An Analog CMOS Universal Membership Function Circuit With Fully Independent, Adjustable Parameters

R. G. Carvajal, A. Torralba, F. Colodro and L. G. Franquelo
Dpto. de Ingeniería Electrónica
Escuela Superior de Ingenieros,
Avda. Reina Mercedes s/n, Sevilla–41012 (SPAIN)
e–mail: carvajal@gte.esi.us.es

Abstract— **A novel CMOS membership function circuit (MBC) is presented. It is based on a linear tunable transconductor proposed in [1] and implements trapezoidal/triangular functions with all parameters (slope, position, width, height and amplitude) independently and continuously adjustable. It is suitable to be used in analog fuzzy circuits working in current mode. The computer simulations that verify the characteristics and performances of this circuit are shown.**

I. Introduction

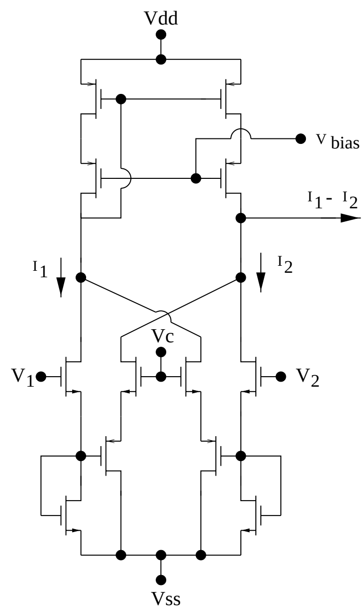
In the last few years several implementations of analog fuzzy controllers have been proposed using either, a voltage-mode [2], [3] and a current-mode approach [3], [4], [5]. The advantages of the current-mode approach are a greater and flexible range of values and higher speed (the voltage-mode basic building block is the Operational Amplifier which is inherently slower than the OTA). Most of the CMOS current-mode circuits proposed to build a MBC are based on the differential pair. This circuit produces sigmoidal type shapes and has good programming properties. But triangular/trapezoidal are the most used shape in fuzzy literature.

In this paper a novel CMOS MBC is presented. It is based on a linear tunable transconductor proposed in [1]. This OTA has excellent properties in terms of linearity and tunability, and with the help of current mirrors it is possible to build triangular and trapezoidal shapes. Furthermore, with the help of MAX-MIN circuits, it is possible to generate any type of piecewise linear (PWL) function [6]. Besides, the MBCs obtained with this method are fully and continuously programmable.

This paper is organized as follows. Section II describes the architecture of the MBC. The way to generate triangular, trapezoidal and PWL circuits is detailed in Section III. Section IV presents some results and advances future research.

II. Architecture of th MBC

Figure 1 shows the OTA circuit used to build the MBC. A linear relation between the differential output current and the differential input voltage can be seen in the equation shown in this figure. This relation depends on the control voltage V_c and it is possible to modify the gain by changing its value.



$$I_1 - I_2 = \frac{K_n}{2}(V_c - V_{ss} - V_{Tn} - V_{Teq}) * (V_1 - V_2)$$

Figure 1: OTA circuit

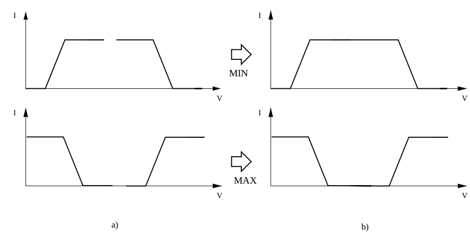


Figure 2: Kind of MBF shapes

The functions shown in figure 2a (Z-functions) can be generated with this circuit. As the inference process in the main fuzzy hardware applications is carried out by means of MAX/MIN operators,

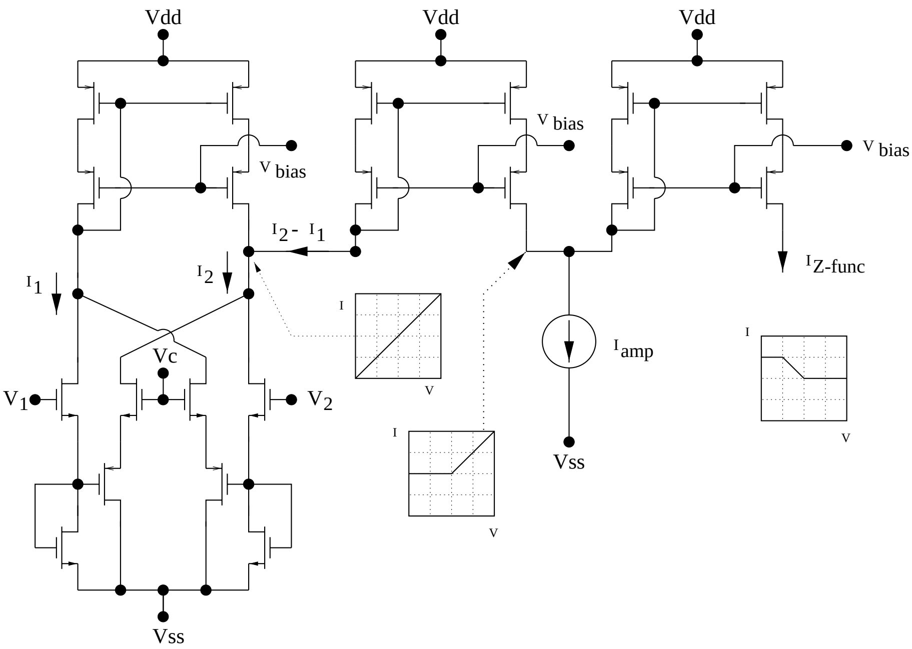


Figure 3: Z-functions circuitry

it is easy to see that if the position and slope of the Z-functions are controlled, any type of triangular / trapezoidal shapes can be constructed with the help of MAX / MIN operators (figure 2b).

MAX / MIN operators are needed to perform the inference process and this type of MBC only duplicates the number of inputs of the MAX / MIN circuits. The complexity of the inference process does not grow excessively because the number of inputs of MAX / MIN operators is equal to the number of inputs of the controller and this number is usually small.

To build a Z-function is necessary to truncate the left and right side of the OTA response. This operation is carried out by means of current mirrors as can be seen in figure 3. A fuzzy controller input directly drives one OTA input, while the other defines the position of the Z-function on the X-axis. The amplitude of the Z-function can be programmed by the current source I_{amp} and the slope with the value of the voltage V_c.

III. Use of the Z-function

With the Z-function it is possible to generate triangular and trapezoidal shapes. We only need two Z-functions to build one MBC as can be seen in figure 4. In this figure a MIN circuit is required, but in usual applications this circuit is part of the MIN circuit who performs the inference process.

The MAX circuit proposed in [7] and later im-

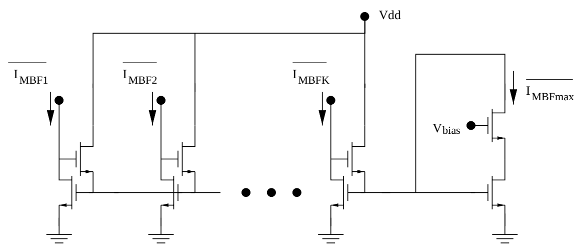


Figure 5: Max Circuitry

proved in [8] for fuzzy hardware applications, is shown in figure 5. The way to build a MIN circuit (with MAX circuits) with the technique proposed in [9] is also shown is figure 6. This circuit has O(n) complexity and is very suitable for this application.

Changing the MIN circuit of figure 4 by a MAX

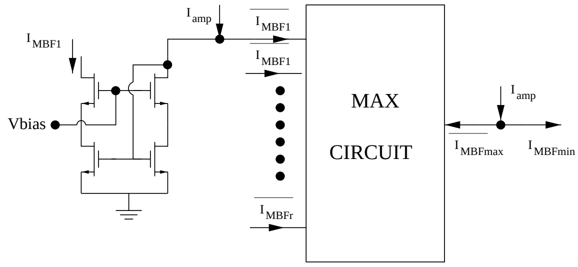


Figure 6: Min Circuitry

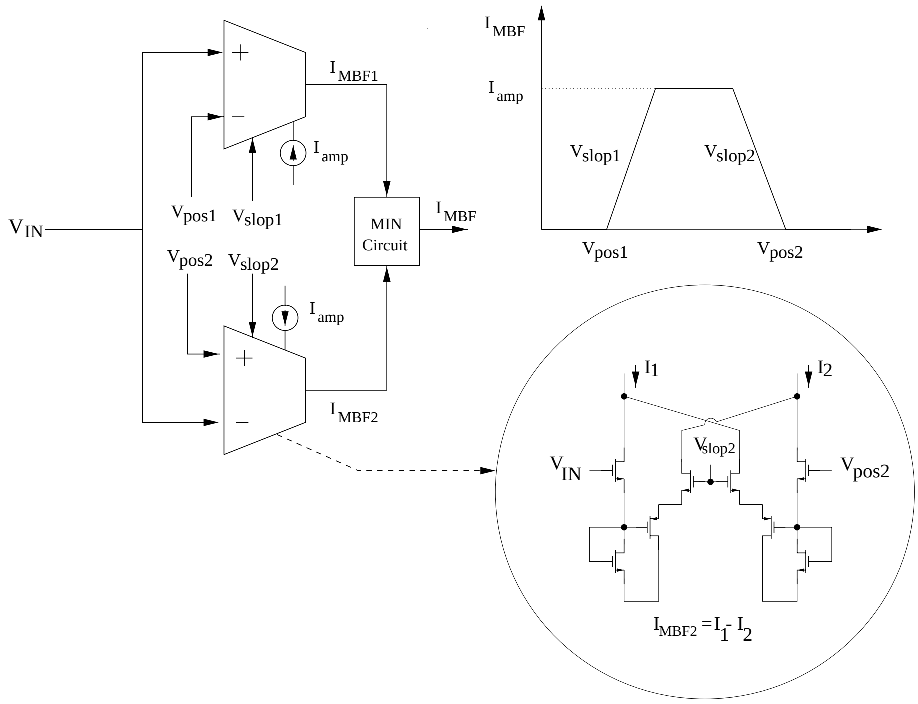


Figure 4: Membership Function Generator

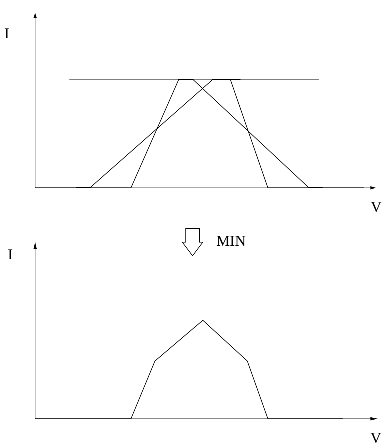


Figure 7: An example of PWL function generation

circuit the complementary shape can be produced. Furthermore it is easy to see that we can construct any PWL function by combining several Z-functions with MAX/MIN circuits (figure 7). In the next section the results obtained with this circuit and the tunability of all the parameters is shown.

IV. Simulation Results

HSPICE simulations using a standard 0.7 μm CMOS technology have been performed. In figure 8 the tunability of the position of the shapes is shown. In figure 9 the gain tunability of the OTA circuit can be seen. This figure has been obtained changing the V_c of one OTA.

As said before, the position of the Z-function is controlled by the value of one of the two OTA input voltages. Changing the same input of the second OTA the membership function aperture can be modified (figure 10).

Finally in figure 11 the transient analysis of the MIN circuit is shown. This simulation also shows how to generate PWL functions by means of several OTAs and MAX/MIN circuits (MIN circuits in this case).
Presently, membership function circuit is being sent to fabrication in order to experimentally test the circuit behavior. Besides new OTA topologies are being explored to eliminate the gain dependence on the transistors threshold voltages.

V. Acknowledgments

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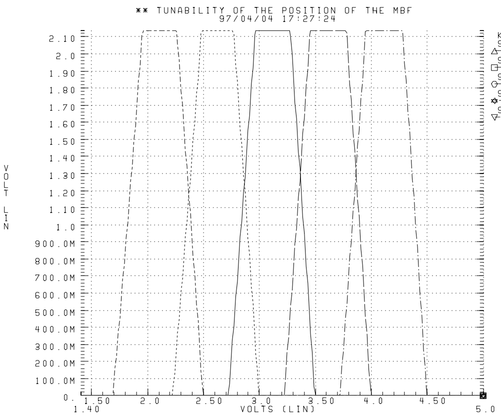

Figure 8: Tunability of the position of the MBC

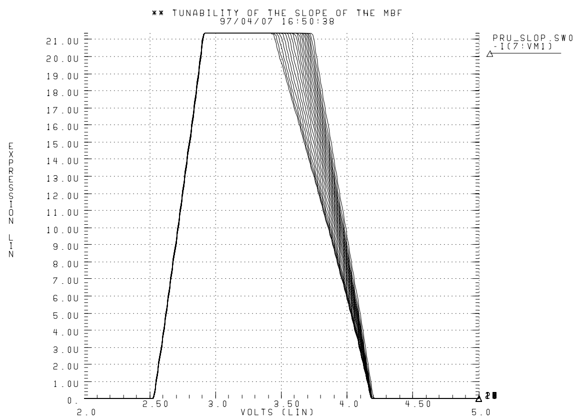

Figure 9: Tunability of the slope of the MBC

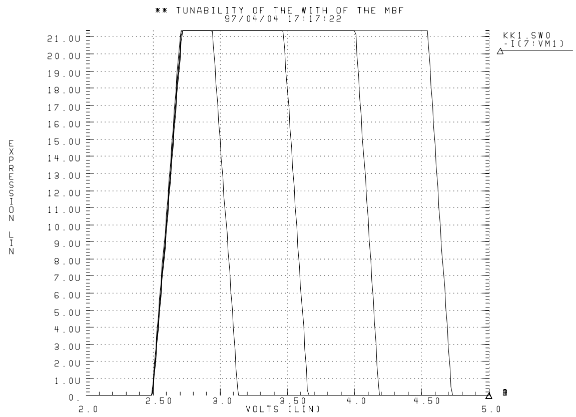

Figure 10: Tunability of the with of the MBC

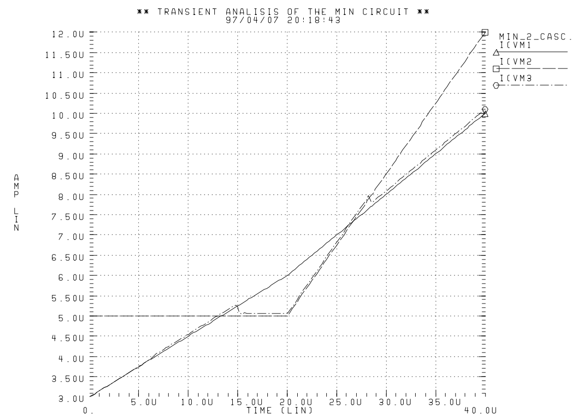

Figure 11: Transient analysis of the MIN circuit

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