ANALOG CIRCUITS AND SIGNAL PROCESSING

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Current Feedback Operational Amplifiers and Their Applications

Springer

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Preface

In spite of all electronic systems prominently being dominated by digital circuits and systems, the analog circuits have neither become obsolete nor avoidable. In fact, despite the dominance of digital circuits, analog circuits and techniques continue to be indispensable and unavoidable in many areas since all real life signals are analog in nature. Thus, several types of processing of natural signals or interface of such signals with digital processing circuits has to be necessarily carried out by analog circuits. Also, many basic functions such as amplification, rectification, continuous-time filtering, analog-to-digital conversion and digital-to-analog conversion etc. need analog circuits and techniques.

Traditionally, the integrated circuit (IC) op-amp has usually been considered to be the workhorse of all analog circuit designs. However, over the years, it was found that there are many situations such as realization of voltage controlled current sources, current controlled current sources, instrumentation amplifiers, non-inverting integrators and non-inverting differentiators etc., where the traditional voltage mode op-amp (VOA)-based circuits suffer from two drawbacks namely employment of more than the minimum required number of passive components and requirement of perfect matching of several of them (due to which any mismatch may not only deteriorate the performance of the intended circuits but may also lead to instability in some cases). Furthermore, VOA-based amplifiers exhibit a gain bandwidth conflict and their frequency range of operation is limited by the effect of finite gain bandwidth product (GBP) of the op-amps on one hand and due to the slew-induced distortion (resulting due to finite slew rate of the op-amps) on the other hand. Consequently, there has been continuous search for alternative analog circuit building blocks to overcome these difficulties while still matching the versatility of the VOAs in realizing almost all kinds of analog functions.

During the past four decades, many alternative new analog circuit building blocks have been proposed out of which only the Operational Transconductance Amplifiers, Current Conveyors and Current Feedback Operational Amplifiers have been made available as of-the-shelf ICs and have therefore attracted the attention of educators, researchers and circuit designers worldwide who have explored their various applications. Among these building blocks, the current

feedback operational amplifier (CFOA), sometimes also referred as operational trans-impedance amplifier, has received notable attention in literature because of its two very significant properties namely, a very high slew rate (theoretically infinite; practically as high as several thousand volts per μs as against a very modest 0.5 V/μs for the general purpose and most popular μA741 type op-amp) and its capability of offering gain bandwidth decoupling (thereby implying the feasibility of maintaining essentially a constant bandwidth and variable gain, for low to medium values of the gains). Though CFOAs have some limitations as compared to the traditional VOAs, their advantageous features coupled by their versatility and flexibility, particularly of a specific type which has its compensation pin accessible externally, overshadows their demerits in a number of applications.

This monograph is basically concerned with CFOAs and their applications and includes an extensive discussion about various types of CFOAs, the basic circuits realizable using them, their merits and demerits and their applications in the realization of continuous time analog filters, simulation of inductors and other type of impedances, synthesis of sinusoidal oscillators and miscellaneous linear and non-linear applications (including a variety of relaxation oscillators and chaotic circuits). Also covered are numerous examples of the use of CFOAs in realizing a number of other newly proposed active circuit building blocks. The monograph closes by giving a brief account of the recent developments in the design of bipolar and CMOS CFOAs, a discussion about various modified forms of CFOAs proposed in the recent literature from time to time, outlining the current directions of research in this area and including a supplementary list of references for further reading.

It is hoped that this monograph, which contains a comprehensive collection of over 200 CFOA-based analog circuits with their relevant theory and design/performance details, should turn out to be a useful source of reference for academicians (both educators and students), practicing engineers and anybody interested in analog circuit design using CFOAs. Readers may also find a number of interesting and challenging problems worthy of further investigations, from the various suggestions given in the respective chapters of this monograph.

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Acknowledgements

The motivation for writing this book came from the involvement of our research group in writing two short chapters for the Springer monograph *Integrated Circuits for Analog Signal Processing* (edited by Prof E. Tlelo-Cuautle) one of which was related to Current Feedback Operational Amplifiers (CFOA). During the process of writing these chapters, it dawned upon the first author that the topic of CFOAs and their applications deserved a full monograph by itself. Accordingly, a detailed proposal of the present monograph was submitted to Charles Glaser, Senior Editor Engineering, Springer US, who, after getting the proposal reviewed, gave us a go-ahead to prepare the proposed monograph.

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Abbreviations

A/D	Analog-to-digital
ABB	Active building block
AD	Analog devices
ADC	Analog-to-digital convertor
AM	Analog multiplier
BJT	Bipolar junction transistor
BW	Bandwidth
CB	Complementary bipolar
CC	Current conveyor
CCCC-TA	Current controlled current conveyor transconductance amplifier
CC-CFOA	Current controlled current feedback operational amplifier
CCCS	Current-controlled-current-source
CCIII	Third generation current conveyor
CCVS	Current controlled voltage source
CDBA	Current differencing buffered amplifier
CDTA	Current differencing transconductance amplifier
CE	Characteristic equation
CFC	Current feedback conveyor
CFOA	Current feedback operational amplifier
CFTA	Current follower transconductance amplifier
CMOS	Complementary metal oxide semiconductor
CMRR	Common mode rejection ration
CO	Condition of oscillation
CVC	Current voltage conveyor
D/A	Digital-to-analog
DBTA	Differential-input buffered transconductance amplifier
DDA	Differential difference amplifiers
DDCC	Differential difference current conveyor
DDCCFA	Differential difference complimentary current feedback amplifier
DOCC	Dual output current conveyor
DVCC	Differential voltage current conveyor

DVCC+	Differential voltage second generation current conveyor (positive-type)
DVCFA	Differential voltage current feedback amplifier
DVCFOA	Differential voltage current feedback operational amplifier
ECO	Explicit-current-output
ELIN	Externally linear but internally nonlinear
FDCC	Fully-differential current conveyor
FDCCII	Fully differential second generation current conveyor
FDCFOA	Fully differential current feedback operational amplifier
FDNC	Frequency-dependent-negative-conductance
FDNR	Frequency-dependent-negative-resistance
FET	Field effect transistor
FI	Floating inductance or floating impedance
FPBW	Full power band width
FTFN	Four-terminal floating nullor
GBP	Gain bandwidth product
GC	Grounded capacitor
GIC	Generalized impedance converter
GNIC	Generalized negative impedance converter
GNII	Generalized negative impedance inverter
GPIC	Generalized positive impedance converter
GPII	Generalized positive impedance inverter
IC	Integrated circuit
ICC	Inverting current conveyor
MCFOA	Modified current feedback operational amplifier
MTC	Mixed translinear cell
NE	Node equation
NMOS	N-type metal oxide semiconductor
OFC	Operational floating conveyor
OTA	Operational transconductance amplifier
OTRA	Operational trans-resistance amplifier
PMOS	P-type metal oxide semiconductor
SEC	Single element controlled
SR	Slew rate
SRC	Single resistance controlled
SRCO	Single resistance controlled oscillator
TAC	Transconductance and capacitance
THD	Total harmonic distortion
TI	Texas instruments
VCC	Voltage-controlled capacitance
VCCS	Voltage-controlled-current-source
VCFI	Voltage controlled floating impedance
VCL	Voltage controlled inductance
VCO	Voltage controlled oscillator

VCR	Voltage-controlled-resistor
VCVS	Voltage controlled voltage source
VCZ	Voltage-controlled impedance
VD-DIBA	Voltage differencing differential input buffered amplifier
VDTA	Voltage differencing transconductance amplifier
VLF	Very low frequency
VOA	Voltage-mode op-amp
WBO	Wien bridge oscillator