GENERATION AND DESIGN OF SINUSOIDAL OSCILLATORS USING OTAS

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ABSTRACT

The design of voltage controlled oscillators using Operational Transconductance Amplifiers (OTAs) is discussed in this paper. Several oscillator structures are proposed. They use only OTA and Capacitors (TAC) and are very appropriate for Silicon monolithic implementations. The resulting oscillation frequencies are proportional to the transconductance of the OTA and this makes the reported structures well suited for building voltage controlled oscillators (VCOs). Amplitude stabilization circuits using both automatic gain control (AGC) mechanisms and limitation schemes are studied which are compatible with TAC oscillators. Experimental results from breadboard prototypes are included showing good potential of OTA based oscillators for high frequency VCO operation.

INTRODUCTION

The generation of sinewaves is a classical problem with application in communication systems, instrumentation, measurement, etc. In particular, the voltage-controlled frequency-variable oscillator (VCO) has a number of important applications in communication circuits [1].

A great variety of RC-active circuits have been developed for generating sinewaves, most of them based on the use of the conventional operational amplifier (op amp) as the active component [2, 3, 4,5 and included references]. On average, these circuits perform correctly in the audio-frequency range (≤*20Khz*) but their performance becomes severely degraded as the frequency increases. Even by using special design techniques [6] or composite amplifiers [7], the useful frequency range is under *100Khz* for general purpose 741 op amps.

Together with this frequency limitations, opamp-based VCOs exhibit other problems further restricting their usefulness. Different variable-frequency RC-active oscillators have been reported whose frequency of oscillation can be controlled by a single resistor without affecting the oscillation condition [5 and included references]. Some additional circuitry has to be added to achieve VCO operation using these oscillator structures. One possible method to do this is substituting the controlling resistor by a FET working in the ohmic region [8]. Anyway, the tunable frequency range is somewhat reduced and switching among different resistors is needed what makes the design approach not readily compatible with monolithic integrated circuits.

Previous problems can be overcome by the use of the operational transconductance amplifier (OTA) as the active building block for VCOs. By interconnecting OTAs and Capacitors (OTA-C), oscillating circuits can be obtained whose frequency of oscillation is proportional to the transconductance gain of the OTA. Thus, as long as this transconductance can be controlled by an external power supply, fully integrated OTA-C VCOs can be obtained with a frequency adjustable over wide frequency ranges, avoiding the necessity of switching passive element values as observed in op amp designs.

By using OTA-C oscillators it is also possible to push the frequency ranges above the maximum op amp oscillator ratings. Practical OTA-C filters have recently appeared in the literature showing very good potential for high-frequency applications [9, 10, 11]. In this communication we exploit the inherent properties of the OTA as an excellent building block for high frequency sinusoidal active oscillators. Several new structures are reported that use only OTAs and capacitors. Experimental results from breadboard discrete circuits are given for frequencies up to *1MHz* with a total harmonic distortion (THD) of *1.03%*. It compares very favorably with previous results obtained for op amp oscillators.

OTA-C OSCILLATOR STRUCTURES

Let us focus on second order oscillators. In [12] we have developed a systematic method for the generation of OTA-C oscillator structures. The general oscillator topology for a second order case is shown in Fig.1, where the sources are voltage-controlled current sources (VCCS) given by

$$I_1 = \sum_{i=1}^{N} g_{1i} V_i \qquad I_2 = \sum_{i=1}^{N} g_{2i} V_i$$

V_i, $1 \le i \le N$, being the *i-th* node voltage in Fig.1.

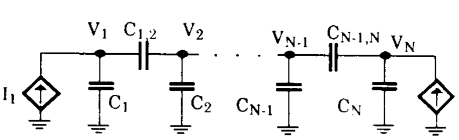

Figure 1: General topology for the generation of second order OTA-C oscillators

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Each term in eq.(1) can be implemented in practice by using an OTA. We have studied the different choices of parameters g_{ji} allowing us to obtain a pair of imaginary roots for the characteristic equation of the general circuit in Fig.1 [12]. Some of the more interesting structures we have obtained by following this method are shown in Fig.2. The general expression for the characteristic equation of Fig.2 is

$$s^2 + sb + \omega_0^2 = 0$$

where the particular values of each parameter b and ω_0 as a function of the transconductance gains of the OTAs are given in Table 1.

For each circuit the oscillation condition can be obtained by making $b = 0$ in the corresponding entry in Table 1. We note that in the cases of the so-called quadrature, 4OTA2C and 4OTA4C structures it is possible to tune the oscillation frequency by changing the transconductance gain g_{mA} and without affecting the oscillation condition. It is a very interesting feature for achieving VCO operation. On the contrary, in the so-called 3OTA2C structure the oscillation frequency and the oscillation condition are not independent, making the tuning procedure more involved. On the other hand, this latter circuit requires only two active components which can be interesting in some applications where tunability is not a critical task.

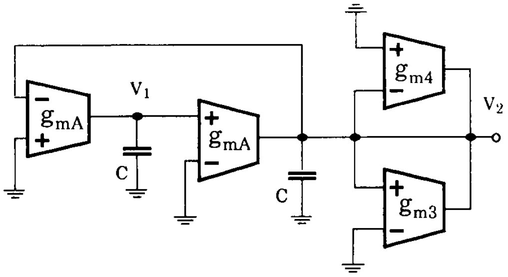

Figure 2a: Quadrature oscillator structure

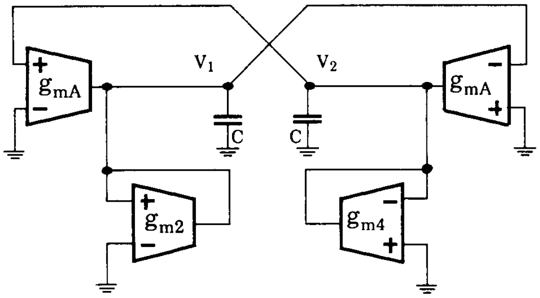

Figure 2b: 4OTA2C oscillator structure

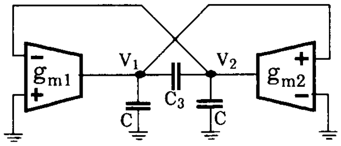

Figure 2c: 3OTA2C oscillator structure

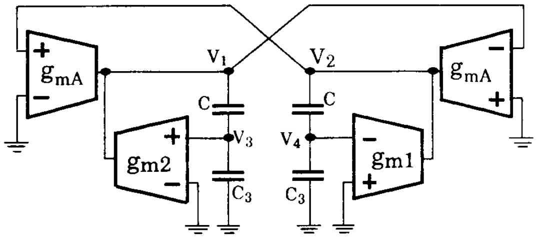

Figure2d: 4OTA4C oscillator structure

Structure	b	ω_0^2
quadrature	$(g_{m4} - g_{m3})C$	g_{mA}^2/C^2
4OTA2C	$(g_{m4} - g_{m2})/C$	$(g_{mA}^2 - g_{m2}g_{m4})/C^2$
3OTA2C	$(g_{m1} - g_{m2})(C_3/(C^2 + 2CC_3))$	$g_{m1}g_{m2}/(C^2 + 2C_3)$
4OTA4C	$(g_{m1} - g_{m2})/C_3$	$g_{mA}^2/C^2 - g_{m1}g_{m2}/(C + C_3)^2$

Table 1: Oscillator parameter values as functions of the transconductance gains

AMPLITUDE CONTROL AND EXPERIMENTAL RESULTS

In any practical oscillator some form of regeneration is needed to ensure that the oscillation is created [1]. For the previously reported circuits, it means that the transconductance gains have to be selected to make b slightly negative. The poles of the characteristic equation are then initially located in the right half plane of the complex frequency plane with a small positive real part, $b/2$. This means obtaining an oscillation that will grow exponentially until some kind of limitation is reached. This form of limitation can be obtained in several ways. The natural nonlinear characteristic of the OTA is the simplest form of limiter. Adding a nonlinear circuit which acts before the natural limitation of the OTA is another alternative. This might provide better controllability of the oscillator. Automatic Gain Control is another more sophisticated way of output voltage stabilization which often requires additional circuitry. Both possibilities have been explored in connection with the OTA-C circuits reported before [12].

By way of example, Fig.3 shows the so-called quadrature circuit including a nonlinear resistor for amplitude limitation. We have built this circuit using CA3080 buffered by Darlington pairs (CA3083) for the OTAs, Silicon diodes and 10% tolerance capacitors with a nominal values of *1.2nF*. The range of linearity of the OTAs was increased until *200mvolts* by using resistive attenuators. Table 2 shows the experimentally measured oscillation frequencies and THDs for different values of the transconductance gains. As it can be seen, the THD is less than 0.81% for frequencies up to 500Khz. It means a big improvement in comparison to previous results for RC-active oscillators [6].

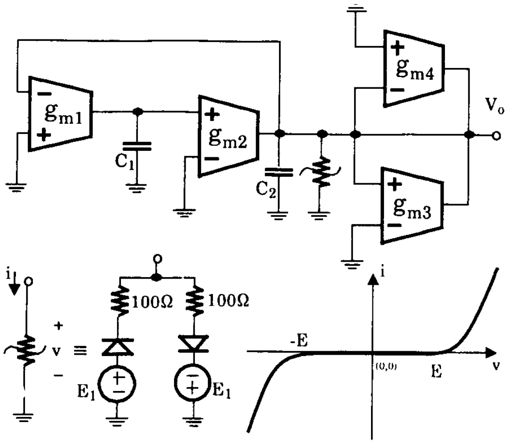

Figure 3: Quadrature oscillator structure including a nonlinear resistor for amplitude control

frequency	THD(%)	$(g_{m1}g_{m2})^{\frac{1}{2}}$
653KHz	1.13	4870
500KHz	0.81	3360
400KHz	0.75	2770
200KHz	0.24	1270
100KHz	0.17	660
50KHz	0.28	350
25KHz	0.15	180
5.2KHz	0.47	80

Table 2: Experimental results for Fig.3

Similar results can be obtained for the other circuits. Fig.4 shows the waveform and corresponding spectrum for an oscillation frequency of $1.053MHz$. This waveform was measured from the circuit shown in Fig.5 for $C=1nF$ and $C_3=1.8nF$. The nonlinear resistor was the same as in Fig.3. The experimentally measured THD for this case was *1.03%*.

Figure 6 shows a practical implementation of the quadrature oscillator including an AGC mechanism. Note that we are controlling the oscillation condition by using an AGC loop that exploits the tunability properties of the transconductance gain of an OTA. Table 3 shows experimentally measured results obtained from this circuit by changing the product $g_{m1}g_{m2}$. Figure 7 illustrates the transient response under a change in the reference voltage of the AGC. A new oscillation amplitude is obtained in steady-state whose value is closely related to that of the reference voltage [12].

DISCUSSION OF RESULTS

A general topology for the generation of OTA based sinusoidal oscillators has been presented. Several circuit structures obtained from this general topology are reported. These structures contains only capacitors and OTAs and are very appropriate for IC

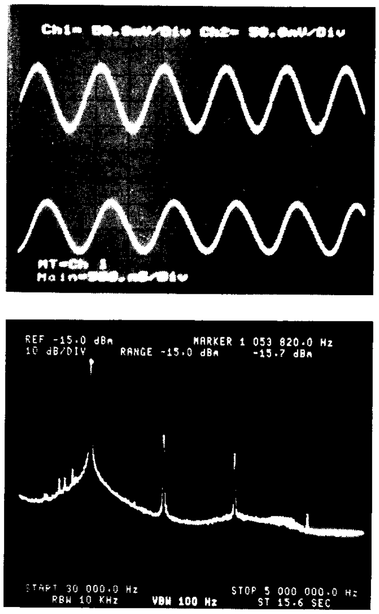

Figure 4: Waveforms and spectrum for a 1.053Mhz oscillation frequency from the 4OTA4C oscillator in Figure 5

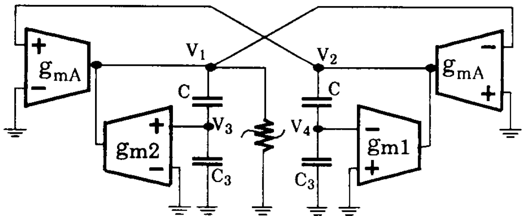

Figure 5 : 4OTA4C oscillator structure including a nonlinear resistor for amplitude limitation

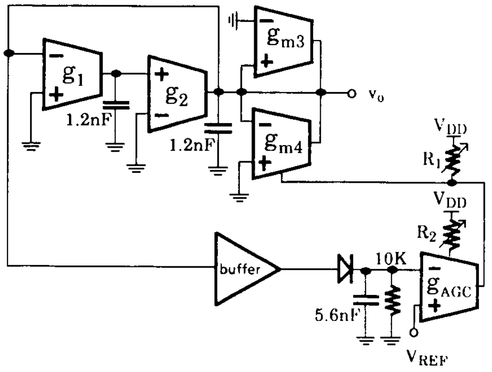

Figure 6: Quadrature oscillator including an AGC loop for amplitude control

frequency	THD(%)	$(g_{m1}g_{m2})^{\frac{1}{2}}$
196KHz	0.27	1250
166KHz	0.24	1060
150KHz	0.17	950
100KHz	0.08	680
88KHz	0.10	580

Table 3: Experimental results for Fig.6

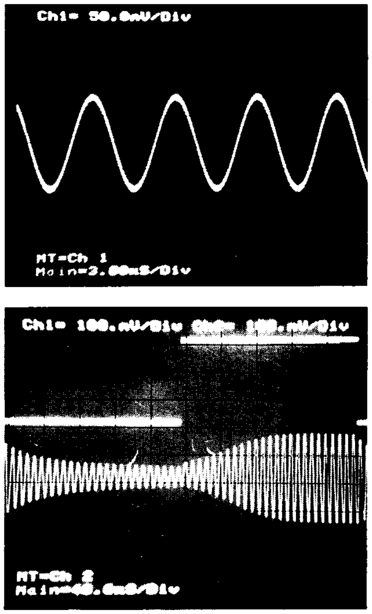

Figure 7: Measured steady-state waveform and transient response of the OTA-C quadrature oscillator including an AGC mechanism

implementation. Furthermore, the obtained experimental results show good potential for high-frequency applications where conventional op amp based circuits are not applicable.

For each reported circuit, the oscillating frequency is proportional to g_m of the OTA. Since the transconductance gain of the OTA is in turn proportional to an external DC source (a bias current in the discrete bipolar case), the reported structures are well suited for VCO operation.

The main drawback of the proposed circuits comes from the fact that the maximum differential input voltage for linear operation of conventional bipolar OTA is very small (less than *50mvolts*). However, since CMOS OTA structures have been recently reported that are capable of handling large input voltage differences (up to 2volts) [13, 14], this drawback does not seem to be a serious one. In fact, using CMOS OTA together with the OTA-C structures reported herein can be a good solution for the realization of high-frequency monolithic sinusoidal oscillators and VCOs.

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