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Research Article

Design and Simulation of Membership Fuzzy Function Generator Circuit by Assistance of Low-Power Linguistic Variables

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Abstract

In the present study, a low-power power function generator circuit is proposed for fuzzy applications. The proposed power function generator circuit consists of squaring, square rooting, and analog multiplier circuits. All the circuits are designed in the subthreshold region to achieve minimum power consumption. The proposed power generator module is based on a fuzzifier circuit, and the analog multiplier circuits are used to adjust the slopes of the fuzzy functions. Besides performing the mentioned adjustments, the proposed circuit can adjust the rising and falling slopes quite separately. Analog multipliers are used in the power generator part to generate desired powers continuously with minimum number of control inputs. The proposed structure is presented in 0.35 µm technology, and the simulation results show that at a supply voltage of 1.3 V, the values of power consumption and error are respectively equal to 0.0036 µw and 0.8%, indicating the improvement of the proposed structure in terms of error and power consumption compared to the best relevant structures in the literature.

Keywords: fuzzy controller - integrated circuits - power function generating circuit - subthreshold

Highlights

- The operation range of the proposed circuit is in the subthreshold region, which can be very efficient in improving power consumption.
- Besides performing basic adjustments, the proposed circuit can adjust the rising and falling slopes.
- This circuit can be used as a function generator, including triangular, trapezoidal, S-shaped, and Z-shaped functions.
- The proposed circuit provides the controllability of all parameters including the maximum fuzzifier current and the lateral shift of the function.

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1. Introduction

The main challenge in designing fuzzifier circuits is to fabricate circuits that can map the sensors output current into values between 0 and 1. Such fuzzifiers are generally designed as circuits that can generate all functions at the same time. Fabricating a fuzzifier in CMOS or CNTFET technology with minimum power consumption has always been an important challenge [1]. Like membership function generator integrated circuits, the implementation of additional circuits for generating linguistic variables has also drawn the attention of electronic engineers. The first experience of the integrated implementation of these types of controllers was carried out in 2003 [2]. Fractional-power function generation with different powers using various methods is still of interest [4,3]. Several reports have shown the fast performance of CNTFETs in the subthreshold region to achieve low power consumption [5]. Reference [6] presents a low-power Gaussian function generator. For the first time, the present study proposes a triangular function generator in the subthreshold region with the ability to program the slopes of the functions.

2. Innovation and contributions

A fuzzy function generator circuit is designed for various applications and includes a triangular or Gaussian function generator. The main idea of this article is to design triangular function generator circuits at low voltage, which requires specific considerations. Using either current or voltage signals as input depends on the type of the used circuits and sensors. However, this is unimportant because these signals can be converted to each other using conductive and resistive circuits. Fuzzy function generators must have specific characteristics and all necessary considerations must be taken before designing. These considerations include generating all functions of triangular types, such as triangular, trapezoidal, S-shaped, and Z-shaped functions. Moreover, controlling parameters, including the maximum fuzzifier current, lateral shift of the function, ascending/descending slope, and capability of choosing between positive or negative input currents, are investigated and considered in the design of the proposed circuit. Among the innovations of the present study, the following items can be mentioned:

1. The ability of analog realization and fully programable generation of the waveforms
2. Adjustability of the ascending/descending slopes separately and fully continuously
3. Symmetric range of positive and negative input current
4. Adjustability of the maximum output current

3. Materials and Methods

For the first time, a circuit is proposed in this study with the ability to adjust the ascending and descending slopes separately. The simulation results of the proposed circuit in 0.35-μm technology using the HSPICE software show the high accuracy of the power function generator circuit with continuous adjustability. For power generation, the coefficients are adjusted by current sources. This shows the high capability of the circuit to adjust continuous powers.

4. Results and Discussion

In this study, the proposed circuits are designed to operate in the subthreshold region. Previous works were focused on the above-threshold region, so the power consumption was higher than that of the proposed design. Designing in the subthreshold region reduces the circuit speed, which is not very important in controller circuits. However, the power consumption in the proposed structure is considered a practical advantage. Additionally, the subthreshold design allows the fabrication of more accurate squaring and square-rooting circuits. This ultimately leads to a significant reduction in the overall error of the proposed structure, which has the lowest error compared to the previous circuits in the literature.

5. Conclusion

In this study, a power function generator circuit was presented. The proposed design uses parabolic and square root approximations to generate exponential functions. The advantage of the proposed circuit is its effective and low-power operation in the subthreshold region. An analog multiplier circuit, which was implemented by successively connecting squaring and square-rooting circuits, was used to adjust the approximation coefficients. For the better performance of the multiplier, circuits must function correctly in a wide range of currents. To evaluate the performance of the circuit, a fuzzifier circuit matched to the power function generator circuit was also designed based on rectifier circuits. All the necessary fuzzifier parameters that needed controlling were designed such that the circuit was capable of analog adjustment of all variables. For the first time, the proposed circuit can adjust the ascending and descending slopes separately. The simulation results of the proposed circuit in 0.35-μm technology using the HSPICE software showed the high accuracy of the power function generator circuit with continuous adjustability.

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Appendix

Table 1. Comparison with designs in the literature

Measurement	Approximation	Fault %	Accuracy	Power Consumption (microwatts)	Input Current Range (microamps)	Power Supply (volts)	Technology (micrometer)	Reference
Synthesis	No	–	–	–	0-30	3.3	0.35	[15]
Simulation	No	–	0.125	–	0-30	3.3	0.35	[3]
Simulation	Yes	1.42%	0.310	1.05	0-30	3.3	0.35	[16]
Synthesis	No	3%	Continuous	0.97	40-130	2.5	0.35	[28]
Simulation	Yes	1.25%	Continuous	0.8	0-10	3.3	0.35	[17]
Simulation	No	1.05%	Continuous	0.48	0-0.2	0.5	0.18	[20]
Simulation	Yes	0.03%	Continuous	–	0-10	–	0.35	[25]
Simulation	Yes	2.35%	Continuous	0.1	0-0.1	±0.5	0.014 (FinFET)	[29]
Simulation	Yes	–	Continuous	2.61	Voltage mode	1.8	0.18	[30]
Simulation	Yes	5.2%	Continuous	0.83	0-30	1.2	0.65	[23]
Simulation	Yes	0.8%	Continuous	0.003	0-0.1	1.3	0.35	Proposed Method

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