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Current-Mode Instrumentation Amplifiers

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Preface

Instrumentation amplifiers (IAs) are among the oldest and most widely used circuits that ensure a weak differential signal amplification in the presence of strong noises and common-mode signals. In the past, IAs were implemented using Op-Amps and resistors. Their major problem is the strict matching requirement between resistors to achieve a high common-mode rejection ratio (CMRR). Another limitation associated with Op-Amp-based IAs is their gain-dependent bandwidth. These weaknesses along with the rapid downscale of CMOS technology with reduced allowed supply voltages have made the Op-Amp-based IAs less attractive. Fortunately, after the emergence of current-mode signal processing, designers took the advantages of current-mode technique to mitigate the problems associated with Op-Amp-based IAs. Compared to conventional voltage-mode signal processing, the new technique showed interesting features such as wide frequency performance, simpler circuitry, low-voltage operation. This new generation of IAs based on current-mode signal processing is known as current-mode instrumentation amplifiers (CMIAs). Although signal processing is performed in current domain, the input and output signals in CMIAs can be current or voltage signals. Therefore, while benefiting from inherent advantages of current-mode signal processing such as low-voltage operation, high-frequency performance, simpler circuitry, CMIAs can cover a wide range of applications. The first CMIA was reported in 1989 by C. Toumazou and F. J. Lidgey, based on supply current sensing technique. This new CMIA utilized two Op-Amps and one resistor. It showed interesting features such as high CMRR without requiring tightly matched resistors and wide bandwidth independent of gain. Later, the famous Wheatstone bridge was also employed and modified to take advantage of current-mode signal processing. The current-mode Wheatstone bridge (CMWB) and mixed-mode Wheatstone bridge were introduced, being capable of operating with current-mode readout circuits. These advances provided the opportunity for nearly all types of sensor readout circuits to benefit from current-mode signal processing. Then, the CMIAs emerged as a rapidly advancing subject, so numerous topologies are found in literature, and new current-mode building blocks were introduced intended for CMIA applications. However, a book entirely and exclusively dedicated to the design of CMIAs is lacking. We decided to write this book to address the need for a guide on CMIA design and applications. It grew out employing the content of published journal and conference papers in the CMIA subject written by researchers all around the world. Our aim is to give an overall knowledge on CMIA design and make the comparison between various structures easier. The operation principle, advantages, and disadvantages of each topology are highlighted. Also, we have classified the reported CMIAs in four categories depending on their input and output signals. This classification simplifies selecting a specific topology for the desired application.

This book is written in nine chapters.

In the first chapter, the general definitions of the common-mode rejection ratio concept in single-ended, fully differential, and cascaded structures are studied. Then, we discuss about the limitations of the conventional Op-Amp-based IAs. The general classification of CMIAs is also developed in this chapter.

In Chap. 2, we cover supply current sensing technique which is the oldest and powerful method used in the design of CMIA. The basic concept and performance analysis of circuits based on this technique are discussed. The first and second generations of CMIAs developed using this technique are reviewed. Then, performance analysis of each generation as well as their limitations is studied. This chapter ends with an interesting comparison between the two generations.

In Chap. 3, we discuss about the Wheatstone bridges. First the fundamentals of conventional voltage-mode Wheatstone bridge (VMWB) and its readout circuits are studied. Then current-mode Wheatstone bridge (CMWB) principle, its readout circuit, and linearization technique are discussed. At the end of this chapter, the mixed-mode Wheatstone bridge principle and readout circuits which are aimed to take the benefits of both voltage-mode and current-mode signal processing are covered.

In Chap. 4, we consider the CMIA topologies designed with current conveyors. As the second-generation current conveyor (CCII) is considered the most famous and widely used current-mode building block, a chapter is solely dedicated to the CCII-based CMIA topologies. These CMIAs include topologies proposed by Wilson, Gift, Khan et al., Galanis and Haritantis, Su and Lidgey, Gkotsis et al., Koli and Halonen, etc. The principles and the effect of CCII's non-idealities on the overall CMRR of each topology are also studied.

In Chap. 5, all CMIA topologies based on various current-mode building blocks are described. These building blocks include operational floating current conveyor (OFCC), current differencing buffered amplifier (CDBA), current feedback operational amplifier (CFOA), operational transresistance amplifier (OTRA), differential difference current conveyor (DDCC), and differential voltage current conveyor (DVCC). The CMIAs studied in this chapter are classified according to their input and output signals.

In Chap. 6, we study CMIA structures with electronically tunable gain feature. Different methods used to achieve electronically tunable gain are discussed. The electronically tunable CMIAs are divided into two groups. In first group, gain is varied by the active building block, while, in second group, electronically variable resistors are used for this purpose.

In Chap. 7, we briefly discuss about the implications (and limitations) caused by mismatches in the CMIAs. Helpful techniques used to reduce the occurrence of mismatches are also reviewed. The chapter is finished by studying a CMIA topology with robust performance against mismatches.

In Chap. 8, we focus on the CMIAs designed for biomedical and low-voltage low-power applications. In particular, design considerations and challenges for biomedical applications are discussed. We study the realization of well-known bootstrapping technique in current-mode domain. Techniques used to improve noise performance of CMIAs are also reviewed. Then, various methods and implementations used to design low-voltage low-power CMIAs are studied.

In the final chapter, the CMIAs intended for sensor applications are reviewed. These include piezo-resistive, differential capacitive, ISFET, pH, and temperature sensors. For each application, background knowledge on the related sensor is given, and then the topology of the used CMIA is studied.

The intended audience for this book includes design engineers, researchers, and students. We tried our best to present each chapter in the simplest form as possible and independent of other chapters, so the readers are able to select and read a single chapter separately, based on their requirement.

We hope that this book will be helpful in inspiring new ideas in CMIA design and applications.

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Contents

Abbreviations

A_0	Open-loop gain
A/D	Analog to digital converter
CMRR	Common-mode rejection ratio
CMIA	Current-mode instrumentation amplifier
CMWB	Current-mode Wheatstone bridge
CCII	Second-generation current conveyor
CDBA	Current differencing buffered amplifier
CFOA	Current feedback operational amplifier
CMOS	Complementary metal oxide semiconductor
COA	Current operational amplifier
CDTA	Current differencing transconductance amplifier
CCCII	Current controlled current conveyor
CCDVCC	Current controlled differential voltage current conveyor
CCCCTA	Current controlled current conveyor transconductance amplifier
BiCMOS	Bipolar complementary metal oxide semiconductor
CDTRA	Current differencing transresistance amplifier
CFDITA	Current follower differential input transconductance amplifier
CMFB	Common-mode feedback
DDCC	Differential difference current conveyor
DVCC	Differential voltage current conveyor
ECG	Electrocardiogram
EEG	Electroencephalogram
ECCII	Electronically current gain controlled second-generation current conveyor
EX-CCCII	Extra-X current controlled current conveyor
FVF	Flipped voltage follower
FF	Flip-Flop
GBW	Gain-bandwidth product
HPF	High-pass filter
IA	Instrumentation amplifier
CNIC	Current negative impedance converter

I-I	Current input-current output
I-V	Current input-voltage output
ISFET	Ion-sensitive field-effect transistor
KVL	Kirchhoff's voltage law
KCL	Kirchhoff's current law
LPF	Low-pass filter
MZC-CDTA	Modified Z copy current differencing transconductance amplifier
MOS	Metal oxide semiconductor
PMOS	P-type metal oxide semiconductor
NFET	Natural FET
OFA	Operational floating amplifier
OFCC	Operational floating current conveyor
Op-Amp	Operational amplifier
OTRA	Operational transresistance amplifier
OC	Operational conveyor
NMOS	N-type metal oxide semiconductor
PSRR	Power supply rejection ratio
VMWB	Voltage-mode Wheatstone bridge
VCII	Second-generation voltage conveyor
V-V	Voltage input-voltage output
V-I	Voltage input-current output
RFET	Reference FET
SI-MO	Single input-multiple output

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