NONLINEAR MEAN ANALOG FILTERS

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Abstract: - In this paper an investigation about realization of nonlinear analog filters for image applications based in current mode circuits is presented. Versatility of translinear circuits is used in these kinds of filters. SPICE simulations have been carried out using 1.6 μm CMOS parameters.

Key-Words: **-** Nonlinear mean filters, current mode circuit, translinear circuit.

1 Introduction

Nonlinear filtering techniques are becoming great importance in image processing applications. These techniques offer better characteristics for remove several noise types than techniques utilized in linear filters [1-3]. In general, when signal-dependent noise is present, linear filters fail. In this work we are concentrated in filters based in the nonlinear mean. Because these filters present a very simple structure they can be used in real time signal processing. Operations of search, sorting, and selection are required in other types of nonlinear filters (Some examples are the median filters, stack filters, and rank filters, among others) [2]. This operations conduct to obtain a great complexity in digital and analog VLSI circuits.

When signals are in the lowest level, once the images have been acquired, nonlinear mean analog filters may be used. Using circuits of low power we can obtain portable and low cost systems.

The purpose of this work is investigate the analog realization of nonlinear mean filters for image processing. CMOS current mode circuits are used for take advantage of the versatility of nonlinear mean filters. In section 2, based in [3], several architectures for nonlinear mean filters are developed. In section 3 some circuits that can be used in the general architectures of the filters are revised. Results are shown in section 4. And finally in section 5 the conclusions are presented.

2 Nonlinear mean filters: General architectures

If we consider the numbers x_i, for $i = 1, 2, \dots, N$, the nonlinear mean is defined by [3]:

$$y = g^{-1}\left(\frac{\sum_{i=1}^{N} a_i \cdot g(x_i)}{\sum_{i=1}^{N} a_i} \right) \tag{1}$$

where *g(x)* is a single valued analytic nonlinear function and a_i are weights. If the weights are constants, the nonlinear mean filters can be reduced to homomorphic filters [3], which also present a great interest in image processing.

In table 1, mean functions of interest for signal processing are presented.

Table 1, Interest filters for processing signal.

g(x)	Function
x	Arithmetic mean
$1 / x$	Harmonic mean
$\ln(x)$	Geometric mean
x^p, $p \in \Re$ {-1, 0, 1}	L_p mean

For the case in which $g(x) = x$, the filter obtained is the nonlinear arithmetic mean filter. Block diagram for this filter for 3–data input is showed in figure 1.

Other possible block diagrams for harmonic, geometric and L_p mean filters also for 3–data input are showed in figure 2.

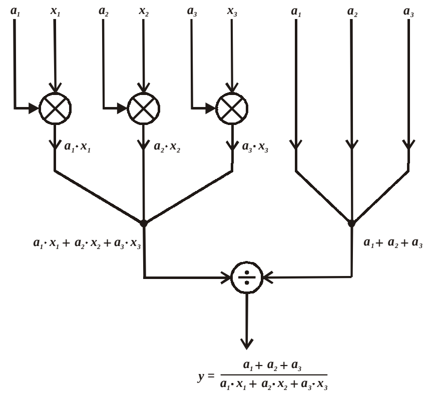

Fig. 1, Block diagram of arithmetic mean filter for 3–data input.

3 Generated circuits of functions in current-domain

Clearly, these filters can be obtained using current mode circuits. Translinear principle can be used for obtain this type of circuits. This theory was formulated how a practical medium for realization of nonlinear signal processing functions through bipolar transistors [4]. Using the exponential characteristic of bipolar transistor, linear proportionality of transconductance with the current collector can be obtained. When this propriety is applied in circuits that contain junction voltage loops, signal processing functions can be obtained [4, 5].

When MOS transistors are handled in weak inversion, a similar behavior to bipolar transistor can be obtained [6]. Geometric mean function, presented in table 1, can be achieved using MOS transistor in weak inversion, and applying translinear principle the other functions presented in table 1 also can be obtained.

Essentially, these circuits work in current mode. Evidently, current mode circuits providing advantages for analog signal processing. Operations of addition and subtraction are carried out very easily in current mode.

Using the square law characteristic of a MOS transistor [7], functions presented in table 1 also can be obtained. In this case, the linear proportionality of transconductance with gate–source voltage can be exploit for to obtain analog signals processing functions. These circuits also work in current domain and they belong to a kind of translinear circuits [8]. In this work, translinear circuits using MOS transistors in weak inversion will be considered.

In figure 1 and 2, multipliers and divisors are the principal circuits used for obtain the nonlinear mean filters. A MOS translinear circuit that can to carry out these operations is presented in figure 3 [6]. Here, transistors M1–M4 work in weak inversion. The exponential characteristic of MOS transistor in weak inversion is [9]:

$$I_{DS} = S \cdot I_{D0} \cdot e^{v_{gs}/n \cdot v_T} \quad (2)$$

where $S = W/L$, n is the subthreshold slope factor, and $V_T = KT/q$ is the thermal voltage.

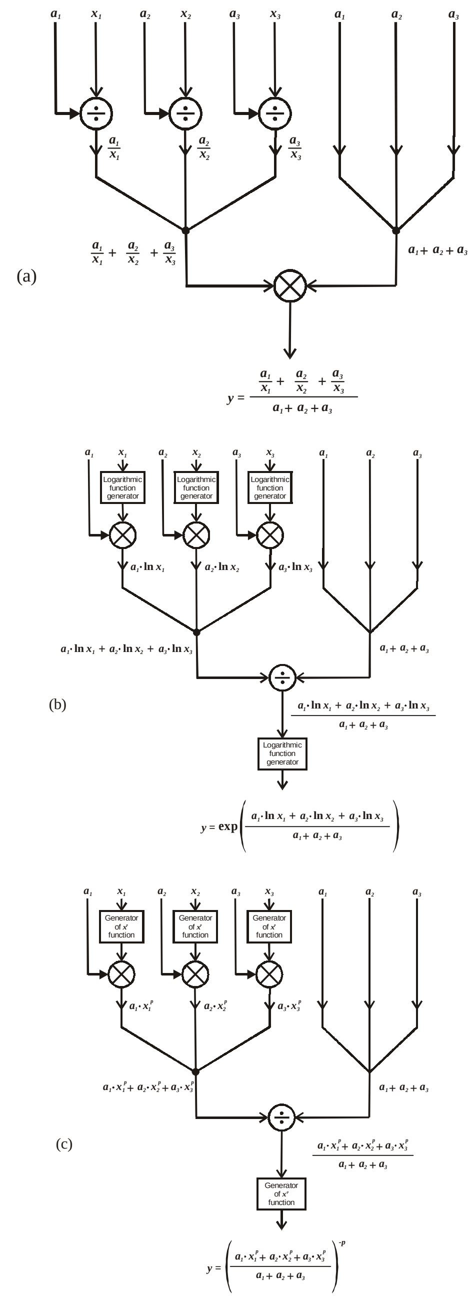

Fig. 2. Block diagrams of (a) harmonic mean filter, (b) geometric mean filter, and (c) L_p mean filter, for 3–data input.

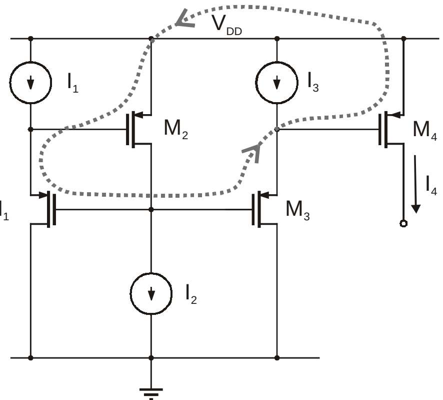

Fig. 3 One–quadrant translinear multiplier/divider using MOS transistors.

Applying the translinear principle to the loop V_{DD}–v_{gs2}–v_{gs1}–v_{gs3}–v_{gs4}–V_{DD}, as it is shown in figure 3, and considering that the dimensions of the transistors are same, we can obtain

$$I4 = \frac{I1 \cdot I2}{I3} \tag{3}$$

For the case $g(x) = \ln(x)$, nonlinear geometric mean filter can be obtained. The block diagram for this filter is shown in the figure 2(b). In this case additional circuits are necessary. A logarithmic circuit for each input data x_i and one that realize antilogarithmic function to obtain wanted output signal. A bipolar version of a circuit that can realize these operations is presented in [5]. A version with MOS transistors for a current mode logarithmic function generator is shown in figure 4. Applying Kirchhoff's voltage law to the loop shown in this figure, we can obtain

$$v_{gs1} + v_{gs2} = v_{gs3} + v_{gs4} + R_1 \cdot I_4 \tag{4}$$

Considering identical MOS transistors and again using the exponential characteristic of MOS transistor in weak inversion we can obtain:

$$I_4 = \frac{n \cdot V_T}{R_1} \ln\left(\frac{I_1 \cdot I_2}{I_3 \cdot I_4}\right) \tag{5}$$

In this case, if $I_2 = I_4$ and $R_1 = R_2$, $v_{gs5} = v_{gs4}$. Then (5) is transformed in:

$$I_4 = \frac{n \cdot V_T}{R_1} \ln\left(\frac{I_1}{I_3}\right) \tag{6}$$

with $I_1 \geq I_3$.

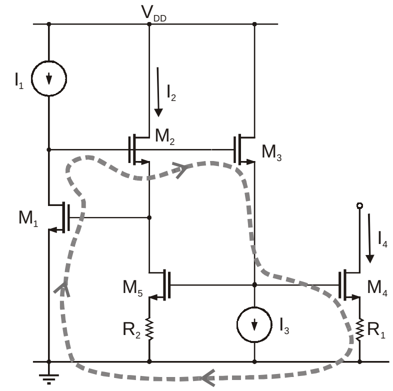

Figure 4 Current-mode logarithmic function circuit.

To obtain antilogarithmic function, we can use the circuit shown in figure 5. Again, MOS transistors work in weak inversion, and considering that dimensions of transistors are same, applying the translinear principle to the loop shown in figure 7, we obtain:

$$Iout = I_1 \cdot \exp\left(\frac{R_2 \cdot I_2}{n \cdot v_T}\right) \tag{7}$$

This way, combining these circuits, we can obtain the nonlinear mean filters presented in table 1.

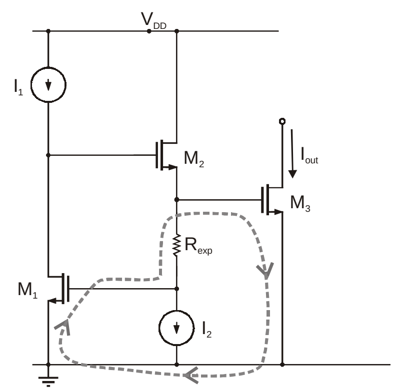

Fig. 5, Current-mode antilogarithmic function translinear circuit.

4 Simulation results

Simulations results were obtained using HSPICE using 1.6 μm process parameters. Simulations of each circuit presented in the previous section are presented. All circuits work with 1.5 volts.

For first circuit, one–quadrant multiplier of fig. 3, graphics characteristics are shown in figure 6. In this case M_1–M_4 dimensions are W/L = 120μm/1.6μm, and polarization current I_3 = 30nA.

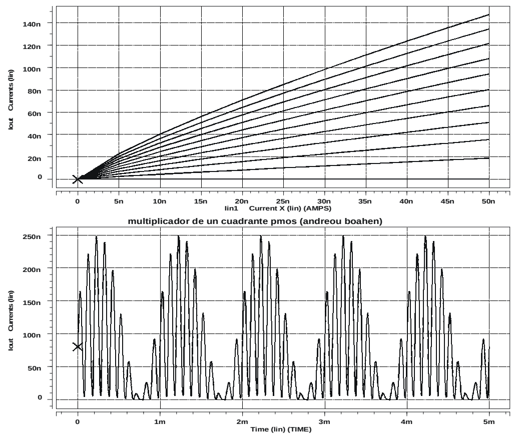

Fig. 6, (a) DC transfer characteristic, and (b) transitory response for one–quadrant multiplier.

For logarithmic circuit (fig. 4.), M_1–M_4 dimensions are W/L = 30μm/4μm, with I_3 = 5nA, and $R_1 = R_2$ = 1KΩ. In figure 7 the DC response of this circuit is shown.

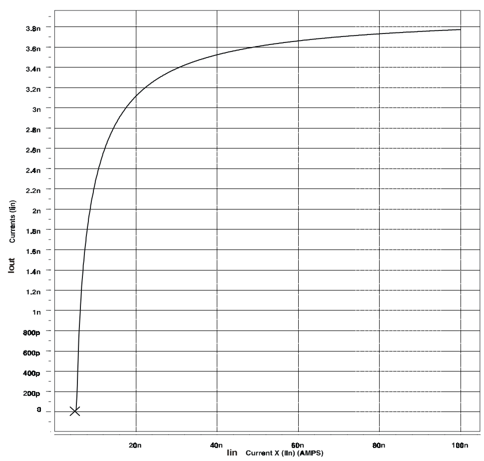

Fig. 7, DC transfer characteristic for logarithmic circuit of figure 4.

For antilogarithmic circuit (fig. 5.), M_1–M_3 dimensions are W/L = 26μ/10μm, with I_3 = 10nA. In figure 8 the DC response of this circuit is shown.

5 Conclusions

In this paper general architectures to achieve nonlinear mean filters have been developed. We have presented circuits for the realization of this kind of filters. MOS translinear circuits in weak inversion have been used for the design of circuits. Because these circuits present few components in their structure, the application for systems of image processing can be achieved.

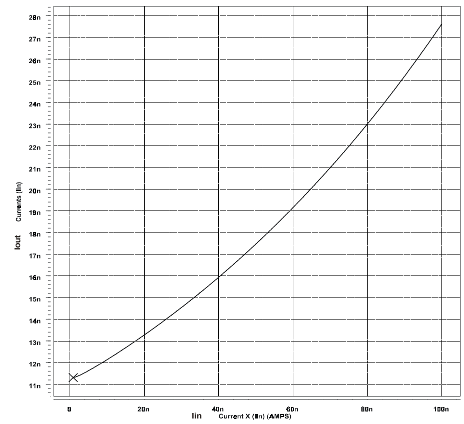

Fig. 8, DC transfer characteristic for antilogarithmic circuit of figure 5.

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