DIGITALLY CONTROLLED QUADRATURE OSCILLATOR EMPLOYING TWO ZC-CG-CDBAs

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ABSTRACT:

A simple quadrature oscillator is proposed, based on the well-known two-integrator topology. Each integrator is employed by ZC-CG-CDBA (Z-Copy Controlled Gain Current Differencing Buffered Amplifier). The current gain is controlled digitally on the principle of R-2R current divider. The designed structure enables an independent control of the oscillation frequency and the oscillation condition. The designed circuit is manufactured with the utilization of commercial integrated circuits and its proper operation is demonstrated.

Keywords: Quadrature oscillator, digital control, ZC-CG-CDBA

1 INTRODUCTION

Quadrature oscillators (QOs) find their applications in analog signal processing, communications, measurements, and controlling systems of power electronics [1]. Recently, several types of active elements were used for QO synthesis such as OTA [2], CCII [3], DVCC [4], CFA [5], CA [6], FTFN [7], voltage and current buffers [8], [9], CDTA [10], [11], and CDBA [12]. The latter QO employs two CDBAs, each of them simulating integrator, and proper negative and positive feedback paths accomplish the oscillation condition (OC) which can be set independently of the oscillation frequency (OF). Also, the OF can be set via external resistors or capacitors without disturbing the OC.

In this paper, we show that the oscillator from [12] can be improved by replacing the conventional CDBA by ZC-CG-CDBA element (Z Copy – Controlled Gain – CDBA), newly introduced in [13]. Digital control of the current gain enables digital control of the oscillation frequency, which will be directly proportional to the digital word. The theory of operation is verified via experimental chip and commercial integrated circuits.

2 ZC-CG-CDBA

Z Copy – Controlled Gain – CDBA in Fig. 1 consists of low-impedance CDU (Current Differencing Unit) [13], CCF (Controlled Current Follower), and unity-gain voltage buffer [14]. The difference of currents I_p and I_n flows to the CCF, being available also at *zc* (z-copy) terminal. CCF operates as a current attenuator, multiplying its input current by the transfer α, $0 < \alpha \leq 1$, and providing its output current to the *z* terminal.

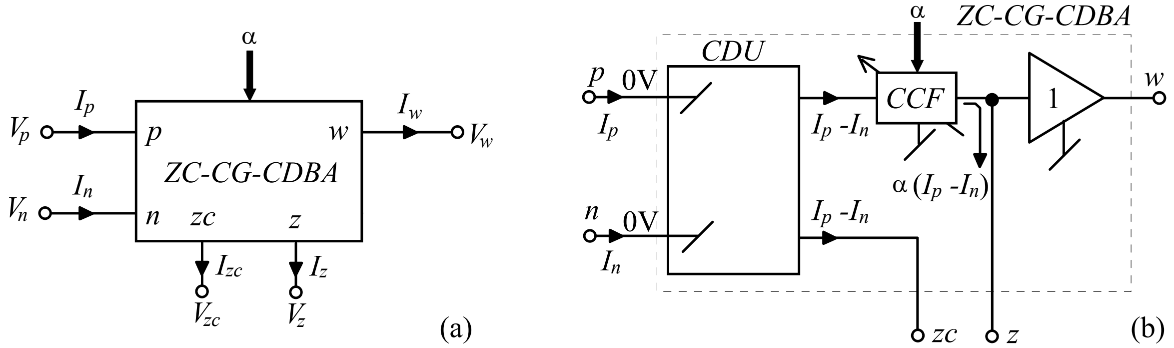

Fig. 1: ZC-CG-CDBA, (a) schematic symbol, (b) behavioral model.

ZC-CG-CDBA operation is defined by the following set of circuit equations:

$$\begin{vmatrix} I_z \\ I_{zc} \\ V_w \\ V_p \\ V_n \end{vmatrix} = \begin{vmatrix} 0 & 0 & 0 & \alpha & -\alpha \\ 0 & 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{vmatrix} \begin{vmatrix} V_z \\ V_{zc} \\ I_w \\ I_p \\ I_n \end{vmatrix} \quad (1)$$

The α coefficient can be set either manually or electronically. The electronic control can be provided by analog or digital method. The latter is advantageous from the point of view of digital control of oscillator parameters.

Since the ZC-CG-CDBA chip is not currently available, it was built according to the diagram in Fig. 2.

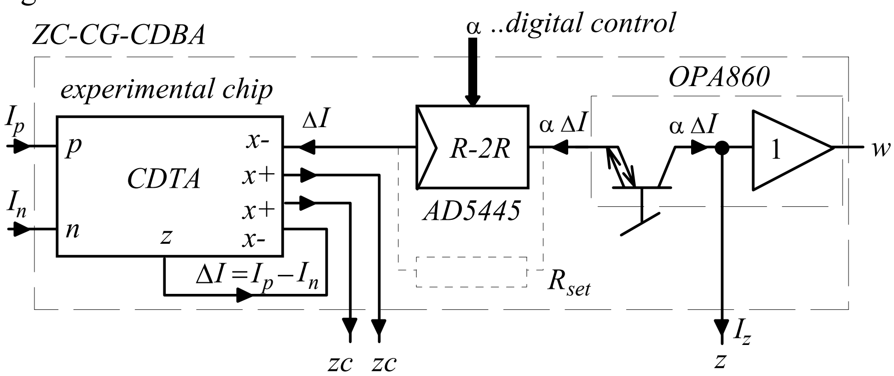

Fig. 2: Implementation of ZC CDBA with digital gain control.

As shown in Fig. 2, the CDU was implemented by an experimental chip with multiple-output CDTA [15], fabricated in CMOS 0.7 μm technology. Four-output OTA, which is a part of the CDTA, provides two copies of difference current to *zc* terminals, and it also drives the *R*-2*R* network which is implemented by commercial 12-bit multiplying digital-to-analog converter AD5445 [16]. Diamond transistor, which is a part of OPA860 [17], provides low-impedance output for proper operation of AD5445 and it also guarantees the high-impedance character of the *z* terminal. The resistor R_{set} together with the input resistance R_{in} of the AD5445 (ca 10 kOhms) is a part of current divider which can precisely change the lower limit of digitally controlled gain from its default value 0 to $R_{in}/(R_{set}+R_{in})$. For example, when selecting $R_{set} = R_{in} = 10$ kOhms, then the current gain can be controlled within the range from 0.5 to 1 with full 12-bit resolution. As shown below, via setting the lower limit of α, we set lower limit of the oscillation frequency of the QO.

3 PROPOSED DIGITALLY CONTROLLED QUADRATURE OSCILLATOR

The proposed QO with digital control, starting from the circuit idea published in [12], is shown in Fig. 3.

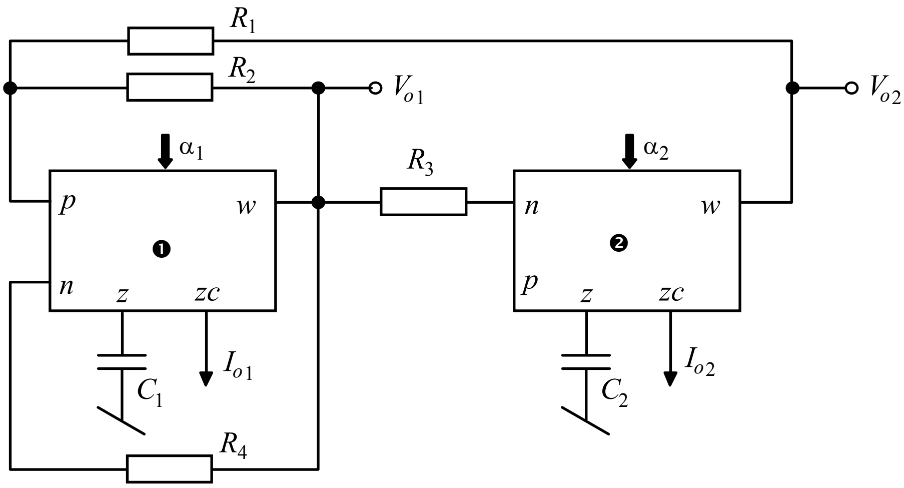

Fig. 3: Quadrature oscillator with digital control of the frequency.

Analysis of the characteristic equation of this circuit yields formulae of the oscillation frequency and oscillation condition:

OF: $$\omega_{osc} = \sqrt{\frac{\alpha_1 \alpha_2}{R_1 R_3 C_1 C_2}}, \tag{2}$$

OC: $$R_2 = R_4 . \tag{3}$$

Note from (2) and (3) that OF can be adjusted by α_1,α_2, R_1, R_3, C_1, C_2 without disturbing the OC, and that the OC can be set by R_2 or R_4 without affecting the OF. Since R_2 sets the positive and R_4 negative feedback, R_2 must be chosen smaller than R_4 for proper starting-up the oscillations. As shown in Section 4, the OC automatic control can be easily accomplished e.g. by optocoupler with photoresistor.

It is evident that circuit in Fig. 3 can provide harmonic signals with the frequency given by Eq. (2) if the condition (3) is fulfilled. An additional analysis determines the ratios of complex magnitudes of generated voltages V_{o2}/V_{o1} and currents I_{o2}/I_{o1}:

$$\frac{V_{o2}}{V_{o1}} = j\sqrt{\frac{\alpha_2}{\alpha_1}\frac{R_1}{R_3}\frac{C_1}{C_2}}, \quad \frac{I_{o2}}{I_{o1}} = j\sqrt{\frac{\alpha_1}{\alpha_2}\frac{R_1}{R_3}\frac{C_2}{C_1}}. \tag{4}$$

As results from (4), the voltage and also current signals are formed by orthogonal pairs. When accomplish the design conditions

$$\alpha_1 = \alpha_2 = \alpha, \; C_1 = C_2 = C, \; R_1 = R_3 = R, \tag{5}$$

then the above ratios of magnitudes remain 1 independently of OF tuning, and Eq. (2) is reduced to the form

OF: $$\omega_0 = \frac{\alpha}{RC}. \tag{6}$$

Thus, the oscillation frequency is directly proportional to the digitally controlled gain α.

4 EXPERIMENTAL VERIFICATION

In order to verify the above principle of digitally controlled QO, the circuit from Fig. 3 was designed with ZC-CG-CDBAs implemented according to Fig. 2. Diamond transistor OPA860 was biased via R_{adj}=330 Ohms, see [17]. The range of α control was defined from 0.5 to 1 by R_{set} = 10 kOhms. The passive elements of the oscillator were designed as follows:

$R_1 = R_2 = R_3 = 4.7$ kOhms, $C_1 = C_2 = 56$ pF.

According to (6), the corresponding theoretical oscillation frequency is 604.7 kHz for α = 1 and 302.35 kHz for α = 0.5.

For automatic amplitude stabilization, resistor R_4 was replaced by a photoresistor which is a part of optocoupler 3WK16341, and the internal LED of the optocoupler was supplied by rectified voltage V_{o1}. Then each increase of V_{o1} causes lowering R_4 and thus boosting the negative feedback which decreases the amplitude back.

Fig. 4 shows measured waveforms V_{o1} and V_{o2} for α = 1. The data measured has been exported from digital oscilloscope to OrCad PSpice 16 in order to perform FFT steady state analysis. The THD was ca 0.9%.

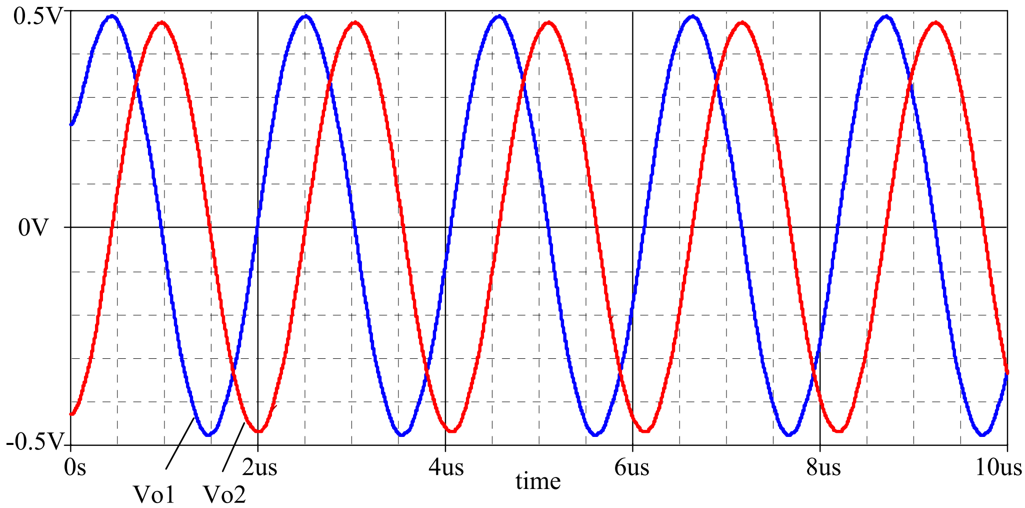

Fig. 4: Measured waveforms for α = 1, exported to PROBE.

The measured relationship between the oscillation frequency and the 16-bit digital word for controlling α is given in Fig. 5. The linearity of this frequency control is excellent. However, the measured frequency range is from 251.3 kHz to 482.8 kHz, which is approximately 20 per cent below the above mentioned theoretical values. The analysis of real influences reveals two sources of this error: 1) Parasitic capacitance of *z*- terminal which is formed by the capacitance of the collector terminal of diamond transistor in parallel to the input capacitance of voltage buffer (see Fig. 2), together more than 4 pF [17]. This capacity is added to the working capacity of 56 pF, causing OF decrease by ca 7 per cent. 2) Parasitic resistance of *z*- terminal, which is determined dominantly by the collector resistance of the diamond transistor. According to [17], its value is rather low, ca 54 kOhms, and thus it influences the OF significantly.

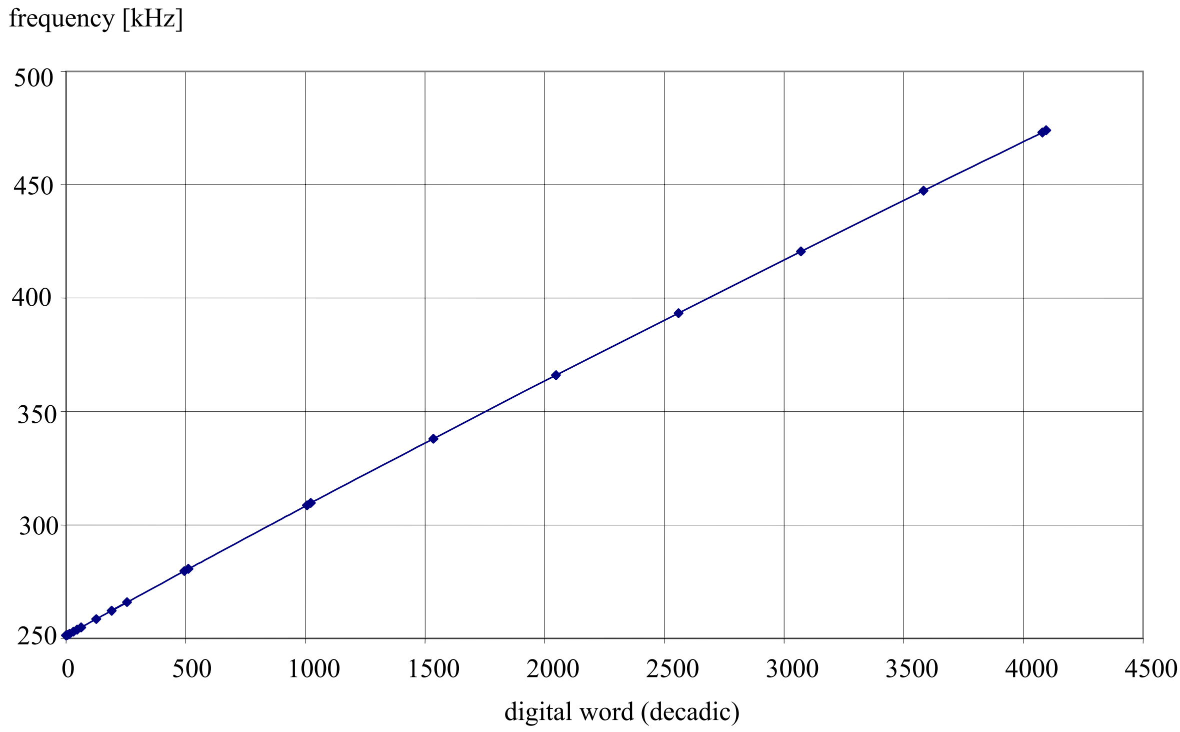

Fig. 5: Frequency versus digital word for α control.

5 CONCLUSIONS

The oscillator proposed here provides voltage and also current signals in a quadrature. It offers more degrees of freedom for mutually independent control of the oscillation frequency and oscillation condition. Digital control of the current gain of the ZC-CDBA, active devices used for QO implementation, enables an easy digital control of the frequency without disturbing the oscillation condition. The experiments described in Section 4 confirmed this important feature, also calling attention to real influences which can decrease the oscillation frequency below its theoretical value. The key parasitic factor seems to be the internal resistance of the *z*-terminal of CDBA. To eliminate the OF decrease, the active elements should be designed with such a resistance as high as possible.

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