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Quadrature oscillator and universal filter based on translinear current conveyors

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ABSTRACT

This paper presents quadrature oscillator and universal filter based on translinear current conveyors. The proposed circuit can realize as a quadrature oscillator or a universal filter without changing the circuit topology. When it works as a quadrature oscillator, four quadrature current outputs and two quadrature voltage outputs can be obtained. The condition and frequency of oscillation of oscillator can be controlled orthogonally and electronically. When it works as a universal filter, low-pass, band-pass, high-stop, band-stop, and all-pass filtering functions can be obtained simultaneously. The natural frequency and quality factor of filters can be controlled orthogonally and electronically. The proposed topology is simulated using PSPICE simulators and experimental results are also used to confirm workability of new circuit.

1. Introduction

A quadrature oscillator (QO) is the circuit that typically provides two sinusoid signals with 90° phase difference. The QO can be applied in communication, measurement and control systems such as quadrature mixers and single sideband generators for communication systems [1], vector generators and selective voltmeters for measurements systems [2]. The condition of oscillation (CO) and frequency of oscillation (FO) are important parameters for designing oscillator circuits. Typically, CO and FO should be controlled independently. The FO will be easily controlled, if it can be electronically adjusted which is suitable for applications to programmable oscillators. Many voltage-mode and current-mode QOs have been reported in technical literature; see, for example [3–12]. In [3], a QO using two operational transresistance amplifiers (OTRAs), four resistors and two capacitors is proposed and in [4], a QO using two current differencing buffered amplifiers (CDBAs), two grounded capacitors and four resistors is reported. However, these circuits are suffering from a lack of electronic tuning capability. In [5–12], several electronically tunable QOs are proposed using different active devices. A QO in [5] uses operational transconductance amplifiers (OTAs), a QO in [6] uses current differencing transconductance amplifiers (CDTAs), a QO in [7] uses current follower transconductance amplifiers (CFTAs) while a QO in [9] uses log-domain circuit and a QO in [12] uses second-generation current conveyor (CCII)/differential voltage current conveyor (DVCC). However, these topologies provide only either a quadrature current output or a quadrature voltage output. A four-phase QO using current-controlled CDTA (CCCDTA) has been proposed in [10], but only quadrature current output is provided. New active building blocks such as z-copy-controlled gain current differencing buffered amplifier (ZC-CG-CDBA) [8], controlled gain-buffered current and voltage amplifier (CG-BCVA)/controlled gain-current follower differential output buffered amplifier (CG-CFDOBA) [11] have been used to realize QOs. The voltage and current gains of these devices are used to control CO and FO of QOs, but QO in [11] provides only a quadrature voltage output while voltage-mode/current-mode QO in [8] suffers from the use of floating passive components which is not ideal for integrated circuit (IC) implementation.

A universal filter is the circuit that can realize various second-order filter into single topology such as low-pass (LP), high-pass (BP), band-pass (HP), band-stop (BS) and all-pass (AP) filters. The second-order filter can be applied to electronic and communication systems such as phase-locked loop (PLL) FM stereo demodulators, touch-tone telephone used for tone decoder, cross-over network used in a three-way high-fidelity loudspeaker [13]. Moreover, second-order filters can be used to realize high-order filters [14]. The natural frequency (ω_o) and the quality factor (Q) are important parameters for designing universal filters. Typically, parameters ω_o and Q should be controlled orthogonally. Also parameters ω_o and Q will be easily controlled, if it can be electronically adjusted which is suitable for high-order filter applications. Generally, high-order filters can be realized by cascading of second-order filters, which each second-order filter could be different parameters ω_o and Q [15]. The universal filter with electronic control of parameter ω_o is suitable for application to digital programmable filters [16]. Several universal filters using variant active devices

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available in technical literature; see, for example [17–22]. In [17], a voltage-mode universal using two CDBAs and six passive components is proposed. In [18], a multiple-input single-output (MISO) current-mode universal filter using two CDTAs and two grounded capacitors is proposed while a MISO voltage-mode universal filter using four current feedback operational amplifiers (CFOAs) and seven passive components is proposed in [19]. A single-input multiple-output (SIMO) current-mode universal filter using three z-copy CFTAs is reported in [20] and a SIMO current-mode universal filter using five CCIIs is proposed in [21]. In [22], a voltage-mode universal filter using three differential difference current conveyors (DDCCs) and seven passive components is proposed. Compared with current-mode SIMO filters in [20,21], current-mode MISO filter in [18] employs lesser active devices and compared with voltage-mode filters in [17,19,22], current-mode filters in [18,20,21] employ lesser both active and passive components. Therefore, this paper is focused on multiple-input multiple-output (MIMO) current-mode universal filter which employs a few active and passive elements. It should be noted that the circuits in [3–12] provide a QOs while the circuits in [17–22] provide a universal filter.

Recently, QO and universal filter can be obtained into single topology which employs different active devices [23–28]. The circuit in [23] realizes QO and universal filter employing four current-controlled current conveyors (CCCIIs), one operational transconductance amplifier (OTA) and two grounded capacitors. This topology can be realized either a QO or a universal filter without changing the connection by using the ratio of two bias currents, but only LP, HP and BP filters are obtained. The circuit in [24] realizes QO, LP and BP filters using only one differential voltage current-controlled conveyor transconductance amplifier (DVCCCTA) and two grounded capacitors and circuit in [25] realizes QO and universal filter using CDTAs, but changing the connection is needed. QO and universal filter in [26] uses three ZC-CFTAs, one resistor and two grounded capacitors which provides four-phase quadrature current outputs and five standard filtering functions. Voltage-mode universal filter and QO using two current feedback amplifiers (CFAs), two capacitors and three resistors is proposed in [27]. The circuit in [28] realizes QO and universal filter using three voltage differencing differential difference amplifiers (VDDDAs), two grounded capacitors and one grounded resistor that offers five standard filtering functions. However, the topologies in [27,28] need a changing the connection for obtaining either a QO or a universal filter.

In recent years, the design and implementation of current-mode analog signal processing circuits using second-generation current conveyors (CCIIs) [29] have received considerable attention because their performances such as signal bandwidth, linearity, circuit realization and dynamic range are better than those of their voltage-mode operational amplifiers (op-amp) counterpart [30,31]. Typically, CCII is assumed as low parasitic resistance on x-terminal and high parasitic resistance on y- and z-terminals. The domain of electronically adjustable function cannot be obtained from conventional CCII. To obtain adjustable function domain, a second-generation current-controlled current conveyor (CCCII) has been introduced [32]. The CCCII exploits the parasitic resistance at x-terminal (R_x). Namely, parasitic resistance R_x can be controlled by adjusting its bias current which is the advantage for analog circuit applications. Usually, conventional CCCII has a unity voltage gain between y- and x-terminals and has a unity current gain between x- and z-terminals. The unity current gain between x- and z-terminals will be limited some applications of CCCIIs. Therefore, CCIIs/CCCIIs with adjustable current gain have been proposed [33–36]. This property will increase the performance of CCII/CCCII in the case of applications such as adjustable Q and current gain of transfer function for universal filters [37,38] electronic control of CO for oscillators [39,40] selecting either a negative or positive resistor into one topology [41]. CCII with adjustable current gain can be implemented using CMOS technology [34,35] and bipolar technology [36]. This work is focused on the translinear current conveyor which implemented by bipolar technology that parasitic resistance R_x and current gain can be obtained into single CCCII.

There are many CCCII-based QOs and universal filters available in open literature; see, for instance [42–72]. The circuits in [42–53] provide QOs and the circuits in [54–72] provide universal filters. A QO in [42] employs four CCCIIs and two grounded capacitors, a third-order QO in [43] employs four CCCIIs and three grounded capacitors, a QO in [46] employs two CCCIIs, two grounded capacitors and one grounded resistor, a QO in [45] employ three CCCIIs, two grounded capacitors and one grounded resistor while a QO in [46] employs four CCCIIs and two grounded capacitors and a QO in [47] employs three CCCIIs and two grounded capacitors. However, these QOs provide only quadrature current outputs. QOs that provide both quadrature voltage output and quadrature current output into single topology, the so-called mixed-mode QO, have been reported in [48–53]. To obtaining a quadrature signal, these structures are realized using either as two/three integrators [42–46,48,50–53] or an all-pass section and an integrator [47,49]. The advantage of integrator-based QOs over the QOs using all-pass section and integrator based circuit is that single-element control can be obtained.

In case of CCCII-based universal filters, the circuits in [53–65,21] propose current-mode SIMO filters, the circuits in [66–68] propose current-mode MISO filters and the circuits in [69–72] propose current-mode MIMO filters. These reported circuits meet the advantage of an electronic tuning capability, but suffer from one or more of the following weaknesses: (i) use of an excessive number of active components [54–67], (ii) cannot provide LP, HP, BP, BS and AP filters into one circuit [60], (iii) use of floating capacitor or resistor [59,61]. It should be noted that the reported CCCII-based circuits in [42–75] can only realize either a QO or a universal filter.

The purpose of this paper is to propose one circuit with the same configuration has two functions, the QO and universal filter, using CCCIIs with controlled current gain. The proposed circuit can realize either as a QO or a universal filter without changing topology. Unlike previous works, the proposed topology uses current gain of CCCII to selecting either a QO or a universal filter. When it works as a QO, the CO and FO of oscillator can be controlled independently and electronically. The oscillator also offers both four quadrature current outputs and two quadrature voltage outputs. When the circuit works as universal filter, LP, BP, HP, BS and AP filters can be obtained. The parameters ω_o and Q of all filters can be controlled electronically and separately by adjusting the bias currents. PSPICE simulation results which confirm the theoretical analysis are also obtained. The comparison between the proposed topology and some previously works is summarized in Table 1. By a careful survey of the existing publications, the topologies in [23,26] can be realized QO and universal filter without changing topology. Compared with [23,26], the proposed topology employs less than active components and can be provided five standard filtering functions.

2. Circuit description

The concept of the CCIIs with adjustable current gain was first introduced by [33] using operational amplifier and OTA. Then, both CMOS and bipolar technologies are used to design CCIIs with adjustable current gain [34–36]. The concept of bipolar CCII with adjustable current gain in [36] is adopted to realize CCCII that used in this work. The schematic of bipolar translinear current conveyor is shown in Fig. 1(a) [37] and its circuit symbol is shown in Fig. 1(b). This schematic is modified from initial report in [36] and the current gain can be obtained using two current mirrors with adjustable gain [31,36]. Compared with the schematic of CMOS CCIIs with adjustable current gain in [34,35], the schematic in Fig. 1(a) is less than circuit complexity and easy to obtain multiple-output plus/minus CCII. Moreover, bipolar-based CCCII is typically varied its bias current over three decades. Thus, the current gain of bipolar CCII can be wide-range tuned whereas the square-law characteristic of MOS transistor in saturation region will be