

# CHAPTER 1

## Introduction

### 1.1 Introduction

At present, CMOS technologies rapidly captures the digital market, the low cost of fabrication and the possibility of placing both analog and digital circuits on the same chip so as to improve the overall performance and/or to reduce the cost of packaging made CMOS technology attractive. The growing importance of CMOS technology in integrated circuit design has initiated a new wave of design efforts i.e. CMOS gates dissipated power only during switching and required very few devices, two attributes in sharp contrast to their bipolar or GaAs counterparts. Moreover the dimensions of MOS devices could be scaled down more easily than those of other types of transistors and the implementation of analog functions in CMOS technology has become important for the complete integration of system or subsystems in a single VLSI chip.

Therefore, in this thesis, the designs of two new analog integrated circuit building blocks based on CMOS technology are proposed. The themes of this work are designed by using current mirrors as the main structure of the circuits and using the square law characteristic where all MOS transistors are operated in saturation regions. Firstly, a simple integrable circuit technique for the realization of A Wide Bandwidth Current-Mode CMOS True RMS-to-DC Converter is proposed. Secondly, an Electronically and Linearly Tunable CMOS OTA (EOTA) will be presented.

For the first circuit building block, the proposed true RMS-to-DC converter will be discussed. Since one of the important parameters in the measurement of electrical signal is the root mean square value of a signal, which gives the average energy content. The energy content is important in noise measurements, power measurements, and measurements of output signals of sensors. The rms value can be used to describe a variety of signals, such as a dc signal, and also a heavily fluctuating non-periodic signal. Although for periodic signals the rms value can be calculated from the average value, a true rms converter should be suitable for signals of arbitrary shape. A true rms-to-dc converter is an important instrument which is useful in the fields of instrumentation, communication and display systems [1]. In the past, many true rms-to-dc converters that based on a bipolar integrated circuit technology are available [2]-[4]. Their conversion schemes are mostly performed through the use of full-wave rectifiers and

multiplier/divider circuits that employing a log-antilog principle. Due to the bandwidth and the slew-rate of the full-wave rectifiers, the useful frequency ranges of these converters are limited to less than 5 MHz. New design techniques based on bipolar dynamic translinear circuits have been proposed to implement true rms-to-dc converters [5], [6]. Unfortunately, only circuit descriptions are outlined, but the characteristics of the rms-to-dc conversion circuits have not been reported. In addition, their circuits are operated in only one quadrant and also required full-wave rectifiers. Recently, a new design technique for rms-to-dc converter that realizes around a dual translinear-base squarer circuit, where the input current can be a two-quadrant current, is proposed [7]. The circuit exhibits a wide bandwidth because the full-wave rectifier is not required by this conversion scheme. However, the implementation scheme is rather complicate and suitable for implementing only in bipolar technology.

For the second circuit building block, this thesis presents the electronically and linearly tuneable CMOS transconductor. This is because the linear transconductors or voltage-to-current converter circuits are fundamental building blocks of analog circuits and systems. They are found useful in interface circuits, instrumentation amplifiers, continuous-time-filters and oscillators. Furthermore, when the transconductance gain of the transconductor can be electronically varied, they can also be applied in automatic gain control circuits and in analog multipliers. In the last two decades, it is well accepted that a linear transconductor, which is constructed from a bi-polar differential pair and current mirrors, called as an operational transconductance amplifier (OTA), is one of the essential active building blocks in the design of analog circuits [8]-[10]. This is due to the fact that the OTA is a low-cost device that has only a single high-impedance node and its transconductance gain  $g_m$  can be linearly controlled over more than four decades by means of an external bias current. Moreover, the implementation of analog circuits in such a way that employs only OTA as standard cells will not only be easily constructed from readily commercial available IC, but also significantly simplifies the design. In CMOS technology, several linearly tuneable transconductors based on the use of MOS transistors operating in saturation region have been proposed in the literatures [11]-[14]. Most of them are functioning in voltage controlled mode. The method of source-follower of the reference [11] is operated in square law characteristic with constant source-bulk voltages, where the control voltage is applied to the gate. Whereas for the cross coupled connection methods [12]-[14], the transconductance control voltages are applied through voltage level shifters. However, their controllable voltage ranges are rather limited and only narrow linearly tuneable transconductance ranges are available. In some applications, such as,

an analog multiplier circuit, a frequency divider/multiplier circuit and an arbitrary power-law circuit, current controlled transconductors that this transconductance gain can be linearly controllable by a DC bias current are preferable [15]-[17]. In the past, a current controlled CMOS transconductor was presented in [18]. But the linearly tunable transconductance range is narrow due to the MOS transistors are working in the weak-inversion region.

## 1.2 Purpose and objective of the study

In this thesis, the design techniques and implementation methods of the two circuit building blocks in the integrable circuit form based on CMOS technology are presented. The theme of this work are to design by using current mirrors as main structure of the circuits and using the square law characteristic, where all MOS transistors are operated in saturation regions. There are a true RMS-to-DC converter and a linear electronically tunable CMOS OTA (EOTA). Proposed circuits yield the following advantages:

(i) The proposed true RMS-to-DC converter that designed by the use of implicit computation to calculate the RMS value of an input signal, is suitable for all input waveforms. The conversion circuit is simple, suitable for implementing in monolithic integrated form. The circuit exhibits a wide bandwidth because the full-wave rectifier is not required by the proposed realization scheme. Moreover the circuit consumes very low power, due to the bias current of the circuit is provided by the root-mean-square current  $I_{RMS}$ .

(ii) The proposed linear electronically tunable CMOS OTA (EOTA) realization method is achieved by squaring the transconductance gain of the balanced CMOS OTA. Therefore the EOTA transconductance gain can be linearly tuned by an external bias current for three decades. The linear input-voltage range of about 1Vp with less than 1% nonlinearity is obtained. The usefulness of the proposed EOTA is demonstrated through application examples, such as a current multiplier, a linearly voltage-controlled current amplifier and a linearly current-controlled CMOS current amplifier.

### 1.3 Theory or idea used in the research

(i) All of the proposed circuits in this thesis are designed based on the MOS transistor square law characteristic and current mirrors as the main structure of the circuits.

(ii) The implicit computation method is used for the realization of root-mean-square function. The advantage of this technique is that the RMS circuit is not requiring the square-root circuit. The circuit structure is composed of a squaring circuit, current mirrors and a first-order low-pass filter. The circuit is simple that suitable for fabricated in CMOS technology and the wide bandwidth characteristic is achieved.

(iii) The realization method of the proposed electronically and linearly tunable CMOS OTA (EOTA) is achieved by squaring the transconductance gain of the CMOS OTA. For this technique the linear transconductance is computed by squaring the transconductance of a balanced CMOS OTA which the proposed circuit is require 3 balanced CMOS OTA for realize the linear transconductance characteristic.

### 1.4 Dissertation Overview

In chapter 2 the active circuit elements which used for designing the circuit building blocks in this thesis are described in this chapter. The circuit descriptions of the CMOS current mirrors, the CMOS current squaring circuit and the CMOS OTAs are outlined.

Chapter 3 concerning with the design and implementation of CMOS based true RMS-to-DC converter. The circuit description and circuit performance, such as: input dynamic range, conversion errors, frequency response and DC and ripple errors, are described. The implementation of the proposed RMS-to-DC converter by both the discrete circuits by using CMOS CD4007 transistor parameters and the real chip by implementing on 0.5 microns CMOS Technology AMIS process are outlined. The performance of the true RMS-to-DC converter has been studied through simulation and experimental results. In addition, the summary of RMS-to-DC converter characteristics is also included.

In chapter 4 the proposed electronically and linearly tunable CMOS OTA (EOTA) is presented. The circuit description, circuit performances, such as: input dynamic range, conversion errors, frequency response, are described. Moreover a current multiplier circuit, a linearly voltage-

controlled current amplifier and a linearly current-controlled CMOS current amplifier, are illustrated in the application examples. The circuit performances are studied through PSPICE simulation results.

Finally, Chapter 5 concerning with the conclusions and discussions.