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Logarithmic Voltage-to-Time Converter for Analog-to-Digital Signal Conversion

Springer

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To my parents, Leonel and Ana, and my wife Yu

To Paula, Inês and Patricia

To Carla, João and Tiago

Preface

Data converters are a fundamental building block for many systems and are used for functions such as digitizing voice, image and wireless telecommunication signals among others. This is due to the enormous potential of digital signal processing nowadays, and without data converters, it would not be possible to have devices such as digital audio and video broadcast, digital cameras and mobile phones. Usually, the converters employed in those applications have a linear scale, and for most applications that is the proper choice, however, for some applications, a nonlinear conversion scale may be more appropriate.

The work presented in this book belongs to the scientific area of analog-to-digital signal conversion and presents a novel logarithmic conversion architecture based on cross-coupled inverter. An overview of the current state of the art of logarithmic converters is given where most conventional logarithmic analog-to-digital converter architectures are derived or adapted from linear analog-to-digital converter architectures; this implies the use of analog building blocks such as amplifiers. The use of such blocks requires additional circuit area and increases the total power consumption. It is also increasingly more difficult to implement these required analog blocks in more advanced technologies due to the decrease of supply voltages, as there is less voltage headroom, in short doing the required analog signal processing in the voltage domain is becoming increasingly difficult. The conversion architecture proposed in this dissertation differs from the conventional logarithmic architectures. There is no requirement to use analog blocks such as amplifiers, and part of the signal processing is done in the time domain. This part of the signal processing is not affected by the reduction in supply voltages and benefits from the advances in integrated circuit manufacturing technologies. The signal conversion from the analog to the time domain is performed by a latched comparator or cross-coupled inverters. While these circuits are usually seen as digital parts, where only obtaining a decision within the allocation time matters, here the time required to reach a decision is the important feature. The study of this voltage-to-time conversion element is presented in this document. All the required blocks to perform the analog-to-digital conversion are almost digital blocks, and their speed and precision should benefit from the advances of integrated circuit manufacturing technologies.

A demonstrator prototype has been designed, simulated, integrated and tested. To test the demonstrator prototype, a fully custom test platform comprising custom test software and printed circuit boards has been developed. The demonstrator prototype achieves a sampling rate of 81.5 MSPS with the full conversion architecture having an estimated figure of merit of 0.0426 pJ/conversion. The direction of future research is also identified and includes work such as integration of calibration in the voltage-to-time conversion element and work on an improved conversion architecture derived from the architecture proposed in this book.

This work is organized into seven chapters. Chapter 1 presents a brief introduction with the motivation and context to develop and propose new data converter topology. Chapter 2 discusses the background and the state of the art of nonlinear A/D converters. Chapter 3 presents and discusses the proposed logarithmic analog-to-digital converter. Chapter 4 describes the design of the voltage-to-time converter. In Chap. 5, the circuit designed and the layout are both validated. Chapter 6 presents and discusses experimental results achieved from an implemented prototype. Finally, in Chap. 7, the conclusions are drawn and possible future research lines are outlined.

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Contents

Abbreviations

ADC	Analog-to-digital converter
ADM	Adaptive delta modulation
ANS-DM	Adaptive nonuniform sampling delta modulation
COTS	Commercial off-the-shelf
CT	Continuous time
DAC	Digital-to-analog converter
DNL	Differential nonlinearity
DT	Discrete time
ENOBs	Effective number of bits
FOM	Figure of merit
INL	Integral nonlinearity
LIDAR	Light detection and ranging
LUT	Lookup table
MOM	Metal-oxide-metal
NS-DM	Nonuniform sampling delta modulation
OSR	Oversampling ratio
PWM	Pulse-width modulation
SAR	Successive approximation register
SNDR	Signal-to-noise dynamic range
SNR	Signal-to-noise ratio
TDC	Time-to-digital converter
TTL	Transistor–transistor logic
USB	Universal serial bus
VCM	Common-mode voltage
VGA	Variable gain amplifier
VTC	Voltage-to-time converter

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Keywords

Logarithmic ADC · Time-to-digital Converter · Cross-Coupled Inverters · Latched Comparator · Logarithmic Voltage-to-Time Converter