11

A Programmable Second Generation SI Integrator for Low-Voltage Applications

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Abstract

A second generation integrator based on the switching current memory cell reported in (Gonçalves, 1996 A) has been prototyped. The constant voltage switching of the integrator is well suited to low voltage applications, since it avoids the conduction gap of the switches as well as the signal dependent charge injection. A programmable biquad has been implemented using the proposed second generation integrator. The center frequency and the quality factor can be tuned independently.

Keywords

Switched current circuits and Digital programmable filter.

VLSI: Integrated Systems on Silicon R. Reis & L. Claesen (Eds.)

1 INTRODUCTION

Sampled data circuits have been intensively employed in VLSI chips. The switched capacitor (SC) technique has been the prevailing one over the last two decades. SC filters achieve a high accuracy with a low distortion. However, besides requiring a double poly process, the standard SC technique has the problem of increasing prohibitively the resistance of the switches for low voltage operation (Crols, 1994). If the supply voltage is lower than a certain minimum value, the switch resistance tends towards infinity (Crols, 1994 and Vittoz, 1994) for a range of the input level. This "conduction gap" is a critical limitation for SC filters. There are some special techniques to deal with this problem, such as the use of dedicated processes, on-chip generation of a voltage larger than the power supply and the switched op-amp (Crols, 1994). Of course, these techniques add some extra cost to the chip.

In the late 1980s a new sampled data technique called switched current (SI) was introduced (Hughes, 1989 and 1990). The basic SI circuit is the current mode track and hold circuit shown in Figure 1(a). This technique presents the same limitation of SC circuits with respect to the conduction gap of the switches when operated at low supply voltages. To overcome the problem of the conduction gap of the switches, the SI mirror scheme shown in Figure 1(b) was presented in (Gonçalves, 1996 A).

In this work we propose a second generation SI integrator. In the new integrator the switches operate at constant voltage, thus avoiding the conduction gap existing in conventional SI circuits. Moreover, the charge injected by the switches becomes signal-independent. The proposed integrator has been prototyped and programmed by using MOSFET-Only Current Dividers (MOCD) (Bult, 1992 and Gonçalves, 1996 A). A programmable integrator-based biquad which allows independent tuning of the center frequency and the quality factor has been implemented.

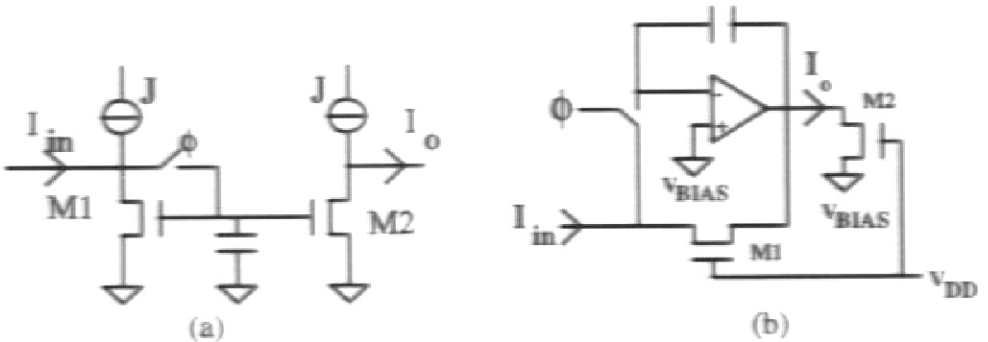


Figure 1 (a)Conventional SI mirror.
(b) SI mirror proposed in (Gonçalves, 1996 A).

2 SECOND GENERATION (SI) INTEGRATOR

The conventional second generation SI integrator (Hughes, 1989) is shown in Figure 2(a). In this paper, we propose a second generation SI integrator based on the SI mirror shown in Figure 1(b). The integrator is made up of two switched current memory cells, as shown in Figure 2(b). Two available outputs are I_{OA} and I_{OB}.

In the odd phase :

$$I_{OA}(n) = \alpha I_A(n) = -\alpha\{I_{in}(n) + I_B(n)\} \qquad (1.a)$$

while in the even phase

$$I_B(n-1/2) = I_B(n-1) = -I_A(n-1) \qquad (1.b)$$

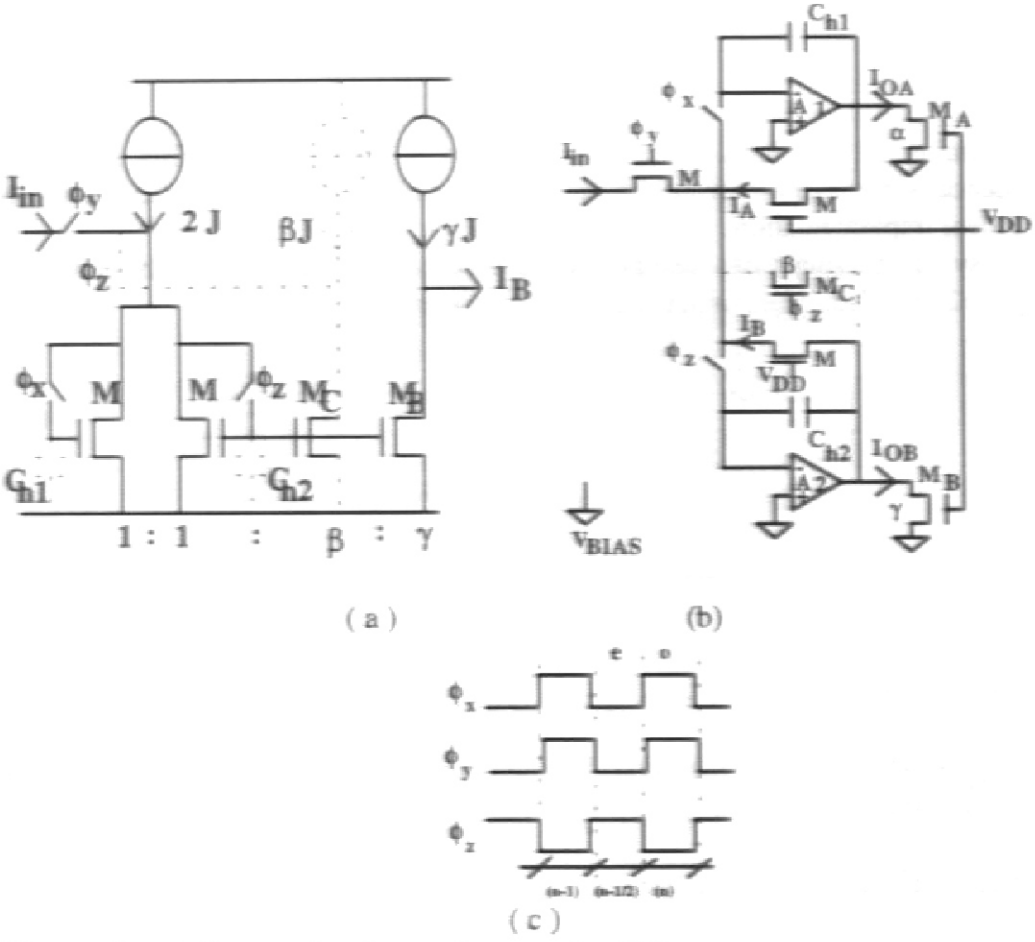


Figure. 2 - (a) Conventional second generation SI integrator.
(b) Proposed second generation SI integrator.
(c)Switching clock sequence.

From equations (1.a) and (1.b) we can write

$$I_{OA}(n) = -\alpha I_{in}(n) + I_{OA}(n-1) \tag{2.a}$$

and

$$I_{OB}(n) = \gamma I_{in}(n-1) + I_{OB}(n-1) \tag{2.b}$$

where $\alpha=(W/L)_{MA}/(W/L)_M$ and $\gamma=(W/L)_{MB}/(W/L)_M$.
W and L are the width and length of the channel, respectively.
The z-transformation of (2.a) and (2.b) gives:

$$\frac{I_{OA}^{\phi_o}}{I_{IN}^{\phi_o}} = -\alpha \frac{1}{1-Z^{-1}} \tag{3.a}$$

$$\frac{I_{OB}^{\phi_o}}{I_{IN}^{\phi_o}} = \gamma \frac{z^{-1}}{1-Z^{-1}} \tag{3.b}$$

The timing of the clock waveforms is shown in Figure 2 (c). This switching sequence is necessary to avoid the loss of information during clock transition in a practical implementation.
A lossy SI integrator can be realized using the dotted feedback path shown in Figure 2 (b). The z-domain transfer functions are:

$$\frac{I_{OA}^{\phi_o}}{I_{IN}^{\phi_o}} = -\alpha \frac{1}{1+\beta-Z^{-1}} \tag{4.a}$$

$$\frac{I_{OB}^{\phi_o}}{I_{IN}^{\phi_o}} = \gamma \frac{z^{-1}}{1+\beta-Z^{-1}} \tag{4.b}$$

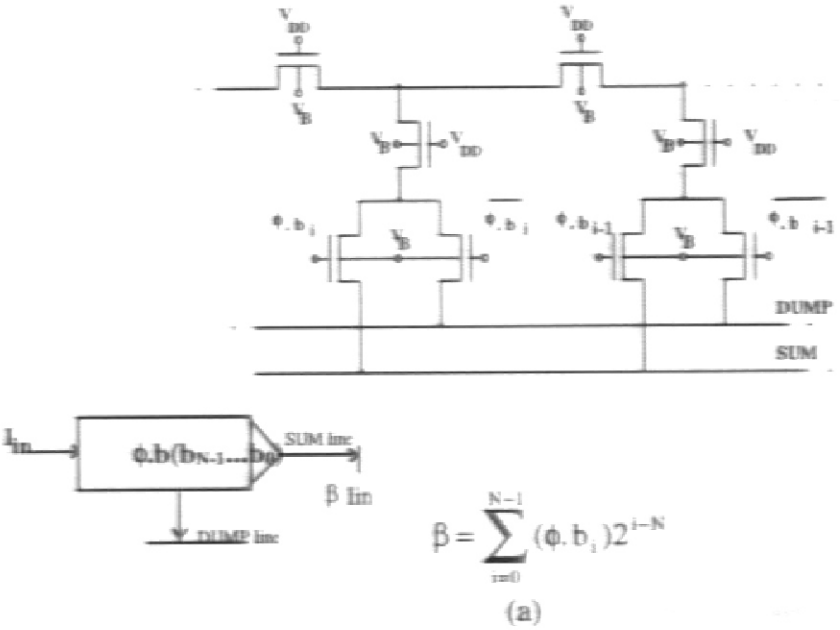
where $\beta=(W/L)_{MC} / (W/L)_M$.

The proposed second generation SI integrator has the same sensitivities to transistor mismatches as the conventional SI integrator (Hughes, 1989).

3 EXPERIMENTAL RESULTS

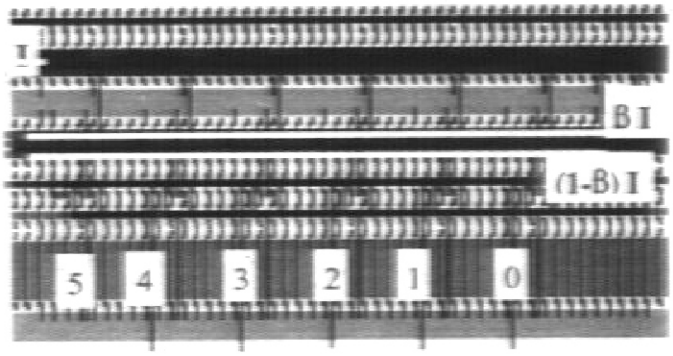
The SI lossy integrator shown in Figure 2 (b) was implemented using operational amplifiers TL 082, MOS integrated transistors (W=48μm, L=1.2 μm), MOS switches CD 4007 and holding capacitors of 1.8nF. The loss factor (β) was set by a 6-bit MOSFET-Only Current Divider (MOCD) (Bult, 1992) whose scheme is shown in Figure3 (a). The 6-bit MOCD was integrated on a Sea of Transistors

(SoT) array, in a 1.2μm technology from ES2 (Gonçalves, 1996 B). The MOCD layout is shown in Figure 3 (b).



$$\beta = \sum_{i=0}^{N-1} (\phi . b_i) 2^{i-N}$$

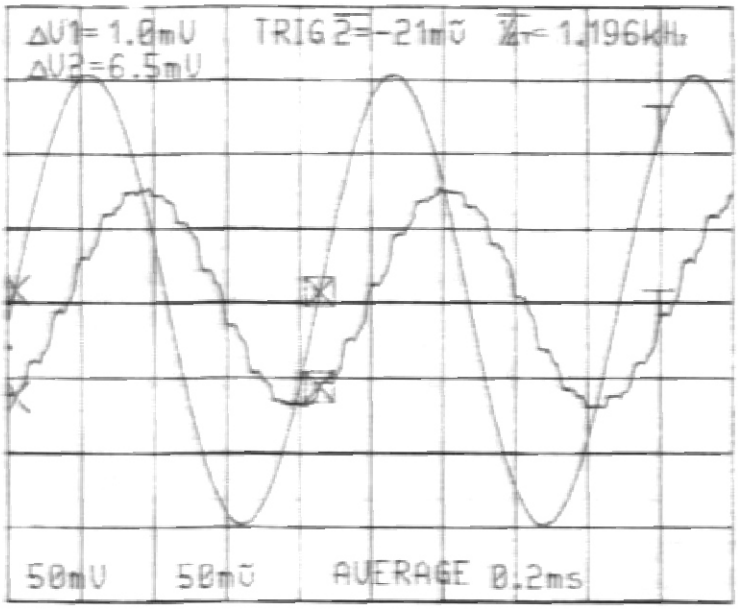
(a)



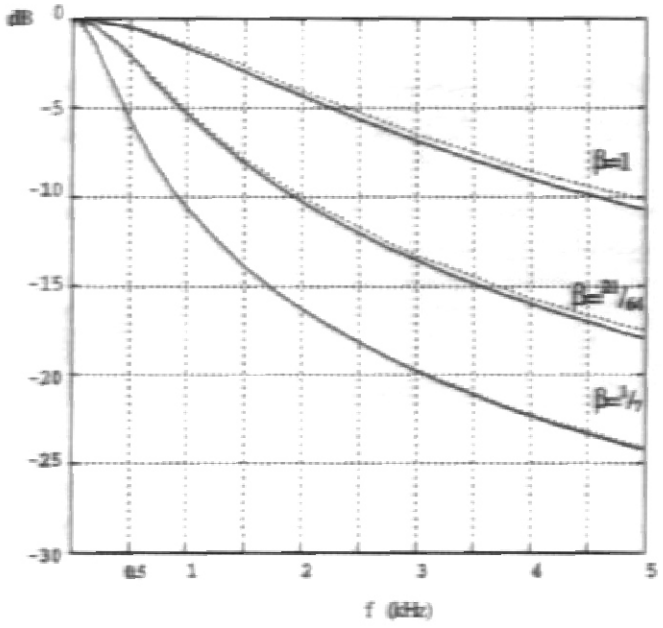
(b)

Figure 3 (a)Switched MOCD and Its Symbol.
(b) MOCD layout on an SoT array.

The MOCD input impedance is independent of both the digital word and the clock phase, thus providing a constant load impedance to the op amps. The MOCD is switched by "ANDing" the digital word and the even phase waveforms $\{\phi_e . \mathbf{b}(b_{N-1} \ldots\ldots b_o)\}$. The experimental time response of the integrator is shown in Figure 4 (a) (β=21/64) for a 1.196kHz input signal. Note that the output signal does not present glitches. This important property is due to the constant voltage switching of the memory cell. The integrator has been simulated using the ASIZ program (Queiroz, 1993). The simulated and experimental frequency responses presented in Figure 4 (b) show excellent agreement.



(a)



(b)

Figure 4 - Experimental output (Fs=15kHz).
(a) time response (β=21/64).
(b) Frequency responses,
..... -Theoretical and __-Experimental.

4 SECOND ORDER SECTION

As an application of the second generation SI integrator we built a biquadratic section, designed using backward LDI transformation (Silva-Martinez, 1989). This transformation leads to smaller frequency prewarping errors than the Euler transformations. The biquad circuit is presented in Figure 5. The center frequency ω_o and the quality factor Q can be controlled independently if the sampling frequency is much higher than the center frequency. In this case:

$$\omega_o T \equiv a \tag{5.a}$$

and

$$Q \equiv 1/f \tag{5.b}$$

A discrete prototype of the filter has been implemented and tested. In this experimental work, the transistors were replaced by resistors. The programmability of the filter was obtained by scaling the resistances. The unit resistor is 20kΩ, and the holding capacitors are C=100pF. The band pass filter has been programmed for center frequencies f_o=150, 300 and 600Hz. The sampling frequency was 15kHz and the quality factor was equal to 8. The simulation and experimental results are shown in Fig 6. In the case of very low $\omega_o T$, the error in the center frequency is large due to the variability of the resistors. To adjust this error we have to decrease the variability of the resistance or, for an IC implementation, increase the resolution of the MOCD.

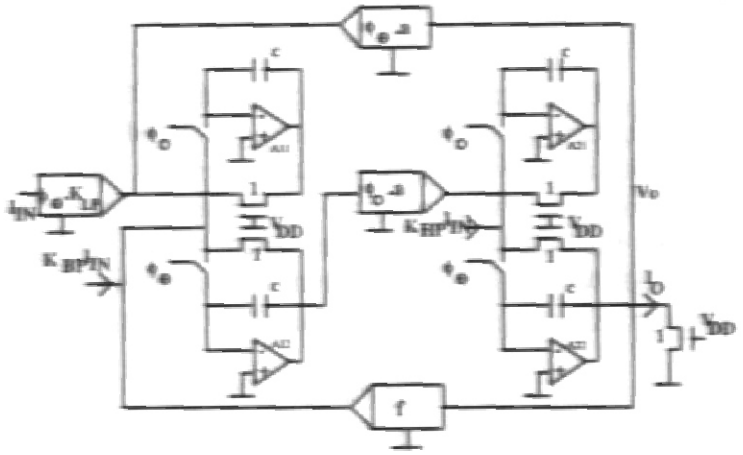


Figure 5 - Biquadratic section using second-generation SI integrator.

The DC output caused by the op amp offsets is

$$V_O = (1+G_{DC})V_{off1} + (2+\frac{1}{Q})\frac{\Delta V}{\omega_o T} \tag{6}$$

where G_{DC} is the low frequency gain (K_{LP}/a),

V_{off1} is the op amp (A_{11}) offset and
ΔV is the offset mismatch$\{V_{off1}(A_{11})-V_{off2}(A_{12})\}$.

The DC component of the output, as given by (6), is not large provided that the sampling frequency is not very much higher than the center frequency of the biquad or the offset mismatch is not high. Dynamic techniques (Vittoz, 1994) can also be employed to reduce the effects of the offset mismatch.

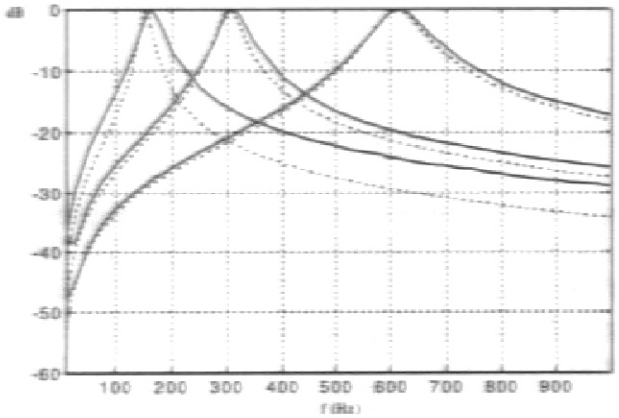


Figure 6 Magnitudes of the bandpass filter,
...-Theoretical and __-Experimental
f_o=150, 300 and 600 Hz (Q=8 and f_c=15kHz)

5 CONCLUSIONS

A second generation SI integrator has been reported in this work. The main advantage of the integrator presented here, when compared to the conventional one, is its applicability in low voltage circuits. Moreover, the constant voltage switching provides the circuit with a signal-independent charge injection. The programmability of the SI integrator has been tested using a digitally programmable MOCD. A bandpass SI filter has been implemented with discrete elements and tested at different center frequencies.

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