Sinusoidal oscillator based on Adjustable Current Amplifier and Diamond Transistors with Buffers

Abstract. Easy tunable oscillator based on current amplifier and diamond transistors with buffers is presented in the paper. Electronic adjusting of oscillation frequency is easy possible due to controllable current gain of used current amplifier. All capacitors of the oscillator are grounded. The characteristic equation, condition of the oscillation and parasitic influences of real active components are discussed. It is possible to verify the function of the circuit using commercially available devices what is strong advantage. The verification of functionality was provided by simulations and laboratory experiments.

Streszczenie. Zaprezentowano łatwo, trzecienny generator bazujący na wzmacniaczu prądu i tranzystorach diamentowych. Ustawianie wybranej częstotliwości jest łatwe dzięki kontrolowanemu wzmacnieniu prądu. Wszystkie kondensatory układu są uzemione. Przedyskutowano równanie charakterystyczne, warunki osyłacji i wpływy pasywnicze. Przeprowadzono symulacje oraz testy laboratoryjne. (Generator sinusoidalny z nastawianym wzmacniciem prądu i tranzystorami diamentowymi z buforem)

Keywords: Electronic adjusting, sinusoidal oscillator, diamond transistor, controllable current amplifier.

Introduction

Today many of modern active functional blocks are available for application in analog signal processing. This fact is discussed in the paper [1] where the review of basic and novel active blocks is given. Some applications of these components have been given in the literature, for example differenting buffered transconductance amplifier (DBTA) [2], current follower transconductance amplifier (CFTA) [3] and others. An attention is now focused on the applications in current mode (CM) [4]. There are some modifications of known circuit components, for example the current conveyors (CC), the current feedback amplifiers (CFA) and the transconductors (OTA) which are called as DO-CCCII [5], MO-CCCII [6], CC-CFA [7], MO-OTA [8], or CDTA [9], CDBA [10] etc [1]. These components offer features for electronic controlling and better frequency response. Mentioned blocks may be used in wide range of applications in the fields of measuring, control, sensor, automotive electronics, acoustic and high-speed communication systems (filters, oscillators, modulators, etc.).

In the text bellow, some interesting features of recently published oscillator circuits will be reviewed. Some realizations are based on a single active component [11-16] and use novel or quite novel active components and design approaches [10, 11, 17-21, 27] however in fact many of them have not been manufactured yet (only theoretical purposes and models for simulations). There are some drawbacks of the previous solutions. For example they contain many floating and grounded passive components [22-24]. Some solutions have quite complicated structures with many active components [19, 25], but it is sometimes a cost for expedience (mainly multiphase structures). Tunability is quite important feature of the designed oscillators. Some of them are not verified for this purpose even if it is theoretically possible [17-18, 20, 26]. The solution of tuning is in the most cases based on one or more passive components (floating or grounded resistor) [10, 11, 13-16, 21, 23, 27-31]. Electronic adjusting can be simply implemented by FET transistors [23, 31], transconductance amplifiers (OTA) [32] or modern digital potentiometers. Unfortunately features of available digital potentiometers are not sufficient for high frequency purposes. Very large parasitic capacitances of tens pF limits useful range to few MHz. Another way is to use controllable active components where driving of transconductance ($g_m$) and current input resistance ($R_I$) via bias control current of designed active component is possible [26, 33, 34]. In some cases it is necessary to simultaneously change of more parameters [19]. Some solutions have quite high total harmonic distortion (THD), in most cases units of percent and more [15, 23, 26, 31]. In [35] conception with almost 10 % distortion (evident also from transient response) was shown. Many circuits were verified by simulations at frequencies of several kHz where the use of these high-speed active components is not substantiated. There a classical voltage mode approach, standard operational amplifiers and digital potentiometers can be sufficient very well. Some solutions (for example [29]) were tested at frequencies of several MHz only with parasitic capacitances of few pF indeed.

There is described simple approach to the design of analog signal processing applications instead of common approach based on non-available and not manufactured active components with quite complicated internal conceptions [1]. Almost all recently introduced active components and solutions are verified and applicable only theoretically or by simulation with transistor model of active components of some bipolar or CMOS technology where practical usability is questionable. Diamond transistors mentioned above (DTs) are easy commercially available (commercially marked OPA 860 [36]) and commonly used in amplifiers and drivers for RF application. OPA 860 contains DT and high speed voltage buffer. Also they are very useful in other analog signal processing applications like basic of more complicated systems.

One example is the sinusoidal oscillator described here. Easy controllable sinusoidal oscillator is studied in detail in the views of the oscillation condition, running range, electronic control, distortion, etc. In comparison with some previous works proposed solution have some advantages. For example in oscillator there is not necessary to change oscillation frequency via floating or grounded resistor, all capacitors are grounded, there was reached very favorable THD (tenths percent) in the whole supposed adjustable oscillation range without circuit for amplitude stabilization. Circuit is based on available active components and the conception is very simple (only four passive components). On the other hand there are also some drawbacks. The oscillation condition is not adjustable without affecting frequency of oscillation. Condition of oscillation of proposed solution is set by floating resistors and therefore is necessary to use floating electronically controllable resistor or automatic gain control circuit (AGC) for amplitude stabilization.
Electronic tunable oscillator employing current amplifier and diamond transistors

In Fig. 1 (a) an explanation of diamond transistor principle is provided. This element works similarly like current conveyor of second generation (CCII+) [1]. Conception of proposed oscillator is based on two current-current conveyor of second generation (CCII+) [1]. This element works similarly like a current amplifier based on one adjustable current amplifier and two diamond transistors with buffers. Characteristic equation, condition of oscillation (CO) and oscillation frequency have following forms

\[ a_s s^2 + a_s a_i + a_e = s^2 + \frac{R_i C_i - R_i C_i}{R_i R_i C_i C_i} + \frac{B - 1}{R_i R_i C_i C_i} = 0, \]  

(1)

\[ R_i C_i = R_i C_i + a_i = \sqrt{\frac{B - 1}{R_i R_i C_i C_i}}. \]  

(2), (3)

Sensitivities of oscillation frequency on circuit parameters are

\[ S_{f_0}^{B} = S_{f_0}^{E} = S_{f_0}^{G} = -0.5, S_{f_0}^{a_0} = 0.5 \frac{B}{B - 1}. \]  

(4), (5)

From (1) it is clear that tunability of oscillation frequency due to the current gain \( B \) of current amplifier is possible. For example we can use current mode conveyor with adjustable gain (they are not very common) or current mode multiplier. Current amplifier based on current mode multiplier EL 2082 [37] was used. From (3) it is obvious that there is necessity of fulfilling condition \( B > 1 \) for stable oscillation.

**Experimental results**

Digital oscilloscope Tektronix TDS 2024 and oscillator developed for laboratory tests based on commercially available components were used for experimental verification. Some features were analyzed in PSpice program. Current amplifier was represented by adjustable current mode multiplier EL 2082 [37]. Component is generally obsolete but sufficient for experimental purposes. Practically we can use any other adjustable current amplifier. There is possible to change current transfer due to the DC control voltage \( B = f_{ce}(V_G) \). From (3) it is obvious that current gain on control voltage is not linear for higher values of \( B \). Passive components are selected \( R_1 = R_2 = R = 470 \ \Omega \), capacitors \( C_1 = C_2 = C = 220 \ \mu \text{F} \) and supply voltage \( \pm 5 \ \text{V} \). Theoretically adjustable range of oscillation frequency (\( f_0 \)) is from 0.67 MHz to 2.38 MHz. Achieved range is 0.62 MHz to 2.20 MHz obtained by measurement and 0.53 MHz to 2.15 MHz by simulation. The control voltage \( V_G \) was changed from 1.2 to 4 V but relation between current gain \( B \) and control voltage \( V_G \) is approximate only (Tab. 1). In Fig. 2 are both output measured transient responses for \( f_0 = 1.02 \ \text{MHz} \) \( (V_G = 1.55 \ \text{V}) \). In Fig. 3 is FFT spectrum of selected output signal. In Fig. 4 comparison of theoretical curve, curve obtained by non-ideal model in Matlab, simulation and measured dependence of harmonic distortion (THD) on \( f_0 \) which is quite low (0.3 - 0.9 %) in all achievable \( f_0 \) range, but for this is necessary to adjust in small range condition of oscillation. All results were carried out for CO controlled via value of resistor \( R_1 \) (very small changes of units \( \Omega \)).

**Fig. 1.** a) Symbol and elementary principle of DT, b) principle of proposed oscillator, c) proposed oscillator circuit

**Fig. 2.** Measured output transient responses

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**Tab. 1.** Experimental laboratory test results (CO controlled)

PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review), ISSN 0033-2097, R. 87 NR 1/2011
Approximately we can determine [36, 37] that small signal components as shown in Fig. 6 (a) and Fig. 6 (b) ($R_i$, $R_o$, $R_e$, $R_b$, $C_o$, $C_b$, $C_c$) influence functionality and cause deviation of real and expected value of oscillation frequency. In Fig. 7 there are depicted nodes where parasitic features (marked as $Z_{p1}$ and $Z_{p2}$) are investigated. Approximately we can determine [36, 37] that small signal parameters in non-ideal models are $R_i \sim 95 \, \Omega$, $R_o \sim 500 \, k\Omega$, $R_e \sim 13 \, \Omega$, $R_b \sim 455 \, k\Omega$, $R_c \sim 54 \, k\Omega$, $R_{buffer} = 1 \, M\Omega$, $C_{buffer} = 2.1 \, pF$, $C_o \sim 5 \, pF$, $C_b \sim 2.1 \, pF$, $C_c \sim 2 \, pF$. Values of parasitic components shown in Fig. 7 can be described as

$$Z_{p1} = \frac{1}{R_{p1}} + sC_{p1} = \frac{1}{R_{p1}} + \frac{1}{R_{i_{buffer}1}} + s(C_{c1} + C_{i_{buffer}}).$$

(6)

$$Z_{p2} = \frac{1}{R_{p2}} + sC_{p2} = \frac{1}{R_{p2}} + \frac{1}{R_{i_{buffer}2}} + s(C_{c2} + C_{i_{buffer}2} + C_o).$$

(7)

Coefficients of the characteristic equation are now

$$a_2 = 1,$$

(10)

$$a_1 = \frac{R_RR_{22}R_{p2} + R_{i2}^2 + R_{i1}^2 + R_{i1}R_{i2} - (R_{i1}R_{i2} + R_{i1}R_{p2})}{R_{i1}R_{i2}R_{p2} + C_{c1}C_{p1} + C_{p1}C_{p2} + C_{c2} + C_{c1}C_{c2}}.$$}

(12)

\[ a_0 = \frac{BR_{p1}R_{p2} + R_{i2}R_{i2} + R_{i1}R_{i2} - (R_{i1}R_{i2} + R_{i1}R_{p2})}{R_{i1}R_{i2}R_{p2} + C_{c1}C_{p1} + C_{p1}C_{p2} + C_{c2} + C_{c1}C_{c2}}. \]

(13)

The condition of oscillation and oscillation frequency have following form

$$\omega_0 = \frac{BR_{p1}R_{p2} + R_{i2}R_{i2} + R_{i1}R_{i2} - (R_{i1}R_{i2} + R_{i1}R_{p2})}{R_{i1}R_{i2}R_{p2} + C_{c1}C_{p1} + C_{p1}C_{p2} + C_{c2} + C_{c1}C_{c2}}.$$}

(14)

In conclusion all these influences cause smaller range of parasitic capacitances have quite high values (over 10 pF). In conclusion all these influences cause smaller range of oscillation frequency changes and even over 0.1 MHz oscillation frequency shift from nominal ideal value (Tab. 1).
construction, low sensitivities on passive components and perhaps 0.6 to 2.2 MHz, grounded capacitors, easy range of tunability (with considering of limited conception of specific active component. For experimental Fig. 7. Focused influences of real active components

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