CMOS Implementation of Low-power Oscillators Based on the Modified Fabre-Normand Current Conveyor

Jelena Popovic[1], Borivoje Nikolic[2], K. Wayne Current[2], Aleksandra Pavasovic[1], Dragan Vasiljevic[1]

[1]Faculty of EE, University of Belgrade, P.O.Box 35-54, 11120 Belgrade, Yugoslavia, e-mail: jelena@el.etf.bg.ac.yu
[2]Department of ECE, University of California, Davis, CA 95616, USA, e-mail: bora@ece.ucdavis.edu

Abstract

Experimental performances of new low-power, reliable start-up CMOS RC and crystal oscillators are presented. The oscillators use a modified Fabre-Normand translinear current conveyor for realization of their negative impedance converter. Measurements show reliable oscillation start-up for power supply voltages that range from 1.5V to 5V with current consumption from 100nA to 1.2mA, respectively. Oscillation frequencies up to 55MHz have been observed in circuits fabricated in a modest 2μm CMOS technology.

1. Introduction

The Fabre-Normand current conveyor is a representative of the second generation, translinear, current conveyors [1]. Its large bandwidth and simple CMOS circuit implementation make it well suited for IC realization. It can be used to create a negative impedance converter (NIC) with either current or voltage controlled negative input resistance. Such NIC circuits are suitable for the design of the active part of relaxation oscillators.

The analysis and design of oscillators based on Fabre-Normand current conveyors have been reported in literature. Considering implementations that use discrete devices, the characteristics of oscillators realized with bipolar transistors are much better than those implemented with MOSFETs [2]. The maximum achieved frequency of these reported bipolar oscillators was around 100MHz, while the oscillation frequencies of these reported CMOS oscillators were an order of magnitude lower. The reason of this poor performance of CMOS oscillators was that the discrete CMOS transistors used had very wide channels. The input capacitance of such transistors is large and it significantly reduces the frequency range of the circuit. This problem is overcome by realizing the oscillators as integrated circuits [3].

In comparison to other IC realizations of oscillators with current conveyors, the oscillators presented here have significantly smaller current consumption and approximately the same operating frequency range. In [4] a current-controlled Wien bridge oscillator based on the second generation current conveyor was presented. It was implemented in a 2μm BiCMOS technology with adjustable operating frequencies from 20 to 90MHz and power consumption of 50mW at 50MHz.

The oscillators presented here should perform comparably to the fastest reported when realized in a finer resolution technology. As opposed to this type of negative resistance oscillator, most recently reported oscillators are feedback type. In [5] a crystal oscillator with reduced power consumption and EMI interference was presented. It was realized in a 0.8μm process, consumed 350μA at about 40.96MHz with single 5V supply. In [6] a self-calibrated RC oscillator realized in 1μm n-well CMOS technology was presented. The calibration was done by sampling the output signal which resulted in low temperature and voltage sensitivity. Maximum operating frequency was 103MHz and the required supply voltage was 2.7-6V.

We modified the original Fabre-Normand current conveyor for low-voltage, low-power operation [7]. In general, when the operating voltage is lowered, the problem of the start-up of oscillations can be aggravated [8]. However, the circuits reported in [7] have a reliable start-up even with very low supply voltages, since the oscillations startup is based on negative resistance.

This paper presents the circuit design and measured performance of oscillators based on both original or modified Fabre-Normand current conveyors that were originally described in [7]. The test chip contains 13 oscillators fabricated in a MOSIS 2μm n-well CMOS technology. The selection of included oscillators was done with the goal of investigating and comparing the characteristics of RC and crystal oscillators realized with variations of the Fabre-Normand circuits, evaluated over a range of supply voltages, with an emphasis on evaluating potential low-voltage operation. The experimental measurements have shown reliable oscillation startup for the supply range from 1.5V to 5V with the current consumption from 100nA to 1.2mA, respectively. The experimental measurements indicate a maximum operating frequency up to 55MHz.

2. The Oscillator Circuit

The two main parts of a relaxation oscillator are the active circuit and the timing network. The active circuit used here is a negative impedance converter (NIC)

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realized using a second generation translinear current conveyor, a block diagram of which is shown in Figure 1. Its DC input resistance characteristics, shown in Figure 2, uniquely defined by the control current i_x, has a negative resistance part around the coordinate origin approximately equal to $-R$. The timing network, which can be composed of a grounded capacitor C or quartz crystal, is connected at node X in Figure 1.

The input impedance of the NIC can be modeled by the series connection of parasitic inductance L_p and negative resistance R_{in}. RC and crystal oscillators are realized by connecting capacitor C or a quartz crystal, respectively, at node X. Analysis of this circuit reveals that the real part of the roots of the system's characteristic equation is always positive and large, approximately equal to $|R_{in}|/L_p$, [3], ensuring reliable and quick build-up of oscillations.

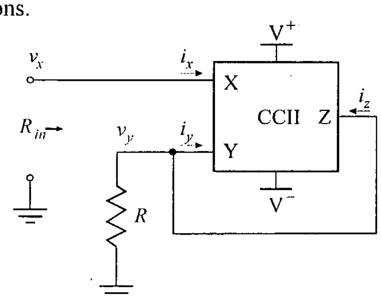

Fig. 1. Negative impedance converter based on second generation current conveyor.

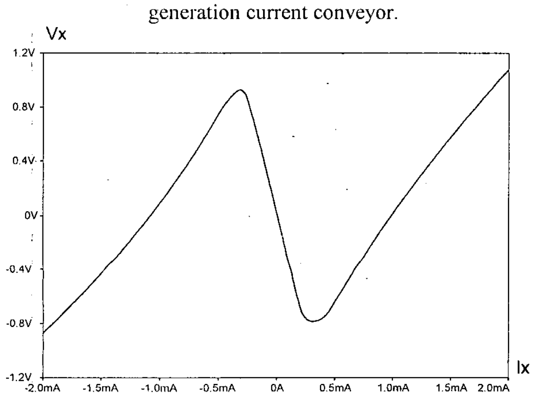

Fig. 2. Spice simulation of the static characteristic of NIC with current conveyor.

The original Fabre-Normand circuit consists of a translinear cell composed of two improved Wilson current mirrors [1]. To provide low-voltage, low-power operation, we replaced improved Wilson with simple current mirrors without affecting the circuit functionality [7]. The RC oscillator with modified Fabre-Normand circuit is shown in Figure 3. The timing capacitor C may be replaced with a quartz crystal unit to create a crystal oscillator.

Detailed analysis of RC and crystal oscillators realized with the Fabre-Normand circuit is given in [7].

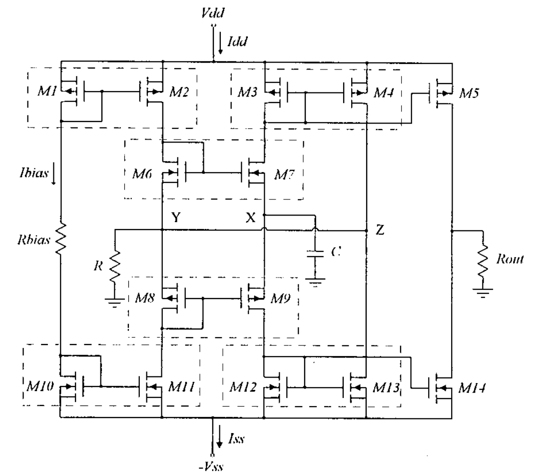

Fig. 3. RC oscillator with modified Fabre-Normand circuit.

3. Test Chip

The test chip was fabricated using a standard MOSIS 2μm n-well double-poly two-metal CMOS technology. The chip contains thirteen oscillators realized with three types of Fabre-Normand circuits described in Table 1. The oscillators of type 1 are based on the original Fabre-Normand current conveyor and are thus not suitable for operation with low supply voltages. Oscillators of types 2 and 3 are based on modified Fabre-Normand circuits that differ from each other in their transistor sizes.

In order to minimize the random mismatch between the matched transistors and to achieve the maximal oscillating frequency, the design and layout are based on unit transistors: 16μm wide and 2μm long in type 1 and 2 oscillators, and 8μm wide and 2μm long in type 3 oscillators. Matched transistors are laid out in an interdigitized and common centeroid format. Each group of p-type transistors in the same oscillator is placed in a separate well to minimize the mutual interference. One oscillator of the each type had separated power supplies for the power consumption measurement. The other oscillators with common power supply pins are separated by the use of two n- and p-contact guard rings.

Osc. type	FN circuit	V_{dd} [V]	W_n [μm]	W_p [μm]	f_{max} [MHz]	Idd [mA]
1	original	5	32/160	80/400	34.60	1.5
2	modif.	2.5 5	32	80	35.6 54.9	0.56 2.46
3	modif.	1.5 5	8	16	0.1 44.1	100nA 1.24

Table 1: Implemented oscillators (R_{out} = 10 kΩ).

In order to obtain a complete set of operating data, each oscillator type is implemented with and without the on-chip biasing circuitry and timing capacitors. Two cells are setup to allow characterization of the current conveyor.

The circuit realization of these oscillators requires implementation of two resistors (R_{bias} and R), with values in the order of kΩ. For the resistor R, which determines the slope of the NIC static characteristic, a passive implementation was chosen to provide characteristic linearity. The resistor R_{bias} in some oscillator circuits is implemented using an MOS transistor with the gate at the midpoint potential between the power rails. The load resistor shown if Figure 3, R_{out}, is always externally connected.

In a fully monolithic realization of a CMOS RC oscillator, the accuracy with which the oscillation frequency may be set depends upon the accuracy of realization of the values of R and C. Capacitor realization is sensitive to underetch effects and oxide thickness. To minimize these effects, our capacitors are realized with combinations of unit poly-poly capacitances of nominal 1pF value.

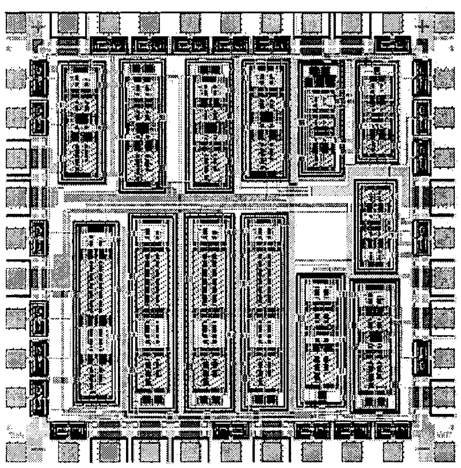

Fig. 4. Layout of the test chip, showing 13 oscillator circuits separated by guard rings.

4. Experimental Results

A. RC Oscillators

Performances of the 3 types of oscillators are summarized in Table 1. Our focus is on type 2 and 3 oscillators, because the type-1 oscillator requires a relatively high supply voltages (±4V) for proper operation. Performances of representative monolithic type 2 and 3 oscillators are summarized in Table 2. The minimum supply voltages for both circuits are given in Table 2. Measurements agree within 10% to values predicted by simulations. The measured frequencies are about 10% higher than simulated, as shown in Figure 5, possibly due to low capacitance values. I_{dd} versus frequency is shown in Figure 6. The output waveform of monolithic implementation "B" of a type-3 oscillator is shown in Figure 7.

osc.	Type	R_{bias}	R [kΩ]	C [pF]	$V_{dd\ min}$
A	2	20 kΩ (poly)	5	2	2.2V
B	3	8u/2u (active)	10	5	1.5V

Table 2: Representative oscillators of type 2 and 3.

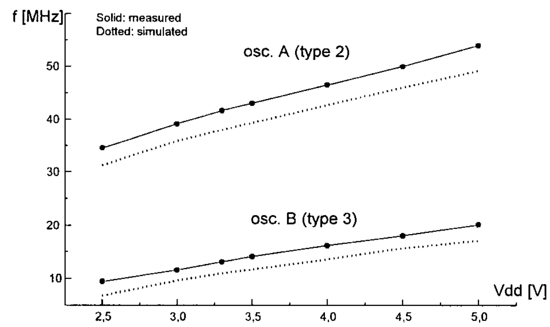

Fig. 5. The oscillating frequency vs. supply voltage for the oscillators A and B.

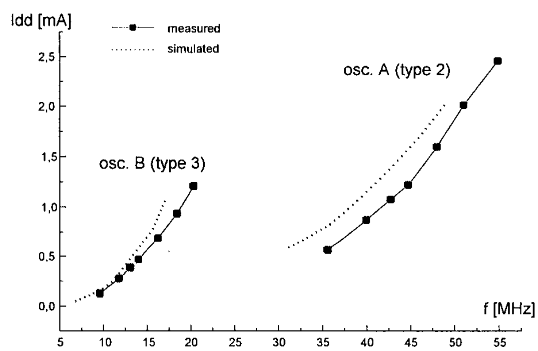

Fig. 6. Current consumption vs. frequency for the oscillators of the type A and B.

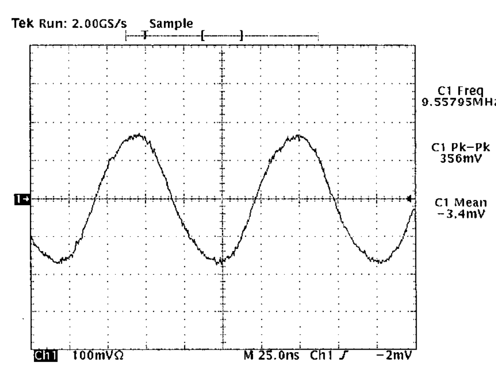

Fig. 7. The output voltage waveform for oscillator B at V_{dd}=2.5V.

Four oscillators were realized without on-chip timing capacitors. An external timing capacitor or a crystal is used to set the oscillation frequency. Figure 8 shows the dependence of the oscillating frequency from the external capacitance, for three supply voltages. The parasitic impedances at the pins limit the operating frequency for this configuration.

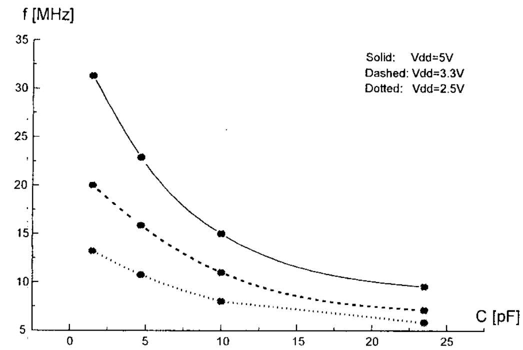

Fig. 8. Oscillating frequency vs. external capacitance for different supply voltages.

B. Crystal Oscillators

Two oscillation modes are experienced when a crystal is used to set the oscillation frequency. When a crystal is attached to the NIC, the parallel capacitance of the crystal unit enclosure forms a parasitic RC oscillator with the active part of the circuit. This parasitic oscillator starts oscillating first and the build up of oscillations of the crystal unit can not be recorded by the oscilloscope. The moment of oscillations setup is determined by the frequency change from parasitic to crystal frequency. For a crystal oscillator of the type 2, at 10MHz, and $V_{dd} = 5$V, the startup time is about 10μs. The reliable startup for the crystal oscillators is demonstrated for supply voltages from 2V to 5V in Figure 9. This oscillator has a consumption of 2.4mA at $V_{dd} = 5$V, and 1mA at 3.3V. The time domain output voltage waveform for a type 2, 20MHz, $V_{dd} = 3.3$V crystal oscillator is shown in Figure 10.

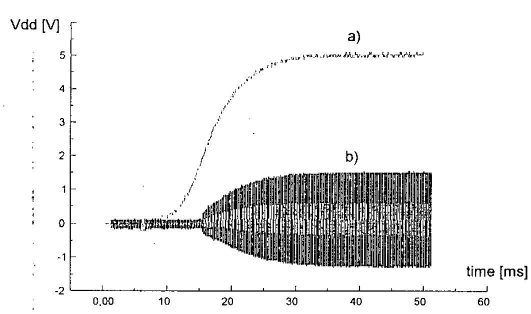

Fig. 9. The oscillations startup at the crystal oscillator: a) supply voltage b) output voltage. Parasitic oscillations start when supply reaches 2V, and the crystal frequency is achieved after 10μs.

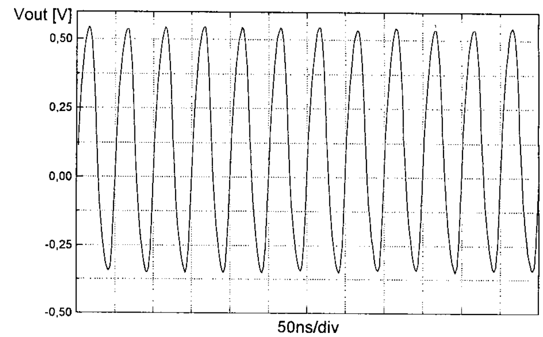

Fig. 10. The time domain waveform of the output voltage for the crystal oscillator (type 2, 20MHz, V_{dd}=3.3V).

5. Conclusion

The characterization of thirteen RC and crystal oscillators realized in a standard 2μm CMOS technology has shown an oscillation frequency range comparable to that possible with similar oscillators realized in bipolar technology [2]. Using a modified Fabre-Normand current conveyor, these new circuits provide reliable startup characteristics and are suitable for low-voltage, low-power applications. RC and crystal oscillators operation are verified with dual power supplies ranging from 1.5V to 5V, and 2V to 5V, respectively.

Realization of these circuits in a submicron technology should provide much wider frequency range and lower power consumption.

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