Quadrature Oscillators with Grounded Capacitors and Resistors Using FDCCIIs

Jiun-Wei Horng, Chun-Li Hou, Chun-Ming Chang, Hung-Pin Chou, Chun-Ta Lin, and Yao-Hsin Wen

Two current-mode and/or voltage-mode quadrature oscillator circuits each using one fully-differential second-generation current conveyor (FDCCII), two grounded capacitors, and two (or three) grounded resistors are presented. In the proposed circuits, the current-mode quadrature signals have the advantage of high-output impedance. The oscillation conditions and oscillation frequencies are orthogonally (or independently) controllable. The current-mode and voltage-mode quadrature signals can be simultaneously obtained from the second proposed circuit. The use of only grounded capacitors and resistors makes the proposed circuits ideal for integrated circuit implementation. Simulation results are also included.

Keywords: Quadrature oscillator, current-mode, voltage-mode, FDCCII.

Manuscript received Sept. 20, 2005; revised Mar. 24, 2006.

Jiun-Wei Horng (phone: + 886 3 265 4621, email: jwhorng@cycu.edu.tw), Chun-Li Hou (email: clhou@cycu.edu.tw), Hung-Pin Chou (email: g9476014@cycu.edu.tw), Chun-Ta Lin (email: hank_lin@rolence.com.tw), and Yao-Hsin Wen (email: g9376040@cycu.edu.tw) are with Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan.

Chun-Ming Chang (email: chunming@dec.ee.cycu.edu.tw) is with Department of Electrical Engineering, Chung Yuan Christian University, Chung-Li, Taiwan.

I. Introduction

A quadrature oscillator is used because the circuit provides two sinusoids with 90^o phase difference, as for example in telecommunications for quadrature mixers and single-sideband generators, or for measurement purposes in vector generators or selective voltmeters. Therefore, quadrature oscillators constitute an important unit in many communication and instrumentation systems [1]-[13]. Note that the quadrature oscillators in [1]-[8] generated voltage-mode signals, and the ones in [9]-[13] generated current-mode signals.

Current-mode oscillators with high-output impedance are of great interest because they make it easy to drive loads without using a buffering device [14]-[16]. On the other hand, circuits that employ only grounded capacitors and resistors are beneficial from the point of view of integrated circuit implementation [16]-[18]. The previous current-mode quadrature oscillators presented in [9]-[11] employ floating passive components and require additional current followers for sensing and taking out the quadrature outputs therein, and the use of these additional current followers with the virtual grounded input may result in floating capacitor realization for what is originally described as grounded capacitor realization. Moreover, the oscillation conditions and oscillation frequencies cannot be independently controllable in [9], [10]. In 2002, Minaei and Cicekoglu proposed a current-mode quadrature oscillator with high-output impedance using three operational transconductance amplifiers and three operational amplifiers [12]. However, the oscillation condition and oscillation frequency cannot be orthogonally controllable. In 2003, the first author proposed a current-mode quadrature oscillator with high-output impedance using two differential voltage current conveyors, two grounded capacitors, and two grounded resistors with orthogonally-controllable oscillation condition and oscillation frequency [13].

Because the fully-differential quality of the input voltage signals are conveyed to the x terminals, and the current signals of the x terminals are conveyed to the z terminals, the fully-differential second-generation current conveyor (FDCCII) [19] was proposed to improve the dynamic range in mixed-mode applications where fully-differential signal processing is required. The applications of FDCCIIs in filter and oscillator designs often use only grounded passive components, and were demonstrated in [19]-[21]. The use of only grounded capacitors and resistors is ideal for integrated circuit implementation [16]-[18]. Some applications of FDCCIIs in the designs of fully-differential second-order filters and voltage-mode universal second-order filters were also presented in [22], [23].

In this paper, two new current-mode quadrature oscillator circuits each using only one FDCCII, two grounded capacitors, and two (or three) grounded resistors are presented. Each of the proposed circuits exhibits two high-output impedance sinusoidal currents with 90^o phase difference. The oscillation conditions and oscillation frequencies of the proposed circuits are orthogonally (or independently) controllable. Although the proposed circuits use more complicated active components (FDCCIIs) with respect to the previous current-mode quadrature oscillators in [9]-[11], the proposed circuits have the advantage of employing only grounded passive components; high-output impedance current outputs without using additional current followers, and the oscillation condition and oscillation frequency, can be orthogonally controllable in the first proposed circuit, and can be independently controllable in the second proposed circuit through grounded passive components. With respect to the high-output impedance current-mode quadrature oscillators in [12], [13], the current-mode and voltage-mode quadrature signals can be simultaneously obtained, while the oscillation condition and oscillation frequency can be independently controllable in the second proposed circuit.

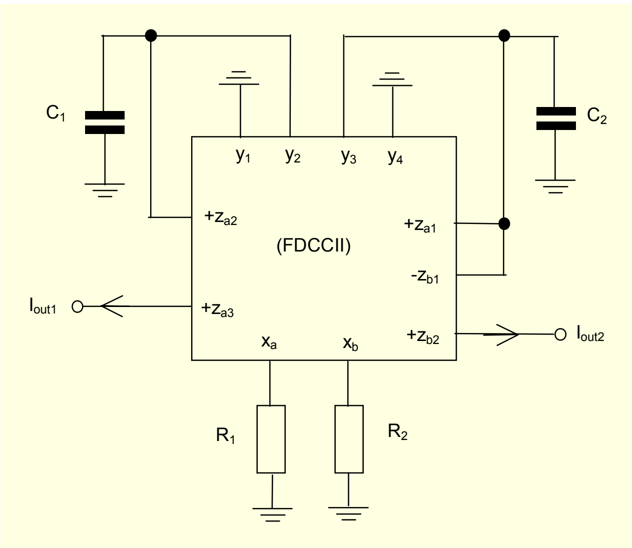


Fig. 1. The first proposed quadrature oscillator.

II. Proposed Circuits

The FDCCII is defined by the equations in [19]:

$$\begin{bmatrix} i_{y1} \\ i_{y2} \\ i_{y3} \\ i_{y4} \\ v_{xa} \\ v_{xb} \\ i_{zai} \\ i_{zbj} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 & 0 & 0 & 0 \\ -1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \pm 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \pm 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_{y1} \\ v_{y2} \\ v_{y3} \\ v_{y4} \\ i_{xa} \\ i_{xb} \\ v_{zai} \\ v_{zbj} \end{bmatrix}. \quad (1)$$

The first proposed quadrature oscillator is shown in Fig. 1. The characteristic equation of the circuit can be expressed as

$$s^2C_1C_2 + sG_1(C_2 - C_1) + G_1G_2 = 0. \quad (2)$$

The oscillation condition and oscillation frequency can be obtained as

$$C_1 = C_2, \quad (3)$$

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_1R_2}}. \quad (4)$$

From (3) and (4), the oscillation condition and oscillation frequency can be orthogonally adjustable.

From Fig. 1, under a steady state, the relationships between output currents I_{out1} and I_{out2} are

$$I_{out1} = \omega C_1 R_2 e^{j90^o} I_{out2}, \quad (5)$$

ensuring that currents I_{out2} and I_{out1} are in quadrature.

The second proposed quadrature oscillator is shown in Fig. 2. The characteristic equation of the circuit can be expressed as

$$s^2C_1C_2 + sC_2(G_1 - G_2) + G_2G_3 = 0. \quad (6)$$

The oscillation condition and oscillation frequency can be obtained as

$$R_1 = R_2, \quad (7)$$

$$\omega_o = \frac{1}{\sqrt{C_1C_2R_2R_3}}. \quad (8)$$

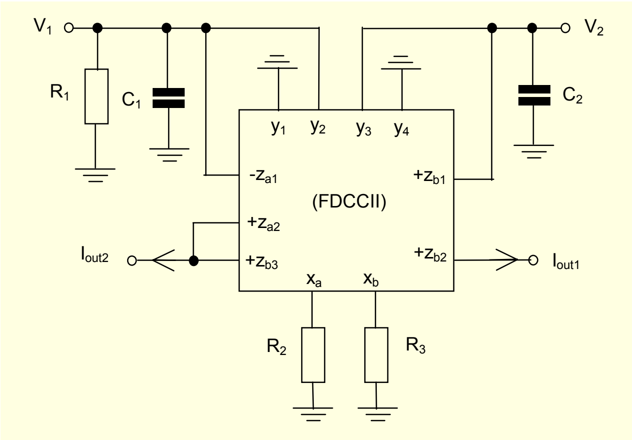


Fig. 2. The second proposed quadrature oscillator.

From (7) and (8), the oscillation condition and oscillation frequency can be independently adjustable.

From Fig. 2, under a steady state, the relationships between output voltages V_1 and V_2 are

$$V_1 = \omega C_2 R_3 e^{j90^o} V_2, \tag{9}$$

ensuring that voltages V_2 and V_1 are in quadrature.

If $R_2 = R_3$, the relationships between output currents I_{out1} and I_{out2} are

$$I_{out1} = \omega C_2 R_3 e^{j90^o} I_{out2}, \tag{10}$$

ensuring that currents I_{out2} and I_{out1} are in quadrature.

The proposed quadrature oscillator circuits employ only grounded capacitors and resistors. The use of grounded capacitors and resistors is particularly attractive for integrated circuit implementation [16]-[18]. Because the output impedances of the currents I_{out1} and I_{out2} in Figs. 1 and 2 are very high, the two output terminals, I_{out1} and I_{out2}, can be directly connected to the next stage. The current-mode and voltage-mode quadrature signals can be simultaneously obtained from Fig. 2. From (5), (9), and (10), the magnitudes of the quadrature signals are not the same. For applications requiring equal magnitude quadrature outputs, other amplifying circuits are needed.

III. Non-ideal Effects

Taking the non-idealities of the FDCCII into account, the relationship of the terminal voltages and currents can be rewritten as $v_{xa} = \alpha_{a1} v_{y1} - \alpha_{a2} v_{y2} + \alpha_{a3} v_{y3}$, $v_{xb} = -\alpha_{b1} v_{y1} + \alpha_{b2} v_{y2} + \alpha_{b4} v_{y4}$, $i_{y1} = i_{y2} = i_{y3} = i_{y4} = 0$, $i_{zai} = \pm\beta_{ai} i_{xa}$ and $i_{zbj} = \pm\beta_{bj} i_{xb}$, where $\alpha_{ak} = 1-\varepsilon_{avk}$ and ε_{avk} ($|\varepsilon_{avk}| \ll 1$) is the voltage tracking error from the k-th v_y terminal to the v_{xa} terminal of the FDCCII, $\alpha_{bk} = 1-\varepsilon_{bvk}$ and ε_{bvk} ($|\varepsilon_{bvk}| \ll 1$) is the voltage tracking error from the k-th v_y terminal to the v_{xb} terminal of the FDCCII, $\beta_{ai} = 1-\varepsilon_{ai}$ and ε_{ai} ($|\varepsilon_{ai}| \ll 1$) is the output current tracking error from the v_{xa} terminal to the i-th v_{za} terminal of the FDCCII, and $\beta_{bj} = 1-\varepsilon_{bj}$ and ε_{bj} ($|\varepsilon_{bj}| \ll 1$) is the output current tracking error from the v_{xb} terminal to the j-th v_{zb} terminal of the FDCCII. The characteristic equation of Fig. 1 becomes

$$s^2 C_1 C_2 + sG_1(C_2\alpha_{a2}\beta_{a2} - C_1\alpha_{a3}\beta_{a1}) + G_1 G_2 \alpha_{b2}\alpha_{a3}\beta_{b1}\beta_{a2} = 0. \tag{11}$$

The modified oscillation condition and oscillation frequency are

$$C_1 = \frac{C_2\alpha_{a2}\beta_{a2}}{\alpha_{a3}\beta_{a1}}, \tag{12}$$

$$\omega_o = \sqrt{\frac{\alpha_{b2}\alpha_{a3}\beta_{b1}\beta_{a2}}{C_1 C_2 R_1 R_2}}. \tag{13}$$

From (12) and (13), the tracking errors slightly change the oscillation condition and oscillation frequency. However, the oscillation condition and oscillation frequency still can be orthogonally controllable. The active and passive sensitivities of the quadrature oscillator are all low and are obtained as

$$S^{\omega_o}_{\alpha_{b2},\alpha_{a3},\beta_{b1},\beta_{a2}} = -S^{\omega_o}_{C_1,C_2,R_1,R_2} = \frac{1}{2}. \tag{14}$$

The characteristic equation of Fig. 2 becomes

$$s^2 C_1 C_2 + sC_2(G_1 - G_2\alpha_{a2}\beta_{a1}) + G_2 G_3 \alpha_{b2}\alpha_{a3}\beta_{a1}\beta_{b1} = 0. \tag{15}$$

The modified oscillation condition and oscillation frequency are

$$R_1 = \frac{R_2}{\alpha_{a2}\beta_{a1}}, \tag{16}$$

$$\omega_o = \sqrt{\frac{\alpha_{b2}\alpha_{a3}\beta_{a1}\beta_{b1}}{C_1 C_2 R_2 R_3}}. \tag{17}$$

From (16) and (17), the tracking errors slightly change the oscillation condition and oscillation frequency. However, the oscillation condition and oscillation frequency still can be independently controllable. The active and passive sensitivities of the quadrature oscillator are all low and are obtained as

$$S^{\omega_o}_{\alpha_{b2},\alpha_{a3},\beta_{a1},\beta_{b1}} = -S^{\omega_o}_{C_1,C_2,R_2,R_3} = \frac{1}{2}. \tag{18}$$

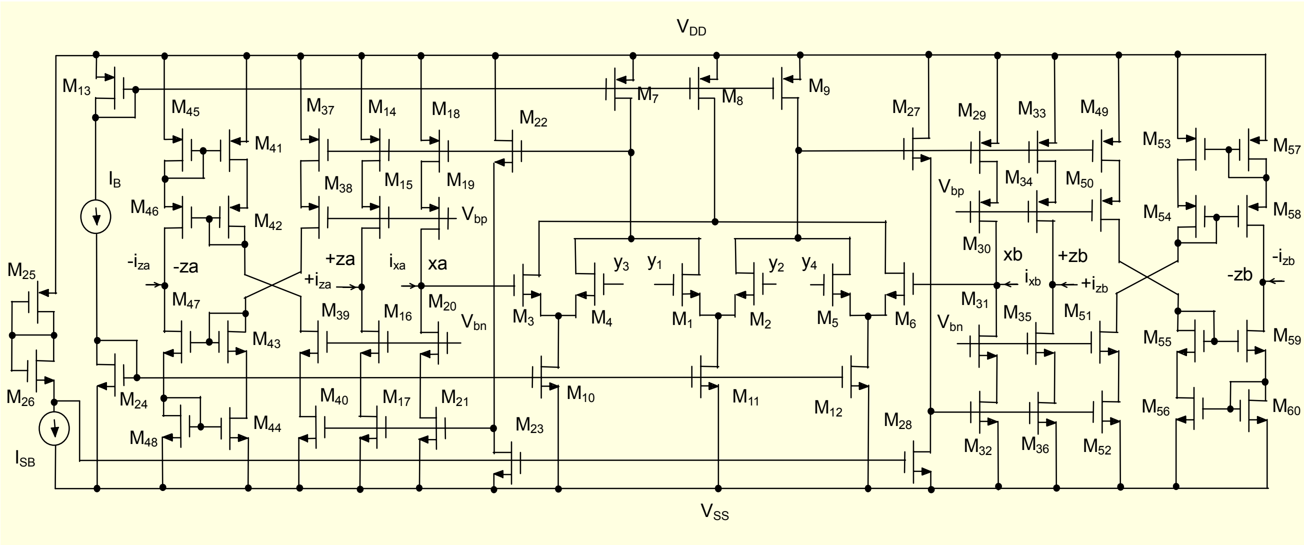


Fig. 3. The implementation of FDCCII.

Table 1. TSMC NMOS parameters for the 0.18 μm process.

LEVEL	= 49				
VERSION	= 3.1	TNOM	= 27	TOX	= 4.1E-9
XJ	= 1E-7	NCH	= 2.3549E17	VTH0	= 0.3662473
K1	= 0.5864999	K2	= 1.127266E-3	K3	= 1E-3
K3B	= 0.0294061	W0	= 1E-7	NLX	= 1.630684E-7
DVT0W	= 0	DVT1W	= 0	DVT2W	= 0
DVT0	= 1.2064649	DVT1	= 0.4215486	DVT2	= 0.0197749
U0	= 273.8094484	UA	= -1.40499E-9	UB	= 2.408323E-18
UC	= 6.504826E-11	VSAT	= 1.355009E5	A0	= 2
AGS	= 0.4449958	B0	= 1.901075E-7	B1	= 4.99995E-6
KETA	= -0.0164863	A1	= 3.868769E-4	A2	= 0.4640272
RDSW	= 123.3376355	PRWG	= 0.5	PRWB	= -0.197728
WR	= 1	WINT	= 0	LINT	= 1.690044E-8
XL	= 0	XW	= -1E-8	DWG	= -4.728719E-9
DWB	= -2.452411E-9	VOFF	= -0.0948017	NFACTOR	= 2.1860065
CIT	= 0	CDSC	= 2.4E-4	CDSCD	= 0
CDSCB	= 0	ETA0	= 2.230928E-3	ETAB	= 6.028975E-5
DSUB	= 0.0145467	PCLM	= 1.3822069	PDIBLC1	= 0.1762787
PDIBLC2	= 1.66653E-3	PDIBLCB	= 0.1	DROUT	= 0.7694691
PSCBE1	= 8.91287E9	PSCBE2	= 7.349607E-9	PVAG	= 1.685917E-3
DELTA	= 0.01	RSH	= 6.7	MOBMOD	= 1
PRT	= 0	UTE	= -1.5	KT1	= -0.11
KT1L	= 0	KT2	= 0.022	UA1	= 4.31E-9
UB1	= -7.61E-18	UC1	= -5.6E-11	AT	= 3.3E4
WL	= 0	WLN	= 1	WW	= 0
WWN	= 1	WWL	= 0	LL	= 0
LLN	= 1	LW	= 0	LWN	= 1
LWL	= 0	CAPMOD	= 2	XPART	= 0.5
CGDO	= 8.23E-10	CGSO	= 8.23E-10	CGBO	= 1E-12
CJ	= 9.466429E-4	PB	= 0.8	MJ	= 0.3820266
CJSW	= 2.608154E-10	PBSW	= 0.8	MJSW	= 0.102322
CJSWG	= 3.3E-10	PBSWG	= 0.8	MJSWG	= 0.102322
CF	= 0	PVTH0	= -2.199373E-3	PRDSW	= -0.9368961
PK2	= 1.593254E-3	WKETA	= -2.880976E-3	LKETA	= 7.165078E-3
PU0	= 6.777519	PUA	= 5.505418E-12	PUB	= 8.84133E-25
PVSAT	= 2.006286E3	PETA0	= 1.003159E-4	PKETA	= -6.759277E-3

Table 2. TSMC PMOS parameters for the 0.18 μm process.

LEVEL	= 49				
VERSION	= 3.1	TNOM	= 27	TOX	= 4.1E-9
XJ	= 1E-7	NCH	= 4.1589E17	VTH0	= -0.3906012
K1	= 0.5341312	K2	= 0.0395326	K3	= 0
K3B	= 7.4916211	W0	= 1E-6	NLX	= 1.194072E-7
DVT0W	= 0	DVT1W	= 0	DVT2W	= 0
DVT0	= 0.5060555	DVT1	= 0.2423835	DVT2	= 0.1
U0	= 115.6894042	UA	= 1.573746E-9	UB	= 1.874308E-21
UC	= -1E-10	VSAT	= 1.130982E5	A0	= 1.9976555
AGS	= 0.4186945	B0	= 1.949178E-7	B1	= 6.422908E-7
KETA	= 0.0166345	A1	= 0.4749146	A2	= 0.300003
RDSW	= 198.321294	PRWG	= 0.5	PRWB	= -0.4986647
WR	= 1	WINT	= 0	LINT	= 2.94454E-8
XL	= 0	XW	= -1E-8	DWG	= -2.798724E-8
DWB	= -4.83797E-10	VOFF	= -0.095236	NFACTOR	= 2
CIT	= 0	CDSC	= 2.4E-4	CDSCD	= 0
CDSCB	= 0	ETA0	= 1.035504E-3	ETAB	= -4.358398E-4
DSUB	= 1.816555E-3	PCLM	= 1.3299898	PDIBLC1	= 1.766563E-3
PDIBLC2	= 7.728395E-7	PDIBLCB	-1E-3	DROUT	= 1.011891E-3
PSCBE1	= 4.872184E10	PSCBE2	= 5E-10	PVAG	= 0.0209921
DELTA	= 0.01	RSH	= 7.7	MOBMOD	= 1
PRT	= 0	UTE	= -1.5	KT1	= -0.11
KT1L	= 0	KT2	= 0.022	UA1	= 4.31E-9
UB1	= -7.61E-18	UC1	= -5.6E-11	AT	= 3.3E4
WL	= 0	WLN	= 1	WW	= 0
WWN	= 1	WWL	= 0	LL	= 0
LLN	= 1	LW	= 0	LWN	= 1
LWL	= 0	CAPMOD	= 2	XPART	= 0.5
CGDO	= 6.35E-10	CGSO	= 6.35E-10	CGBO	= 1E-12
CJ	= 1.144521E-3	PB	= 0.8468686	MJ	= 0.4099522
CJSW	= 2.490749E-10	PBSW	= 0.8769118	MJSW	= 0.3478565
CJSWG	= 4.22E-10	PBSWG	= 0.8769118	MJSWG	= 0.3478565
CF	= 0	PVTH0	= 2.302018E-3	PRDSW	= 9.0575312
PK2	= 1.821914E-3	WKETA	= 0.0222457	LKETA	= -1.495872E-3
PU0	= -1.5580645	PUA	= -6.36889E-11	PUB	= 1E-21
PVSAT	= 49.8420442	PETA0	= 2.827793E-5	PKETA	= -2.536564E-3

Table 3. Aspect ratios of the MOS in Fig. 3.

MOS transistors	Aspect ratio (W/L)
M_1–M_6	60/4.8
M_7, M_8, M_9, M_{13}	480/4.8
M_{10}, M_{11}, M_{12}, M_{24}	120/4.8
M_{14}, M_{15}, M_{18}, M_{19}, M_{25}, M_{29}, M_{30}, M_{33}, M_{34}, M_{37}, M_{38}, M_{41}, M_{42}, M_{45}, M_{46}, M_{49}, M_{50}, M_{53}, M_{54}, M_{57}, M_{58}	240/2.4
M_{16}, M_{17}, M_{20}, M_{21}, M_{26}, M_{31}, M_{32}, M_{35}, M_{36}, M_{39}, M_{40}, M_{43}, M_{44}, M_{47}, M_{48}, M_{51}, M_{52}, M_{55}, M_{56}, M_{59}, M_{60}	60/2.4
M_{22}, M_{23}, M_{27}, M_{28}	4.8/4.8

IV. Simulation Results

The quadrature oscillators were simulated using HSPICE. The FDCCII was realized by the CMOS implementation in Fig. 1 of [19] and is shown in Fig. 3 (using a 0.18 μm MOSFET from Taiwan Semiconductor Manufacturing Company, Ltd., the model parameters are given in Tables 1 and 2). The aspect ratios of the MOS transistors were chosen as in Table 3. The multiple current outputs can be easily implemented by adding output branches. Figure 4(a) represents the current-mode quadrature sinusoidal output waveforms of Fig. 1 with C_1 = 100 pF, C_2 = 90 pF, R_1 = 2 kΩ, R_2 = 2 kΩ, V_{bp} = 0 V, V_{bn} = 0 V, I_B = 1.1 mA, I_{SB} = 2.2 mA, and a power supply of ±2.5 V, where C_1 was designed to be larger than C_2 to ensure that the oscillations would start. The power dissipation is 118.1 mW. Figure 4(b) shows the

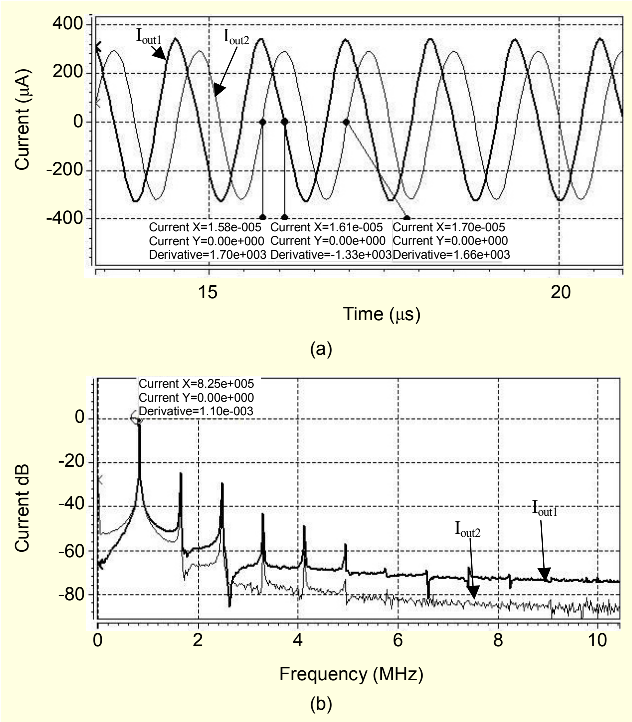


Fig. 4. (a) The simulated current-mode quadrature output waveforms of Fig. 1 and (b) the simulated frequency spectrum of I_{out1} and I_{out2} in Fig. 1.

Table 4. Total harmonic distortion analysis of I_{out2} in Fig. 1.

Harmonic number	Frequency (Hz)	fft_mag (dB, A)	fft_mag (A)	fft_phase (°)
1	825.0000k	-76.8265	144.1035μ	-8.4780
2	1.6500M	-108.8059	3.6283μ	157.9699
3	2.4750M	-115.7742	1.6266μ	-158.8260
4	3.3000M	-133.7474	205.4142n	-51.8204
5	4.1250M	-140.2199	97.5001n	-55.7816
6	4.9500M	-150.3637	30.3259n	-120.8754
7	5.7750M	-153.7060	20.6395n	-53.5568
8	6.6000M	-158.6050	11.7422n	-35.2600
DC component: 7.443E-06				
Total harmonic distortion: 2.7640 %				

simulated frequency spectrum of I_{out1} and I_{out2} in Fig. 1. The results of the I_{out2} total harmonic distortion analysis are summarized in Table 4. Figure 5 shows the simulation results of the oscillation frequency of Fig. 1 by varying the value of resistor R_1 with C_1 = 100 pF, C_2 = 90 pF and R_2 = 2 kΩ. The non-idealities may be due to the ignored parasitic elements and tracking errors of the FDCCII.

Figures 6(a) and 6(b) represent the current-mode and

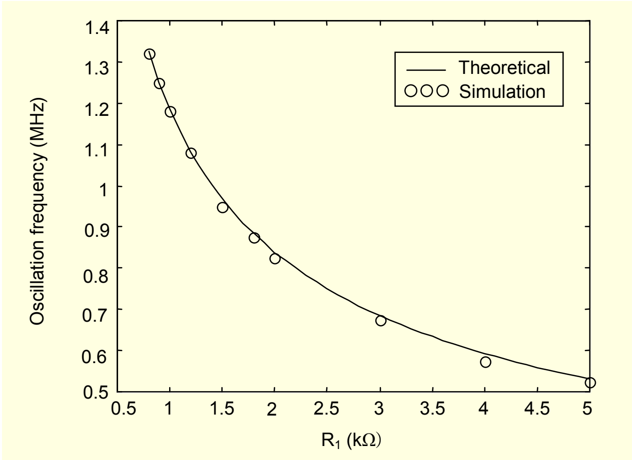


Fig. 5. Simulation results of the oscillation frequency of Fig. 1, which is obtained by varying the value of the resistor R_1.

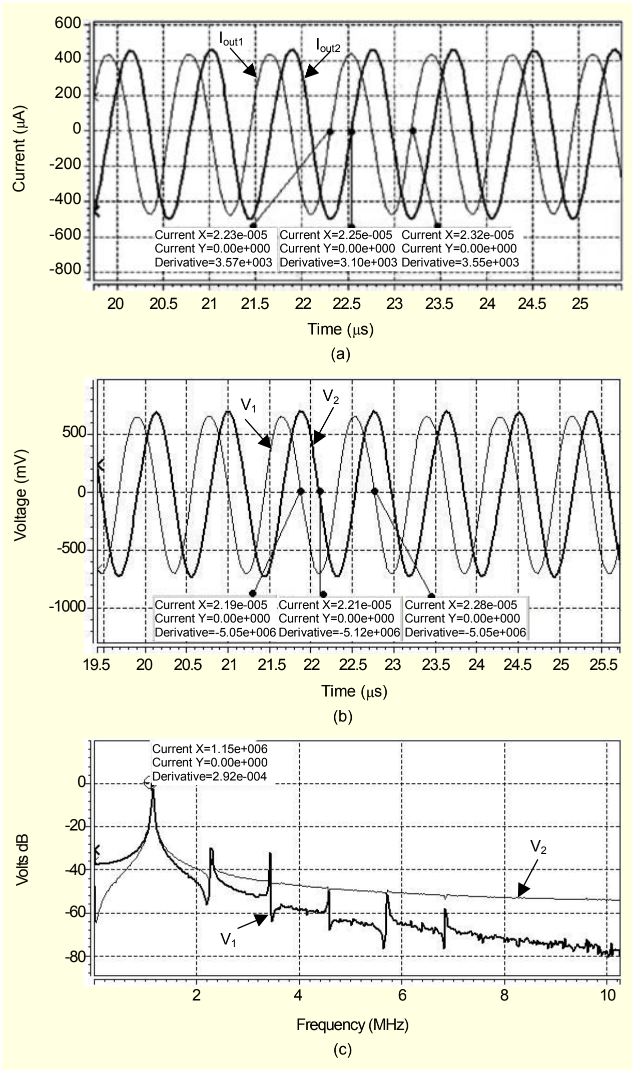


Fig. 6. From Fig. 2, the (a) simulated current-mode quadrature output waveforms, (b) simulated voltage-mode quadrature output waveforms, and (c) simulated frequency spectrum of V_1 and V_2,.

Table 5. Total harmonic distortion analysis of V_1 in Fig 2.

Harmonic number	Frequency (Hz)	fft_mag (dB, V)	fft_mag (V)	fft_phase (°)
1	1.1500M	-10.5387	297.2124m	-169.3633
2	2.3000M	-41.4345	8.4777m	-174.0034
3	3.4500M	-71.4849	266.5367μ	1.7294
4	4.6000M	-78.6715	116.5260μ	173.5110
5	5.7500M	-68.6289	370.3004μ	-138.6174
6	6.9000M	-76.7537	145.3170μ	-110.6239
7	8.0500M	-81.9323	80.0542μ	-104.4065
8	9.2000M	-86.2410	48.7474μ	-97.5189
DC component: 9.9901E-03				
Total harmonic distortion: 2.8574 %				

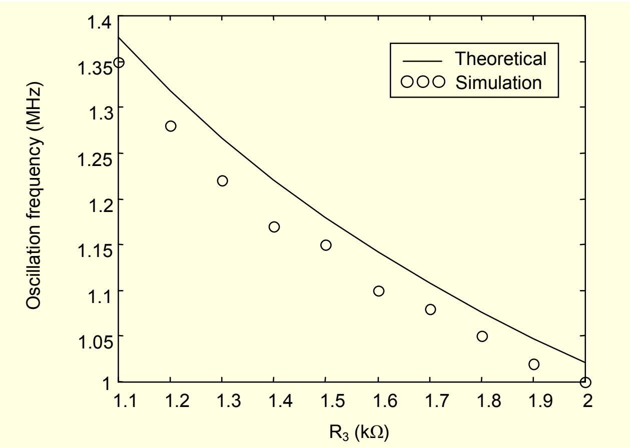


Fig. 7. Simulation results of the oscillation frequency of Fig. 2, which is obtained by varying the value of the resistor, R_3.

voltage-mode, respectively, with quadrature sinusoidal output waveforms of Fig. 2 with $C_1 = 90$ pF, $C_2 = 90$ pF, $R_1 = 1.52$ kΩ, and $R_2 = R_3 = 1.5$ kΩ, where R_1 was designed to be larger than R_2 to ensure that the oscillations would start. The power dissipation is 129.4 mW. Figure 6(c) shows the simulated frequency spectrum of V_1 and V_2 in Fig. 2. The results of the V_1 total harmonic distortion analysis are summarized in Table 5. Figure 7 shows the simulation results of the oscillation frequency of Fig. 2 by varying the value of resistor R_3 with $C_1 = 90$ pF, $C_2 = 90$ pF, $R_1 = 1.52$ kΩ, and $R_2 = 1.5$ kΩ. The non-idealities may be due to the ignored parasitic elements and tracking errors of the FDCCII.

V. Conclusions

In this paper, two new quadrature oscillators, each using one FDCCII, two grounded capacitors, and two (or three) grounded resistors, are proposed. The oscillation conditions and oscillation frequencies of the proposed quadrature oscillators have the advantage of being orthogonally (or independently) controllable. Two high-output impedance sinusoid currents with a 90^{o} phase difference are available in each circuit configuration. The use of only grounded capacitors and resistors makes the proposed circuits ideal for integrated circuit implementation. The current-mode and voltage-mode quadrature signals can be simultaneously obtained in the second proposed circuit.

References

[1] A.S. Sedra and K.C. Smith, *Microelectronic Circuits*, 4th ed. Oxford University Press, New York, 1998, pp. 984-986.

[2] I.A. Khan and S. Khwaja, “An Integrable Gm-C Quadrature Oscillator,” *Int'l J. Electronics*, vol. 87, 2000, pp. 1353-1357.

[3] R. Holzel, “A Simple Wide-Band Sine Wave Quadrature Oscillator,” *IEEE Trans. Instrumentation and Measurement*, vol. 42, 1993, pp. 758-760.

[4] M.T. Ahmed, I.A. Khan, and N. Minhaj, “On Transconductance-C Quadrature Oscillators,” *Int'l J. Electronics*, vol. 83, 1997, pp. 201-207.

[5] A.M. Soliman, “Synthesis of Grounded Capacitor and Grounded Resistor Oscillators,” *J. Franklin Institute*, vol. 336, 1999, pp. 735-746.

[6] J.W. Horng, “Current Differencing Buffered Amplifiers Based Single Resistance Controlled Quadrature Oscillator Employing Grounded Capacitors,” *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, vol. E85-A, 2002, pp. 1416-1419.

[7] P. Prommee and K. Dejhan, “An Integrable Electronic-Controlled Quadrature Sinusoidal Oscillator Using CMOS Operational Transconductance Amplifier,” *Int'l J. Electronics*, vol. 89, 2002, pp. 365-379.

[8] J.W. Horng, C.L. Hou, C.M. Chang, W.Y. Chung, H.W. Tang, and Y.H. Wen, “Quadrature Oscillators Using CCIIs,” *Int'l J. Electronics*, vol. 92, 2005, pp. 21-31.

[9] J.J. Chen, C.C. Chen, H.W. Tsao, and S.I. Liu, “Current-Mode Oscillators Using Single Current Follower,” *Electronics Letters*, vol. 27, 1991, pp. 2056-2059.

[10] M.T. Abuelma'atti, “Grounded Capacitor Current-Mode Oscillator Using Single Current Follower,” *IEEE Trans. Circuits and Systems-I: Fundamental Theory and Applications*, vol. 39, 1992, pp. 1018-1020.

[11] M.T. Abuelma'atti and H.A. Alzaher, “Comment on Current-Mode Quadrature Sinusoidal Oscillator Using Single FTFN,” *Int'l J. Electronics*, vol. 85, 1998, pp. 177-180.

[12] S. Minaei and O. Cicekoglu, “New Current-Mode Integrator, All-Pass Section and Quadrature Oscillator Using only Active

Elements," *1st IEEE Int'l Conf. Circuits and Systems for Communications*, vol. 26-28, 2002, pp.70–73.

[13] J.W. Horng, "Current-Mode Quadrature Oscillator with Grounded Capacitors and Resistors Using Two DVCCs," *IEICE Trans. Fundamentals of Electronics, Communications and Computer Sciences*, vol. E86-A, 2003, pp. 2152-2154.

[14] M.T. Abuelma'atti and H.A. Al-Zaher, "Current-Mode Sinusoidal Oscillators Using Single FTFN," *IEEE Trans. Circuits and Systems-II: Analog and Digital Signal Proc.*, vol. 46, 1999, pp. 69-74.

[15] U. Cam, A. Toker, O. Cicekoglu, and H. Kuntman, "Current-Mode High Output Impedance Sinusoidal Oscillator Configuration Employing Single FTFN," *Analog Integrated Circuits and Signal Proc.*, vol. 24, 2000, pp. 231-238.

[16] S.S. Gupta and R. Senani, "Realisation of Current-Mode SRCOs Using All Grounded Passive Elements," *Frequenz*, vol. 57, 2003, pp. 26-37.

[17] M.T. Abuelma'atti and A.A. Al-Ghumaiz, "Novel CCI-Based Single-Element-Controlled Oscillators Employing Grounded Resistors and Capacitors," *IEEE Trans. on Circuits and Systems-I: Fundamental Theory and Applications*, vol. 43, 1996, pp. 153-155.

[18] M. Bhusan and R.W. Newcomb, "Grounding of Capacitors in Integrated Circuits," *Electronic Letters*, vol. 3, 1967, pp. 148-149.

[19] A.A. El-Adawy, A.M. Soliman, and H.O. Elwan, "A Novel Fully Differential Current Conveyor and Applications for Analog VLSI," *IEEE Transactions on Circuits and Systems-II: Analog and Digital Signal Proc.*, vol. 47, 2000, pp. 306-313.

[20] C.M. Chang, B.M. Al-Hashimi, H.P. Chen, S.H. Tu, and J. A. Wan, "Current-Mode Single Resistance Controlled Oscillators Using Only Grounded Passive Components," *Electronics Letters*, vol. 38, 2002, pp. 1071-1072.

[21] C.M. Chang, B.M. Al-Hashimi, C.L. Wang, and C.W. Hung, "Single Fully Differential Current Conveyor Biquad Filters," *IEE Proc.: Circuits, Devices and Systems*, vol. 150, 2003, pp. 394-398.

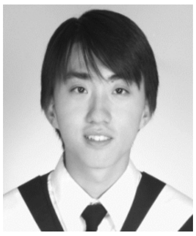
[22] S.M. Al-Shahrani, "Fully Differential Second-Order Filter," *The 47th IEEE Int'l Midwest Symposium on Circuits and Systems,* vol. 3, 2004, pp. III299-III301.

[23] C.M. Chang and H.P. Chen, "Single FDCCII-Based Tunable Universal Voltage-Mode Filter," *Circuits, Systems, and Signal Proc.*, vol. 24, 2005, pp. 221-227.

Jiun-Wei Horng was born in Tainan, Taiwan, Republic of China, in 1971. He received the BS degree in electronic engineering from Chung Yuan Christian University, Chung-Li, in 1993, and the PhD degree from National Taiwan University, Taipei, in 1997. From 1997 to 1999, he served as a Second-Lieutenant in China Army Force. From 1999 to 2000, he joined CHROMA ATE INC. where he worked in the area of video pattern generator technologies. Since 2000, he has been an Assistant Professor with the Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan, where he is now an Associate Professor. His teaching and research interests are in the areas of circuits and systems, analog and digital electronics, active filter design and current-mode signal processing.

Chun-Li Hou was born in Taipei, Taiwan, Republic of China, in 1951. He received the BS degree, MS degree, and PhD degree in electrical engineering from National Taiwan University, Taipei, in 1974, 1976, and 1991, respectively. From 1977 to 1979, he taught as a lecturer in Tamkang College. Since 1981, he has been a lecturer in the Department of Electronic Engineering, Chung-Yuan Christian University, Chung-Li, Taiwan. Since 1992 he has been an Associate Professor. His teaching and research interests are in the areas of current-mode analog circuit analysis and design, active network synthesis circuit theory and applications.

Chun-Ming Chang obtained his bachelor and master degrees, both in the field of electrical engineering, from National Cheng Kung University, Tainan, Taiwan, R. O. China, and his PhD degree in the field of electronics and computer science from the University of Southampton, U. K. Since 1985, he has been a Professor at Chung Yuan Christian University in Taiwan, where he has been a Full Professor since 1991. Prior to 1991, his research interest was in the field of network synthesis. Since 1991, he has been pursuing research in the field of analog circuit design. He was a Chairman of the Electrical Engineering Department of Chung Yuan Christian University from 1995 to 1999. Recently, he was recommended for inclusion in The Contemporary Who's Who of Professionals 2004 Edition, and was nominated by the Governing Board of Editors of the American Biographical Institute for the prestigious title Man of the Year-2005. He became an Advisor of the ABI's distinguished Research Board of Advisors due to the invention of Analytical Synthesis Method and OTA-Only-Without-C circuits in the field of analog circuit design.



Hung-Pin Chou was born in Hsinchu, Taiwan, Republic of China, in 1983. He received the BS degree in electronic engineering from Chung Yuan Christian University, Chung-Li, Taiwan, in 2005. Since 2005, he has been working towards a MS degree in the Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan. His research interests are in the areas of circuits and systems, analog and digital electronics, active filter design and current-mode signal processing.

Chun-Ta Lin was born in Taoyuan, Taiwan, Republic of China, in 1979. He received the BS degree in electronic engineering from National Taiwan Ocean University, Kee-Lung, Taiwan, in 2001. Since 2005, he has been working towards a MS degree in the Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan. His research interests are in the areas of circuits and systems, analog and digital electronics, active filter design and current-mode signal processing.

Yao-Hsin Wen was born in Hsinchu, Taiwan, Republic of China, in 1982. He received the BS degree in electronic engineering from Chung Yuan Christian University, Chung-Li, Taiwan, in 2004. Since 2004, he has been working towards a MS degree in the Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan. His research interests are in the areas of circuits and systems, analog and digital electronics, active filter design and current-mode signal pro