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Four-phase Quadrature Oscillator using DO-CCCFTA

***Abstract**. This article introduces novel current-mode quadrature oscillator circuit based on DO-CCCFTA and three grounded passive components. The oscillator circuit can be generated by four-phase sinusoidal current signal. The oscillation condition can be non-interactively controlled from oscillation frequency. Furthermore, its high impedance of outputs can directly connect in current-mode circuit and use only grounded passive components that are very suitable to be furthered fabricated into integrated circuit. The PSPICE simulations and experimental method were implemented for theoretically analysing the proposed oscillator.*

***Streszczenie.** Przedstawiono nową koncepcję układu generatora bazującego na układzie DO-CCCFTA oraz trzech pasywnych elementach. Generator może wytwarzać cztery prądy o sterowanej częstotliwości. Układy generatorów mają wyjścia prądowe. Teoretyczna analiza potwierdzona jest symulacją I eksperymentem. (**Cztery kwadraturowe generatory bazujące na układzie DO-CCCFTA**)*

Keywords: four-phase quadrature oscillator, current-mode, non-interactive control, DO-CCCFTA.
Słowa kluczowe: generator o wyjsciu prądowym, układy DO-CCCFTA.

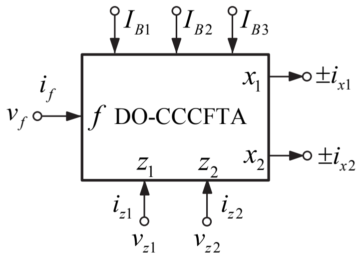
Introduction

The quadrature oscillator (QO) is an oscillator circuit that provides two sinusoidal signals with $90°$ phased difference. A quadrature signal was occasionally implemented for quadrature mixers and the modulator with single-sideband modulators in electronic telecommunications [1]. In the last decade, there were papers concerning the designs of oscillator circuits with can provide quadrature signals having been suggested as current-mode technique stating that the circuit designed from current-mode technique were advantageous for designing; larger dynamic range, spontaneously wide bandwidth, higher slew-rate, higher linearity and lower rate of power consumption [2-3].

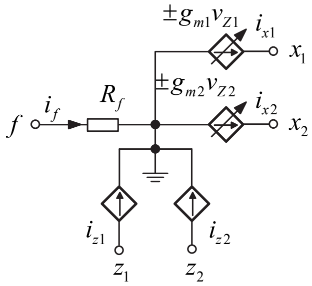
Recently, the researches in [4-27] conducted the study regarding the use of a brand-new active element to design a oscillator circuit with current-mode technique. From literature survey, the quadrature oscillators were widely implemented using different active elements [11-27]. However, there are still some weaknesses found as follows:

1. Non-interactively controlled for both of the condition and frequency of oscillation [11-14] is inconvenient for implementation.
2. The condition and frequency of oscillation cannot be electronically adjusted [15-16], which are unsuitable to be used in control systems and microcontroller system.
3. The floating passive elements [12-18] were not desirable for the fabrication of integrated circuit.
4. The excessive use of the passive resistors [19-27], consequently, the power consumption became increased.

This paper highlights on a current-mode four-phase quadrature oscillator circuit that needs only single active element namely dual-output current controlled current follower transconductance amplifier (DO-CCCFTA). This circuit generates the four-phase current output signals with a 90-degree phase deference. Additionally, it is suitable to use grounded capacitors and resistor for the four-phase oscillator circuit to be developed into an integrated circuit [5-6]. Moreover, it is possible to instigate electronic method and non-interactive dual current control to adjust the condition and the frequency of oscillation.



(a) Symbol of DO-CCCFTA



(b) Equivalent circuit of DO-CCCFTA

Fig. 1. Symbol and equivalent circuit of DO-CCCFTA.

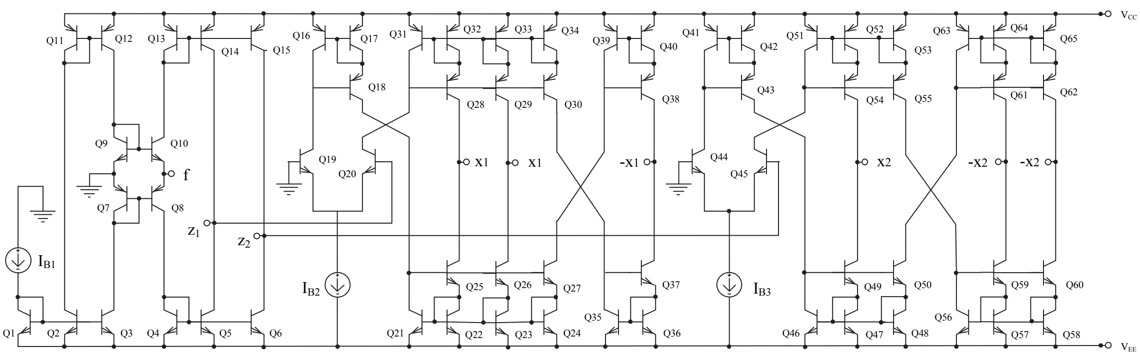


Fig. 2. Internal construction of DO-CCCFTA

Basic concept of DO-CCCFTA

The DO-CCCFTA is a modification form of current controlled current follower transconductance amplifier (CCCFTA). The characteristics of DO-CCCFTA were represented by the following hybrid matrix:

(1) $$\begin{bmatrix} v_f \\ i_z, i_{zc} \\ i_{x1} \\ i_{x2} \end{bmatrix} = \begin{bmatrix} R_f & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_{m1} & 0 \\ 0 & 0 & 0 & \pm g_{m2} \end{bmatrix} \begin{bmatrix} i_f \\ v_x \\ v_z \\ v_{zc1} \end{bmatrix}.$$

R_f is the parasitic resistance at f port, and it is capable of being adjusted by I_{B1}. The g_{m1} and g_{m2} are the transconductance to be adjusted by I_{B2} and I_{B3}, respectively. For a bipolar junction transistor, the R_f, g_{m1} and g_{m2} of DO-CCCFTA can be specified as the following equations :

(2) $$R_f = \frac{V_T}{2I_{B1}}$$

(3) $$g_{m1} = \frac{I_{B2}}{2V_T}$$

(4) $$g_{m2} = \frac{I_{B3}}{2V_T}$$

From Equations (2) – (4), I_{B1}, I_{B2} and I_{B3} are bias currents of DO-CCCFTA. The symbol and the equivalent circuit of DO-CCCFTA were illustrated in Figs 1 (a) and (b), respectively. The BJT internal construction of DO-CCCFTA was showed in Fig. 2.

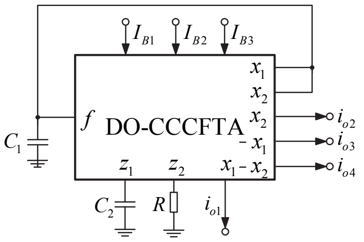


Fig. 3. Four-phase current-mode quadrature oscillator

Four-phase Current-mode Quadrature Oscillator

The proposed four-phase current-mode quadrature oscillator illustrated in Fig. 3 was consisted of single DO-CCCFTA, two grounded capacitors and single grounded resistor. The characteristic equation of oscillator can be illustrated in Equation (5).

(5) $$s^2 + s\frac{C_2 - g_{m2}RC_1}{R_f C_1 C_2} + \frac{g_{m1}}{R_f C_1 C_2} = 0$$

From Equation (5), the oscillation condition (OC) and oscillation frequency (OF) are as follows:

(6) $$OC: \quad 1 = g_{m2}R$$

(7) $$OF: \quad f_{osc} = \frac{1}{2\pi}\sqrt{\frac{g_{m1}}{R_f C_1 C_2}}$$

By substituting the g_{m1}, g_{m2} and R_f, the parameters OC and OF are developed into :

(8) $$OC: \quad 2V_T = I_{B3}R$$

(9) $$OF: \quad f_{osc} = \frac{1}{2\pi V_T}\sqrt{\frac{I_{B1}I_{B2}}{C_1 C_2}}$$

From Equations (8) and (9), the OC can be adjusted independently from the OF. The relation of the output signals was defined as:

(10) $$\frac{i_{o2}}{i_{o1}} = \frac{g_{m2}RC_2 s}{g_{m1}}$$

(11) $$\frac{i_{o3}}{i_{o2}} = -\frac{g_{m2}RC_2 s}{g_{m1}}$$

(12) $$\frac{i_{o4}}{i_{o3}} = \frac{g_{m2}RC_2 s}{g_{m1}}$$

(13) $$\frac{i_{o1}}{i_{o4}} = -\frac{g_{m1}}{g_{m2}RC_2 s}$$

According to Equation (10) – (13), the oscillator can generate four-phase quadrature sinusoidal output signals.

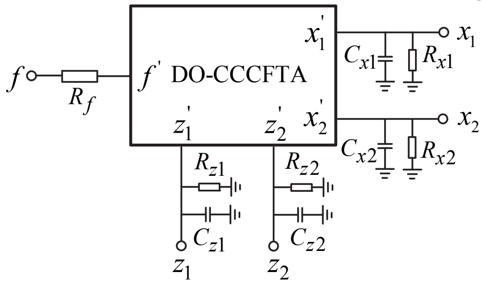


Fig. 4. Parasitic component of DO-CCCFTA

Analysis of non-ideal case

For non-ideal case, the characteristic equation of DO-CCCFTA in Equation (1) becomes:

(14) $$\begin{bmatrix} v_f \\ i_z, i_{zc} \\ i_{x1} \\ i_{x2} \end{bmatrix} = \begin{bmatrix} R_f & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 \\ 0 & 0 & \pm\beta_1 g_{m1} & 0 \\ 0 & 0 & 0 & \pm\beta_2 g_{m2} \end{bmatrix} \begin{bmatrix} i_f \\ v_x \\ v_z \\ v_{zc1} \end{bmatrix}$$

The parameters β and α are the voltage and current transfer, respectively. These parameters were changed on the intrinsic impedances and temperatures. In addition, DO-CCCFTA consists of parasitic elements R_f, R_z, C_z, R_x and C_x, as showed in Fig. 4. Then, when $R_x, R_z \gg R_f$, the Equations (5) – (7) become

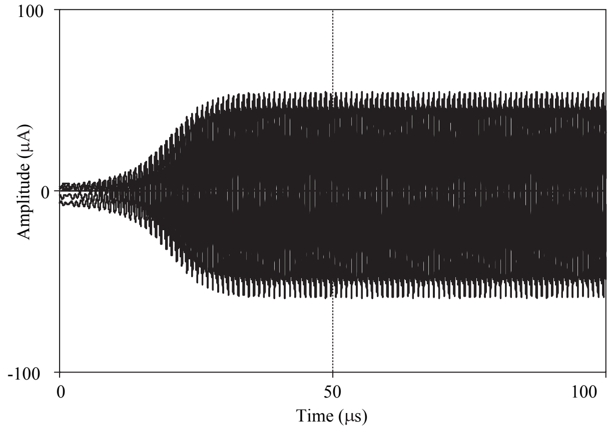
(15)
$$\left\{ \begin{array}{l} (C_1 + C_{x1} + C_{x2})(C_2 + C_{z1})C_{Z2}R_f s^3 + (C_2 + C_{z1})C_{Z2}s^2 \\ +\frac{1}{R}(C_2 + C_{z1})s^2 - \alpha\beta_2 g_{m2}(C_2 + C_{z1})s + \alpha\beta_1 g_{m1}C_{Z2}s \\ +\frac{1}{R}\alpha\beta_1 g_{m1} \end{array} \right\} = 0$$

(16) $$OC: \quad (C_1 + C_{x1} + C_{x2})C_{Z2}R_f = \frac{1}{R^2}\alpha^3\beta_1^2\beta_2 g_{m1}^2 g_{m2}$$

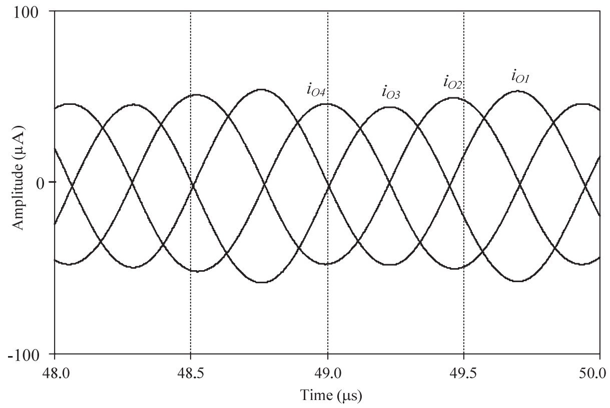
(17) $$OF: \quad f_{osc} = \frac{1}{2\pi V_T}\sqrt{\frac{\alpha\beta_1 g_{m1}}{(C_1 + C_{x1} + C_{x2})(C_2 + C_{z1})C_{Z2}R_f R}}$$

Simulation Results

To examine the stability of the proposed circuit in Fig. 3, the PSPICE simulation program was used for the examination. The parameters of transistor in [6] were used for the simulation and the implementation of internal construction of DO-CCCFTA as showed in Fig.2. The simulation was set with $\pm 1.5\text{V}$, $I_{B1} = 100\mu\text{A}$, $I_{B2} = 400\mu\text{A}$, $I_{B3} = 115\mu\text{A}$, $R = 500\Omega$ and $C_1 = 1\text{nF}$, $C_2 = 1\text{nF}$. Fig. 5 demonstrates the simulated quadrature waveforms of output in initial and steady state, the outputs frequency, about 1.05MHz was deviated about 13.92%. The deviation of the OF must be occurred with the parasitic elements and the voltage and current transfer of DO-CCCFTA.



(a) Initial state signals



(b) Steady state signals

Fig. 5. The simulation of output waveforms

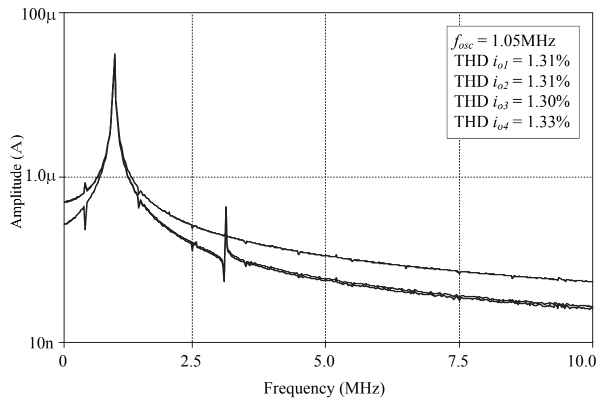


Fig. 6. The spectrum of quadrature oscillator

Fig.6 indicates the result of output spectrum. These results were confirmed for electronic tuning of the OF without effect of the OC. The total harmonic distortion (THD) of i_{o1}, i_{o2}, i_{o3} and i_{o4} were about 1.31%, 1.31%, 1.30% and 1.33%, respectively. Additionally, Fig. 7 illustrates the OF when the bias current I_{B2} and the value of capacitor are deviated. Moreover, the tolerances of external passive elements were affected to the OF. The Monte Carlo analysis can be computed of the OF by using 100 trials and 10% of the tolerances of the external passive elements. The simulation in Fig.8 (a) and (b) illustrated the spectrums and histograms of the OF, respectively. The maximum, minimum and medium of the OF are 2.158MHz, 0.4941MHz and 1.068MHz, respectively.

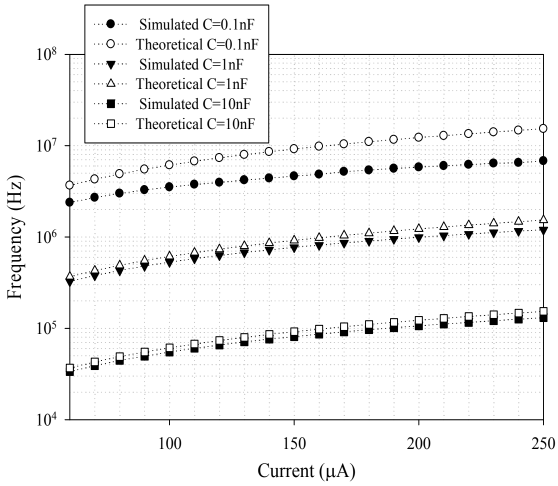
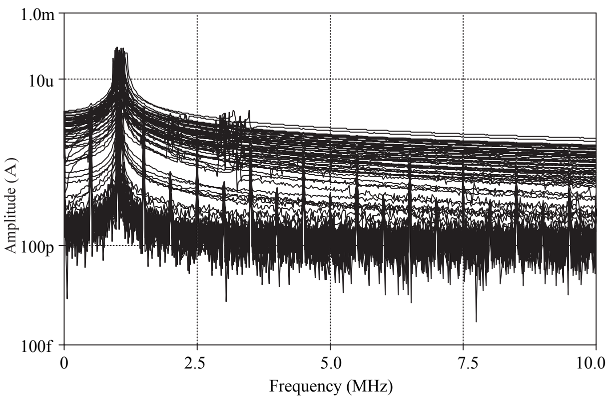
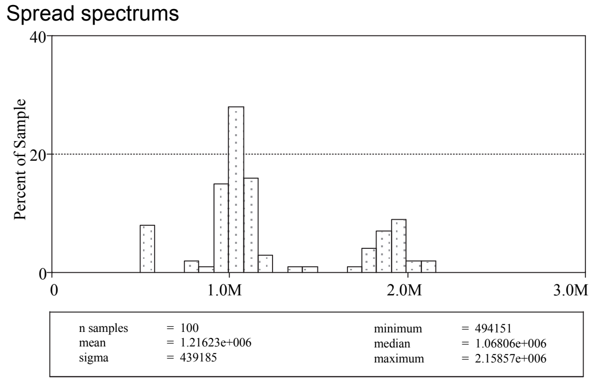


Fig. 7. Electronic tuning of proposed oscillator



(a) Spread spectrums



(b) Histograms

Fig. 8. Monte Carlo simulation

Experimental Results

The four phase quadrature oscillator in Fig. 3 was experimentally set up by using current feedback operational amplifier AD844 IC and operational transconductance amplifier LM13700 ICs (LM13700 with g_m about $I_B / 2V_T$) in order to confirm the theoretical prediction. The implementation of the DO-CCCFTA used in experiment was depicted in Fig. 9. The circuit was biased with $\pm 5\text{V}$ supply voltages and being used, consisting of $C_1 = C_2 = 1\text{nF}$, $I_{B2} = 400\mu\text{A}$ and $I_{B3} = 130\mu\text{A}$. The parasitic resistance R_f was configured by external passive resistor which was $R_f = 130\Omega$. The output currents i_{o1}, i_{o2}, i_{o3} and i_{o4} were converted to output voltage v_{O1}, v_{O2}, v_{O3} and v_{O4}, respectively, by using external passive resistors that were about $1\text{k}\Omega$. The output voltage waveforms used the oscilloscope Rigol model DS1074B for the measurement.

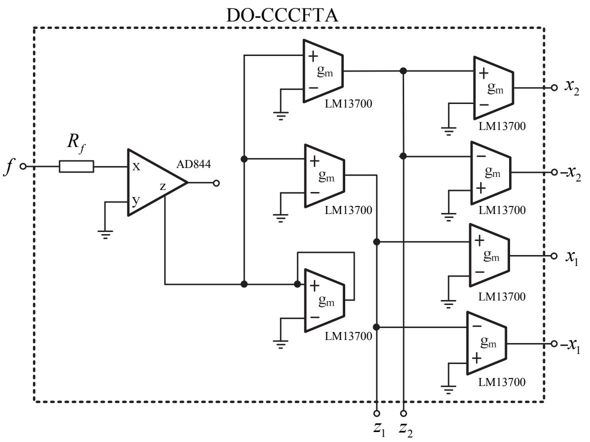
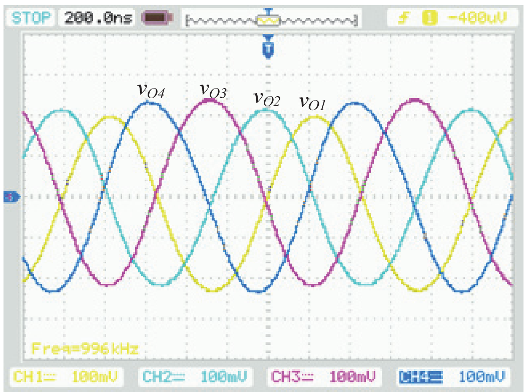
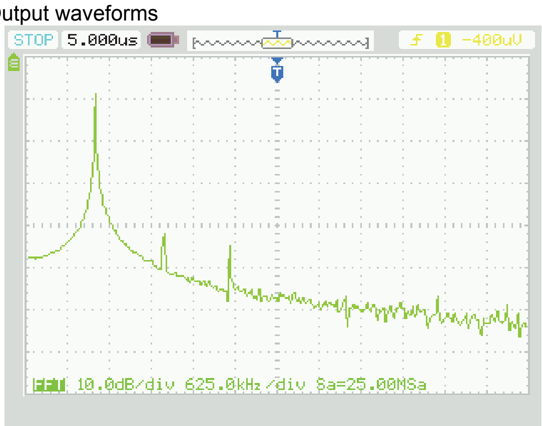


Fig. 9. Internal construction of DO-CCCFTA using commercial ICs.



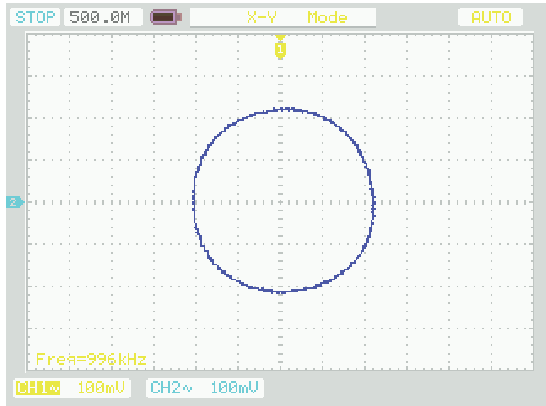
(a) Output waveforms



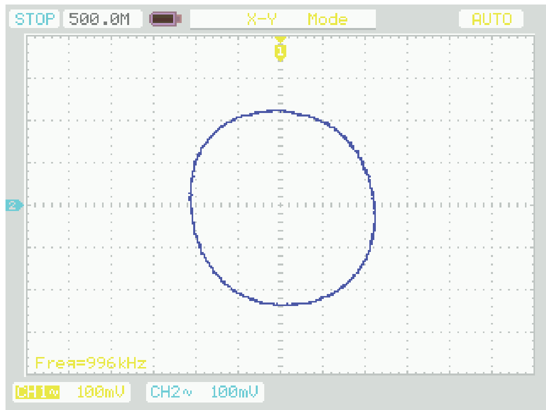
(b) Output spectrum

Fig. 10. The output waveforms

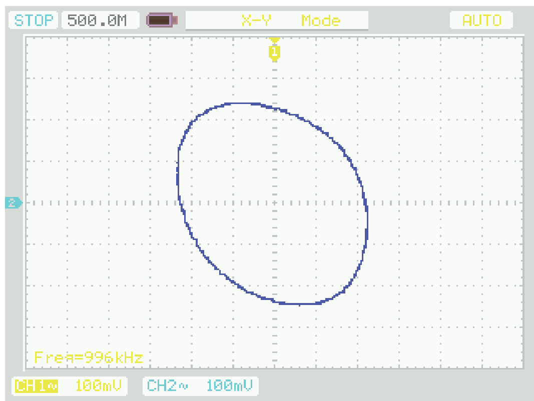
Fig 10 (a) displayed the quadrature output waveforms during steady state and Fig. 10 (b) displayed the output spectrum. The oscillation frequency was about 996kHz where the calculated value of this parameter from equation (7) yielded 1.22MHz (deviated about 18.36%). As well, the voltage waveforms correlation can be detailed in Figs 11. However, the deviation of frequency and phase were arisen by the tolerances of external passive elements, parasitic elements and transfer errors of DO-CCCFTA as explained in Topic of non-ideal case.



(a) Waveforms correlation of v_{O1} and v_{O2}



(b) Waveforms correlation of v_{O2} and v_{O3}



(c) Waveforms correlation of v_{O3} and v_{O4}

Fig. 11. The waveforms correlation

Conclusion

This research study proposes the current-mode four-phase sinusoidal quadrature oscillator. The current-mode oscillator has a single active element. It constructs single DO-CCCFTA and three grounded passive components. Consequently, the oscillation frequency can be electronically tuned with non-interactive dual-current control from the oscillation condition which is a benefit of oscillator circuit. With high output impedance, the oscillator is suitable for connecting in current-mode circuit. The simulation of Monte Carlo method can demonstrate the output frequency of proposed four-phase current-mode quadrature oscillator. Moreover, PSPICE simulation and experimental was applied to certify the theoretical method.

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