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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 strojony generator bazujący na wzmacniaczu prądu I tranzystorach diamentowych. Ustawianie wybranej częstotliwości jest łatwe dzięki kontrolowanemu wzmocnieniu prądu. Wszystkie kondensatory układu są uziemione. Przedyskutowano równanie charakterystyczne, warunki oscylacji i wpływy pasożytnicze. Przeprowadzono symulacje oraz testy laboratoryjne. (**Generator sinusoidalny z nastawianym wzmacniaczem prądu i tranzystorami diamentowymi z buforem**)*

Keywords: Electronic adjusting, sinusoidal oscillator, diamond transistor, controllable current amplifier.
Słowa kluczowe: generator sinusoidalny, tranzystor diamentowy..

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 differencing 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-CCII [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_x) 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, tunning 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 it is necessary to use floating electrically controllable resistor or automatic gain control circuit (AGC) for amplitude stabilization.

Electronically 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-mode lossy integrators in the loop (Fig. 1 (b)) where one has adjustable parameter in a transfer function. In Fig. 1 (c) there is an oscillator based on one adjustable current amplifier and two diamond transistors with buffers. Characteristic equation, condition of oscillation (CO) and oscillation frequency have following forms

(1) $$a_2s^2+a_1s+a_0=s^2+\frac{R_2C_2-R_1C_1}{R_1R_2C_1C_2}s+\frac{B-1}{R_1R_2C_1C_2}=0,$$

(2), (3) $$R_2C_2=R_1C_1,\ \omega_0=\sqrt{\frac{B-1}{R_1R_2C_1C_2}}.$$

Sensitivities of oscillation frequency on circuit parameters are

(4), (5) $$S_{C_1}^{\omega_0}=S_{C_2}^{\omega_0}=S_{R_1}^{\omega_0}=S_{R_2}^{\omega_0}=-0.5,\ S_B^{\omega_0}=0.5\frac{B}{B-1}.$$

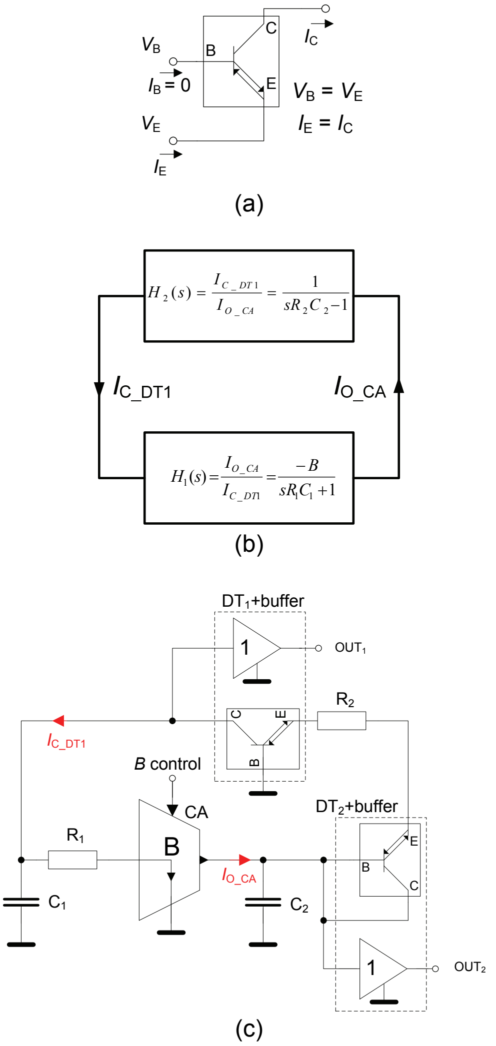

Fig.1. a) Symbol and elementary principle of DT, b) principle of proposed oscillator, c) proposed oscillator circuit

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 = fce(V_G). The dependence of current gain on control voltage is not linear for higher values of B. Passive components are selected $R_1 = R_2 = R = 470$ Ω, capacitors $C_1 = C_2 = C = 220$ pF and supply voltage ± 5 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 MHz (V_G = 1.55 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 f_0 on V_G are depicted. In Fig. 5 is shown dependences of output total 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 Ω).

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

V_G [V]	B [-]	f_0 ideal [MHz]	f_0 Matlab [MHz]	f_0 PSpice [MHz]	f_0 measured [MHz]	Suppression of higher harmonics [dBc]	THD [%]
1.2	1.19	0.67	0.61	0.53	0.62	45	0.6
1.5	1.46	1.04	0.94	0.90	0.94	45	0.6
1.6	1.55	1.14	1.03	1.03	1.02	46	0.5
1.8	1.72	1.31	1.18	1.18	1.18	50	0.3
2.0	1.89	1.45	1.31	1.38	1.31	45	0.6
2.2	2.06	1.59	1.43	1.47	1.45	47	0.4
2.5	2.31	1.76	1.59	1.70	1.61	48	0.4
3.0	2.69	2.00	1.81	1.88	1.85	45	0.6
3.5	3.05	2.20	1.99	2.02	2.06	42	0.8
4.0	3.39	2.38	2.15	2.15	2.20	41	0.9

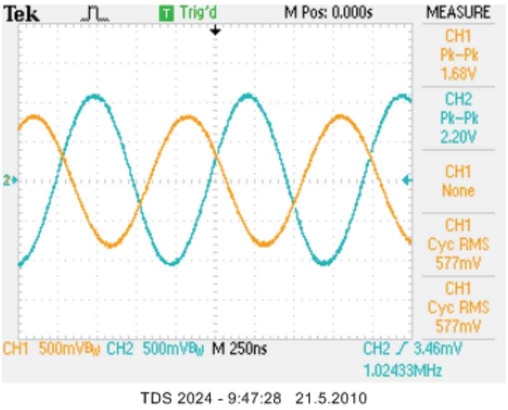

Fig. 2. Measured output transient responses

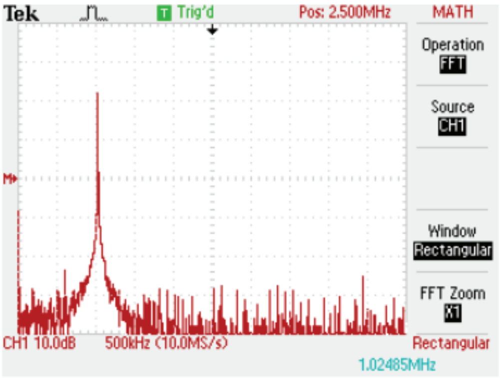

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Fig. 3. Measured FFT spectrum

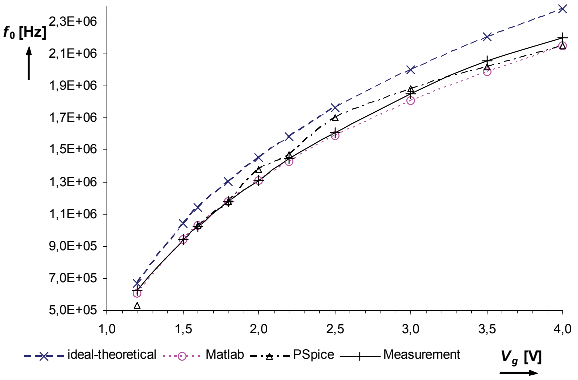


Fig. 4. Comparison of theoretical, simulated and measured dependences of oscillation frequency on control voltage

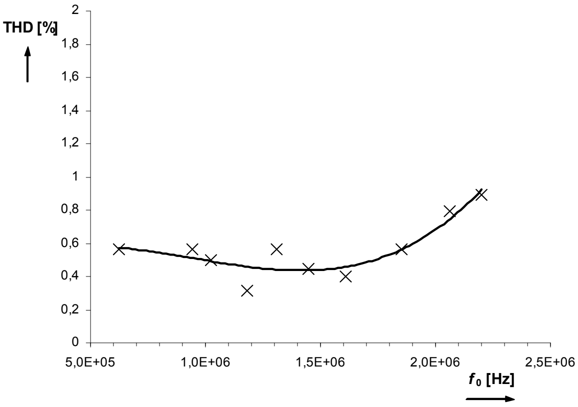


Fig. 5. Dependence of THD on oscillation frequency

Influences of real active components

Parasitic input and output features of used active components as shown in Fig. 6 (a) and Fig. 6 (b) (R_I, R_O, R_E, R_B, R_C, 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 $R_I \sim 95\ \Omega$, $R_O \sim 500\ \mathrm{k\Omega}$, $R_E \sim 13\ \Omega$, $R_B \sim 455\ \mathrm{k\Omega}$, $R_C \sim 54\ \mathrm{k\Omega}$, $R_{i\_buffer} = 1\ \mathrm{M\Omega}$, $C_{i\_buffer} = 2.1$ 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

(6) $$Z_{p1} = \frac{1}{\frac{1}{R_{p1}} + sC_{p1}} = \frac{1}{\frac{1}{R_{C1}} + \frac{1}{R_{i\_buffer1}} + s\left(C_{C1} + C_{i\_buffer1}\right)},$$

(7) $$Z_{p2} = \frac{1}{\frac{1}{R_{p2}} + sC_{p2}} = ,$$
$$= \frac{1}{\frac{1}{R_{B2}} + \frac{1}{R_{C2}} + \frac{1}{R_{i\_buffer2}} + \frac{1}{R_O} + s\left(C_{B2} + C_{C2} + C_{i\_buffer2} + C_O\right)}$$

(8), (9) $$R_1^* = R_1 + R_I, \quad R_2^* = R_2 + R_{E1} + R_{E2}.$$

Coefficients of the characteristic equation are now

(10) $$a_2 = 1,$$

(11) $$a_1 = \frac{R_1^* R_2^*\left(2R_{p2}C_2 + 2R_{p1}C_1\right) + R_1^* R_{p1} R_{p2}\left(C_2 + C_{p2}\right) - R_2^* R_{p1} R_{p2}\left(C_{p1} + C_1\right)}{R_1^* R_2^* R_{p1} R_{p2}\left(C_2 C_{p1} + C_{p1} C_{p2} + C_1 C_2 + C_1 C_{p2}\right)},$$

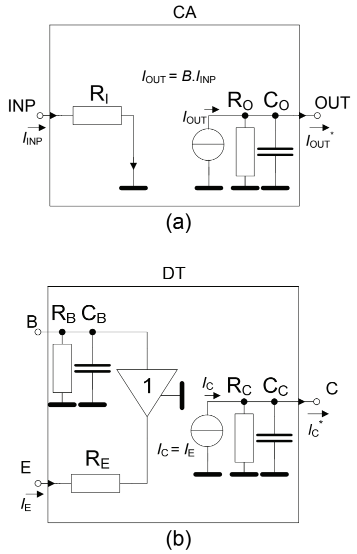
(12) $$a_0 = \frac{BR_{p1}R_{p2} + R_1^* R_2^* + R_1^* R_{p1} - \left(R_2^* R_{p2} + R_{p1} R_{p2}\right)}{R_1^* R_2^* R_{p1} R_{p2}\left(C_2 C_{p1} + C_{p1} C_{p2} + C_1 C_2 + C_1 C_{p2}\right)}.$$

The condition of oscillation and oscillation frequency have following form

(13) $$R_1^* R_2^*\left(2R_{p2}C_2 + 2R_{p1}C_1\right) + R_1^* R_{p1} R_{p2}\left(C_2 + C_{p2}\right) = R_2^* R_{p1} R_{p2}\left(C_{p1} + C_1\right),$$

(14) $$\omega_0^{/} = \sqrt{\frac{BR_{p1}R_{p2} + R_1^* R_2^* + R_1^* R_{p1} - \left(R_2^* R_{p2} + R_{p1} R_{p2}\right)}{R_1^* R_2^* R_{p1} R_{p2}\left(C_2 C_{p1} + C_{p1} C_{p2} + C_1 C_2 + C_1 C_{p2}\right)}}.$$

Influences in nodes in neighborhood of R_2 are negligible, because emitors are low impedance inputs of DTs. However, we have to take into account that real input resistances are serial with R_1 and R_2 and it influences condition of oscillation and shifted oscillation frequency (in Fig. 7 are not depicted). Also parasitic capacitances cause similar problems. Mainly part of impedance Z_{p2} where 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).



(a)

(b)

Fig. 6. Non-ideal (a) CA and (b) DT model

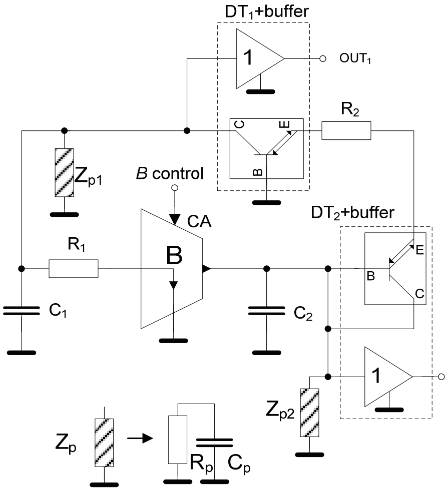


Fig. 7. Focused influences of real active components

Conclusion

Easy construction of the oscillator with controllable oscillation frequency based on commercially available active components was proposed. Simulation and measurement results reveal some interesting conclusions about this circuit. For fixed oscillation frequency there is not necessary amplitude stabilization subcircuit. Amplitude stabilization is realized due to the non linear parts of inp-out characteristic of used active components. For adjustable applications external amplitude stabilization and automatic gain control (AGC) circuit is necessary. In other case (without CO control) THD is very high, there is quite big difference between expected and real oscillation frequency but oscillator is still functional. In this point of view conception is quite resistant to drop out of the oscillation. With manual control of condition of oscillation we can see that ideal, simulated and measured dependences of oscillation frequency on control voltage (V_G) are similar in whole range of V_G and THD is quite low. Non-precise CO setting is probably a reason why in similar publications [15, 23, 26, 31, 35] is THD so high. Circuit model with non ideal features of used active components confirmed practical behavior of proposed circuit. Traces of modeled, simulated and measured dependences are very similar. For control of condition of oscillation there is necessary to change floating resistors and it is drawback of this solution, the CO is not adjustable without affecting of oscillation frequency. Another disadvantage is very limited range of current gain of used EL 2082 and nonlinear dependence of B on V_G (for 1 V is B = 1 but for V_G = 4 V it is only 3.4). But this is only problem of conception of specific active component. For experimental verification it is not so important. Advantages are sufficient range of tunability (with considering of limited B) from perhaps 0.6 to 2.2 MHz, grounded capacitors, easy construction, low sensitivities on passive components and availability of used active elements.

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