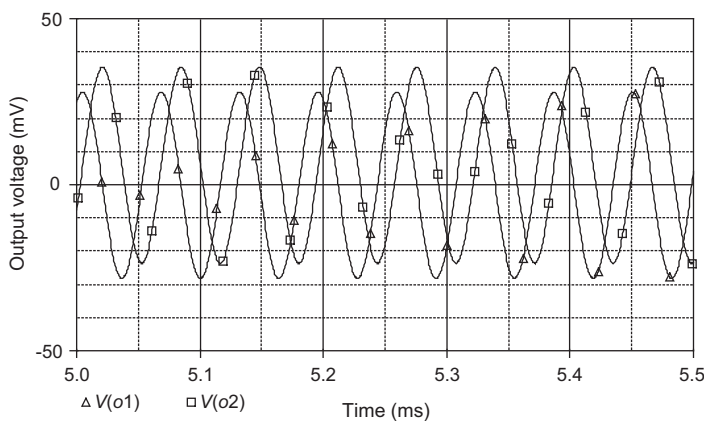

Figure 5. Quadrature voltage outputs V_{o1} and V_{o2} during steady stage.
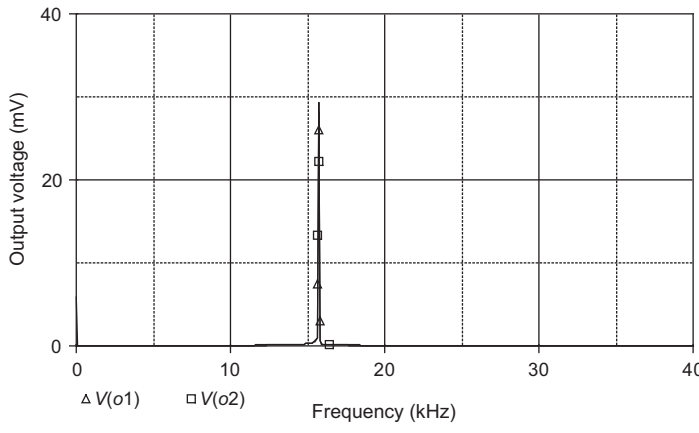
Figure 6. Simulated frequency spectrums of outputs V_{o1} and V_{o2}.

Table 3. Total harmonic distortion analysis of the proposed CFTA and UGVF-based quadrature oscillator: (a) output V_{o1}, (b) output V_{o2}.

Harmonic no.	Frequency (Hz)	Fourier component	Normalized component	Phase (Deg)	Normalized phase
1	1.592E+04	2.796E–02	1.000E+00	–1.113E+02	0.000E+00
2	3.183E+04	3.358E–04	1.201E–02	–1.289E+02	9.365E+01
3	4.775E+04	3.080E–04	1.102E–02	–7.385E+01	2.600E+02
4	6.366E+04	8.644E–05	3.091E–03	–1.232E+02	3.219E+02
5	7.958E+04	4.949E–05	1.770E–03	–1.303E+02	4.260E+02

DC component = 2.517015E–04

Total harmonic distortion = 1.667991E+00 PERCENT

(a)

Harmonic no.	Frequency (Hz)	Fourier component	Normalized component	Phase (Deg)	Normalized phase
1	1.592E+04	2.796E–02	1.000E+00	–1.111E+02	0.000E+00
2	3.183E+04	3.358E–04	1.201E–02	–1.286E+02	9.354E+01
3	4.775E+04	3.069E–04	1.098E–02	–7.338E+01	2.599E+02
4	6.366E+04	8.617E–05	3.082E–03	–1.229E+02	3.214E+02
5	7.958E+04	4.938E–05	1.766E–03	–1.300E+02	4.254E+02

DC component = 2.527028E–04
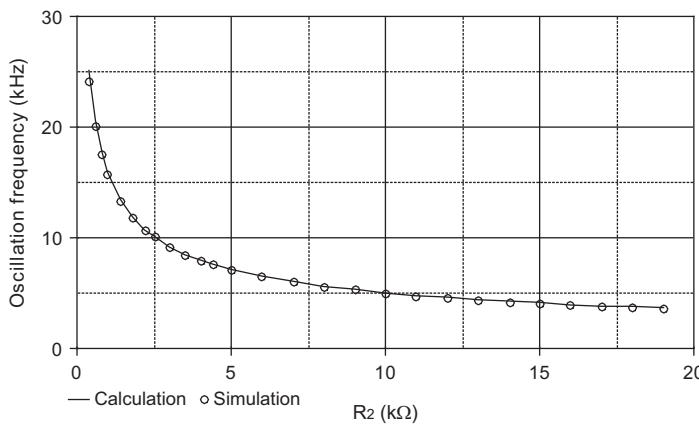
Total harmonic distortion = 1.665571E+00 PERCENT

(b)

Figure 7. Variation of oscillation frequency with R_2.

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4.   Brief discussion

Several realizations of SRCOs using different ABBs are available in the literature (Senani and Singh 1996, Liu and Tsay 1996, Gupta and Senani 1998, Gunes and Toker 2002, Bhaskar 2003, Bhaskar and Senani 2006, Tangsrirat and Surakampontorn 2009, Kilinc *et al.* 2006, Salama and Soliman 2000, Kumngern and Dejhan 2009, Herencsar *et al.* 2009a), which use at least five external passive components to provide non-interactive controls of the CO and the FO. Further, the use of ABBs like CFAs in (Senani and Singh 1996, Liu and Tsay 1996, Gupta and Senani 1998, Gunes and Toker 2002, Bhaskar and Senani 2006, Tangsrirat and Surakampontorn 2009, Kilinc *et al.* 2006) do not provide any inherent electronic control to the circuit parameters. The use of electronically controlled ABBs are receiving much attention nowadays, since they not only provide electronic tunability to the circuit parameters, compensate for the process tolerances, but, also reduce the use of external linear resistors. A few popular examples of such ABBs are, operational transconductance amplifiers (OTAs) and second-generation current-controlled conveyors (Fabre *et al.* 1996). Recently proposed CFTA in (Herencsar *et al.* 2008a) is a versatile ABB, which consists of current follower (CF) at the front-end (input) and a balanced OTA at the rear-end (output). Since a CFTA has a transconductance stage in it, hence a sinusoidal oscillator employing one CFTA, two external resistors and two capacitors would create a minimum component (and canonic) SRCO. The proposed SRCO in this paper, uses an extra component, viz. a unity-gain voltage follower (buffer) to create the SRCO. Discovering an alternate SRCO using only one CFTA, two resistors and two grounded capacitors appears to be a challenging problem and is open for further investigation.

5.   Concluding remarks

The paper presents a first of its kind single GCFTA based single-resistance-controlled sinusoidal oscillator (SRCO) employing two resistors, grounded capacitors and one unity-gain voltage follower (UGVF). It serves as a new application of GCFTA and offers advantages of monolithic integration, non-interactive control of condition of oscillation and frequency of oscillation by means of two different external resistors, good sensitivity performance and availability of two quadrature voltage outputs. PSPICE simulation results have confirmed the workability of the circuit.

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