# A NOVEL CURRENT-MODE RECONFIGURABLE MEMBERSHIP FUNCTION CIRCUIT FOR MIXED-SIGNAL FUZZY HARDWARE

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## ABSTRACT
This paper presents a new current-input current-output reconfigurable membership function circuit (RMFC) in analog fuzzy system. The membership function can be reconfigured in terms of its shapes--the S-shape, the Z-shape, the trapezoidal-shape, and the triangular-shape. The easily adjustable characteristics of the proposed RMFC make it more suitable in industrial control applications compared to the MFC proposed in [8]. Its fully current mode circuitry makes it work under low power-supply voltage and high frequency. By proper signal arrangement, the RMFC can re-sample the same input current in different configuration, which contributes to reducing the number of MFC in analog fuzzy controller. Thus, the power consumption and chip area can be reduced compared to the MFC proposed in [4], which makes it functional in portable electronic devices and the smart sensors. The proposed RMFC is CMOS-based and its operations have been confirmed by Cadence simulations.

## KEY WORDS
Current mode, Mixed-Signal, Fuzzy logic, Reconfigurable, Membership Function.

## 1. INTRODUCTION

Fuzzy logic is designed to mimic human thinking process by incorporating the uncertainty inherent in all physical systems by Zadeh in 1965[1]. Relying on the human nature of the fuzzy logic, an increasing number of successful applications have been developed, such as automatic process control, pattern-recognition systems, fuzzy neurons and chaos, etc.

Fuzzy system can be implemented by software or hardware. Software solution can be highly effective and compatible if volume production, speed or portability is not demanded. Different kinds of hardware fuzzy controllers, such as digital microprocessors, field-programmable fuzzy processors, application-specific fuzzy processors, analog fuzzy controllers and mixed signal fuzzy controllers, have been proposed over the last decade.

Analog fuzzy logic controllers have better performance than digital implementations in the real-time control system because of their parallel architecture. However, chip area consumption is becoming larger and larger as the fuzzy rules increase. Sampled-analog implementation looks like a better solution in consideration of speed and chip area consumption.

During the last decade a growing interest in low voltage low power circuit in standard CMOS technology can be observed because of the portable electronic devices and the smart sensors. Current mode circuit shows great future since using current as signal carriers enables it to be unrestricted by supply voltage. A fully current-mode mixed-signal fuzzy controller will meet the demand as mentioned above and this paper presents a novel current mode reconfigurable membership function circuit in low voltage supply as the fuzzification unit of the mixed-signal fuzzy controller.

## 2. CURRENT MODE RMFC

### *A. Fuzzificaiton unit*

A fuzzy processor consists of four fundamental units: *the so-called fuzzification unit, the inference unit, the defuzzification unit and the rule data base unit* as shown in Fig.1. Fuzzification unit is the key building block in fuzzy controllers, which converts the crisp value to fuzzy value. A non-linear analog circuit which is called the membership function circuit is the best solution because of the analog nature of fuzzy theory.

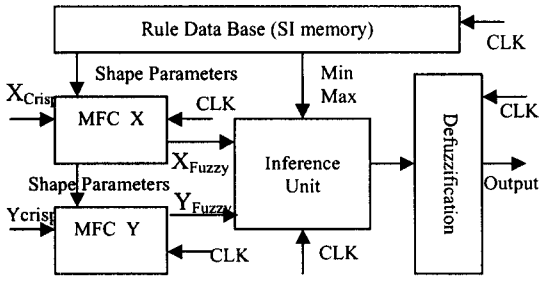


Fig. 1 Block Diagram of Fuzzy Controller

The fuzzification operation is performed by circuits known as membership function circuit (MFC). Several classes of parameterized functions are used to define membership functions: S-shape, Z-shape, trapezoidal-shape, and triangular-shape. They are popular in industrial control applications. However, the membership function parameters have either fixed parameters or they have very poor resolution adjustment reported in [2]. The attempt was made to implement a reconfigurable membership function circuit for analog fuzzy controller by the authors [2,3,4]. However, the structure of voltage input and current output makes it incompatible in low supply voltage.

Since a grade of membership handled in the fuzzy system is 0 ~ 1 and a resolution of 10% (20dB) is enough, the designer should not suffer from accuracy including linearity, low thermal drift, low offset, etc [5]. The characteristics of current copier are suitable in the mentioned situation. A novel full current mode RMFC for mixed signal fuzzy controller in low supply voltage is proposed in this paper.

*B. Circuit Description*

The building block of proposed RFMC is shown in Fig.2. The input-output characteristics can be assigned by external signals such as Iw, Iw', Ih, K and K'. Iw is the first turning point of the membership function while Iw' is the second turning point of the membership function. When Iw and Iw' are the same, a triangular-shape is formed. Similarly, a Z-shape is formed when Iw is zero. On the other hand, there will be a result of an S-shape if Iw is large enough. K and K' are the slopes of the membership function as shown in Fig.2. Lastly, Ih is the maximum output current in the proposed circuit. As a result, the shape of the membership function can be fine tuned.

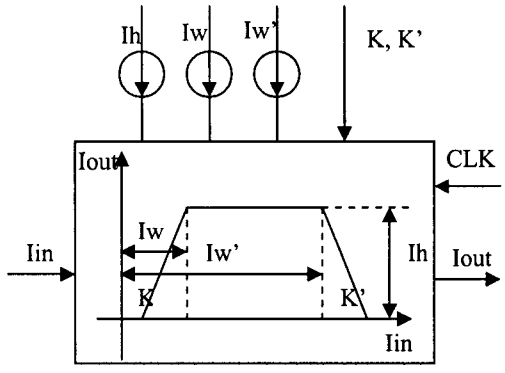


Fig.2 Block diagram of RMFC

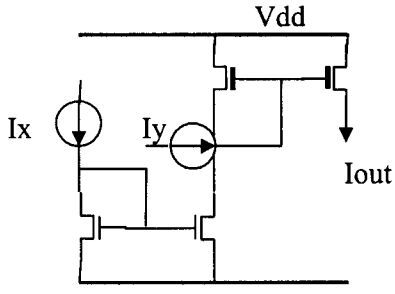


Fig.3 Current rectification circuit

The membership function shown in Fig.2 is carried out by mathematical equation (1) as follows[6]:

$$fuzzy(Iin) = I_h \Theta[k(Iin \Theta Iw) + k'(Iw' \Theta Iin)] \quad (1)$$

where $\Theta$ is a rectification or bounded difference operator defined as:

$$Ix \Theta Iy = \begin{cases} Ix - Iy & if\ Ix > Iy \\ 0 & otherwise \end{cases} \quad (2)$$

Circuit mentioned in [7] realizes equation (2). This simple current mirror circuit works under low supply voltage. The operator "+" in equation (1) is a max operator defined in equation (3) and the circuit in Fig. 4 realizes this function.

$$I_1 + I_2 = Max(I_1, I_2) \quad (3)$$

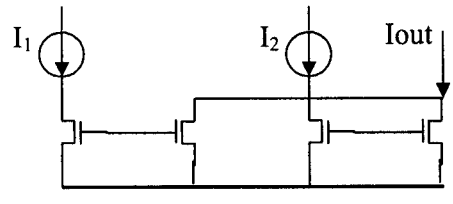


Fig.4 Current Max Circuit

Finally, the proposed RMFC uses a digital weight current mirror to tune the slope of the membership function, which is the parameters K and K'. The circuit in Fig.5 is a digital weight current mirror as a scalar.

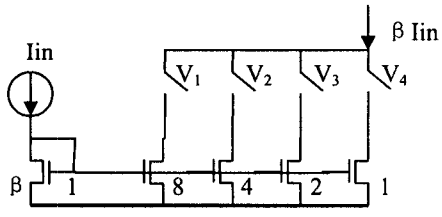


Fig. 5 A digital weight current mirror

*C. Circuit simulation*

The analog cells mentioned above compose the proposed RMFB circuit as shown in Fig. 6. This circuit is simulated by Cadence 0.35 μ m technology under 1.5V power-supply voltage. The universe of discourse is 100uA and the full grade of membership is set to be 25uA.

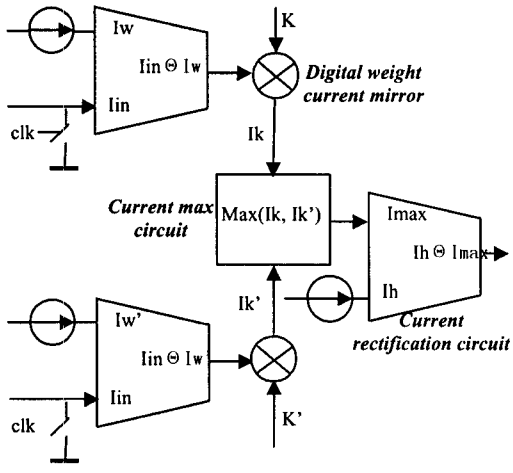


Fig. 6 Circuit function diagram

The DC characteristic of the proposed RMFB appears in the following figures. Fig.7 to Fig. 10 show the different shapes such as S-shape, Z-shape, trapezoidal-shape, and triangular-shape generated by the proposed RMFB with different Iw and Iw'. Fig.11 shows the ability of changing the slope of the mentioned shapes by reconfiguring the parameters of K and K'. Fig.12 shows the slopes of the left and the right shoulders can be tuned independently. Fig.13 is the sweep of the width of the membership function. All of the parameters of different shapes mentioned above such as Iw, Iw', Ih, K, K' can be tuned independently and this gives the RMFC circuit a wide range of uses.

Because of the reconfigurable characteristics of the membership function circuit and the high speed current mirror component, the input current can be re-sampled by the same RMFC with different configurations. Thus, reducing the number of membership function circuit contributes to less power and area consumption.

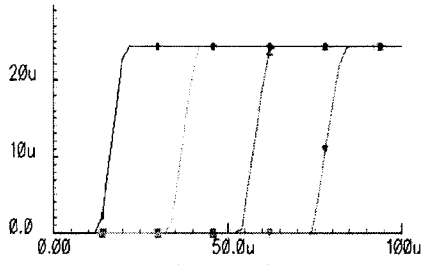


Fig. 7 S-shape

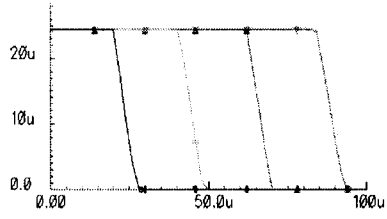


Fig.8 Z-shape

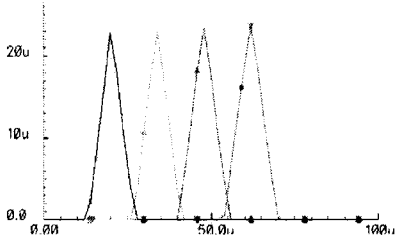


Fig.9 Triangular-shape

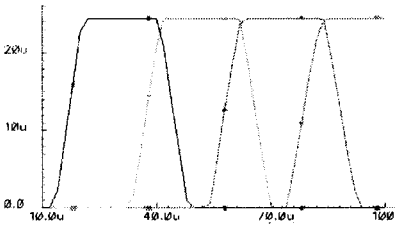

Fig.10 Trapezoidal-shape

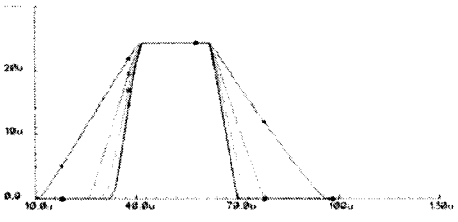

Fig.11 Sweep of the slope

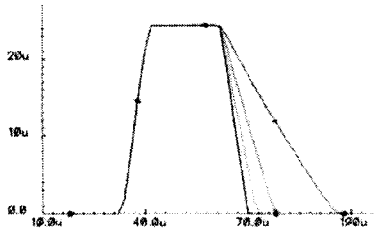

Fig.12 Sweep of the right slope

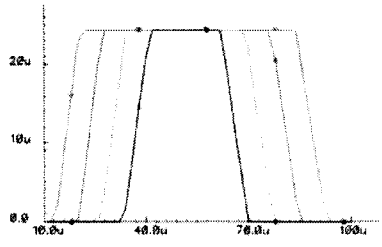

Fig.13 Sweep of the width

## 3. CONCLUSION

A novel current-mode reconfigurable membership function circuit for mixed-signal fuzzy hardware is proposed in this paper. The structural input-output current mode circuit makes it possible work under low power-supply voltage and high frequency. The re-sampled of the input current by the same RMFC in different configuration can reduce the number of MFC in fuzzy hardware, and thus reduce the area and power consumption. Moreover, the fully tunable parameters of the proposed RMFC are proved suitable in industrial applications. However, the digital weight current mirror limits it from continuous adjustment of the slope compared to the MFC proposed in [8].

## 4. ACKNOWLEDGEMENT

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