Study of Active Filters Topologies

for

Telecommunications Applications

by

Cristian Andriesei

Technical University of Iaşi, Romania
Faculty of Electronics, Telecommunications and Information Technology

Université de Cergy–Pontoise, France
Ecole Nationale Supérieure de l’Electronique et de ses Applications

Thesis Supervisers

Prof. Liviu GORAŞ
Prof. Farid TEMCAMANI
Prof. Bruno DELACRESSONNIERE

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Cristian Andriesei
B.S Electrical Engineering, Technical University of Iaşi, 2005
M.S Engineering, Technical University of Iaşi, 2006

Thesis Supervisers

Liviu Goraş, Technical University of Iaşi, Romania
Farid Temcamani, Université de Cergy Pontoise, France
Bruno Delacresonnièrre, Université de Cergy Pontoise, France

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In memory of my father

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You see, wire telegraphy is a kind of very, very long cat. You pull his tail in New York and his head is meowing in Los Angeles. Do you understand this? And radio operates exactly the same way: you send signals here; they receive them there. The only difference is that there is no cat.

Albert Einstein, 1879–1955

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ABSTRACT

The scope of this thesis is to propose solutions to improve the performances of the CMOS transistor only simulated inductors (TOSI) aiming RF filtering applications. We are interested in TOSI architectures because they prove better performances than the classical g_m–C filters, being superior with respect to the number of transistors, power consumption, frequency capability and chip area. Furthermore, TOSI architectures have many potential applications in RF design.

In the general context of the multi–standard trend followed by wireless transceivers, TOSI based RF filters may offer the possibility of implementing reconfigurable devices. However, satisfying the telecommunications requirements is not an easy task therefore high order TOSI based filters should be implemented. Consequently, using good second order TOSI cells is a matter of the utmost importance and we propose a novel quality factor tuning principle which offers an almost independent tuning of self resonant frequency and quality factor for simulated inductors. An improved TOSI architecture with increased frequency capability is also reported.

Thesis Supervisors: Liviu Goraş, Farid Temcamani and Bruno Delacressonnière

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This thesis may have been written well enough, had sufficient number of relevant references, transmit interesting ideas and valuable information or maybe not but what this thesis has to prove is the intellectual maturity and design experience I have attained during this doctoral program and mandatory for any research based post doctoral activity (educational research or in industry). Consequently, I express first my acknowledgements to my Romanian adviser, Prof. Liviu Goraş, for his guidance, patience, effort, enthusiasm and support of any kind to create a perfect research climate while conducting the research activity. The same appreciation goes to the French advisers, Mr. Farid Temcamani and Bruno Delacressonnière for their guidance, valuable advices and effort in having this thesis finished.

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Abbreviations and Symbols

1G	First Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
4G	Fourth Generation
AC	Alternating current
ADC	Analog–to–Digital Converter
AES	Advanced Encryption Standard
AM	Amplitude Modulation
AMPS	Advanced Mobile Phone System
ASIC	Application–Specific Integrated Circuit
BAW	Bulk Acoustic Wave
BB	Baseband
BiCMOS	Bipolar CMOS
BOK	Bi–Orthogonal Keying
BPF	Bandpass Filter
BPSK	Bipolar PSK
CCK	Complementary code keying
CCO	Current controlled oscillator
CD	Common Drain
CDMA	Code division multiple access
CG	Common Gate
CMOS	Complementary metal–oxide semiconductor
CS	Common Source
DAC	Digital–to–Analog Converter
DCR	Direct Conversion Receiver
DC	Direct current
DCS	Digital Cellular Service
DECT	Digital Enhanced Cordless Telecommunications
DL	Downlink
DoD	Department of Defense
DPSK	Differential PSK
DQPSK	Differential QPSK
DSP	Digital Signal Processor
DSSS	Direct–sequence spread spectrum
EDGE	Enhanced Data rates for GSM Evolution
EGSM	Extended GSM
ESA	European Space Agency
ETACS	Extended Total Access Communication System
FCC	Federal Communications Commission
FDD	Frequency–division duplexing
FDMA	Frequency division multiple access
FDNR	Frequency Dependent Negative Resistance
FET	Field–effect transistor
FHSS	Frequency–Hopping Spread Spectrum
FM	Frequency Modulation
FPGA	Field–Programmable Gate Array
FSK	Frequency–Shift Keying

GaAs	Gallium arsenide
GFSK	Gaussian Frequency–Shift Keying
GIC	General Impedance Converter
GLONASS	Global Navigation Satellite System
GMSK	Gaussian MSK
GNSS	Global Navigation Satellite Systems
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global Systems for Mobile Communications
HPSK	Hybrid PSK
HSDPA	High–Speed Downlink Packet Access (3.5G)
IEEE	Institute of Electrical and Electronics Engineers
IM3	Third–Order Inter–Modulation
IMEC	Interuniversity Microelectronics Centre
IIP2	Second–order Intermodulation Intercept Point
IIP3	Third–order Input Intercept Point
	Third–order Intermodulation Intercept Point
IP3	Third–order Intercept Point
IF	Intermediate Frequency
IMT2000	International Mobile Telecommunications–2000
IS–95	Interim Standard 95 (cdmaOne)
ISM	Industrial, Scientific, and Medical
LAN	Local area network
LNA	Low noise amplifier
LO	Local Oscillator
M–BOK	M-ary BOK
MEMS	Micro–Electro–Mechanical Systems
MESFET	Metal Semiconductor FET
MIMO	Multiple-Input, Multiple-Output
MMIC	Monolithic Microwave Integrated Circuits
NF	Noise Figure
NIC	Negative Impedance Converter
NMOS	n-channel MOSFET
NMT	Nordic Mobile Telephony
NRZ	Non–return–to–zero
OFDM	Orthogonal frequency–division multiplexing
OFDMA	Orthogonal Frequency–Division Multiple Access
OQPSK	Offset QPSK
OTA	Operational Transconductance Amplifier
PA	Power Amplifier
PCS	Personal Communications System
PDC	Personal Digital Cellular
PMOS	p-channel MOSFET
PSK	Phase Shift Keying
QAM	Quadrature amplitude modulation
QPSK	Quadrature Phase Shift Keying
Rx	Receiver
SAW	Surface Acoustic Wave
SDD-AI	SourceDegenerated Differential Active Inductor

SDR	Software defined radio
SiGe	Silicon–germanium
SMR	Specialized mobile radio
SNR	Signal–to–noise ratio
TACS	Total Access Communication System
TAI	Tunable Active Inductor
TDD	Time Division Duplexing
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
THD	Total Harmonic Distorsion
TOI	Third–order Intercept Point
TOSI	Transistor only simulated inductor
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UWB	Ultra Wide Band
VCO	Voltage–controlled oscillator
VHF	Very High Frequency (30 MHz–300 MHz)
WCDMA	Wideband CDMA
WiMAX	Worldwide Interoperatibility for Microwave Access
WLAN	Wireless Local Area Network
WPAN	Wireless personal area network
WWiSE	World Wide Spectrum Efficiency

1. INTRODUCTION

1.1 Motivation

The telecommunications market requirements and continuous technology development impose a continuous research for both baseband and RF transceiver sides. During the last three decades, telecommunications transceivers evolved from entirely analog 1G terminals (AM and FM transmitters) to multistandard wireless devices with mixed digital baseband – analog front–end parts, the fourth generation (4G) being expected. On the transceiver side, the filtering part (active and passive) had an important contribution to the transceiver reconfigurability and smaller size. However, if the analog baseband filtering does not impose problems in implementing reconfigurable terminals, the RF passive filtering still represents a challenge. Thus, the surface acoustic wave (SAW) RF filters used in any wireless transceiver are external, bulky and offer no frequency tuning opportunity therefore, decreasing the customer satisfaction degree against size and device portability. Although SAW filters are cheap, the final cost for a multi–standard terminal is greatly increased since at least 8 such filters are used for different filtering operations. Many passive (MEMS), pseudo–passive (Q–enhanced LC) and active (g_m–C) solutions have been proposed until now in literature but no one can beat the excellent frequency performances offered by the SAW filters. A promising small size, low power entirely active implementation makes use of transistor only simulated inductors (TOSI) which have the main benefit of being reconfigurable devices. These architectures are addressed in this research.

1.2 Thesis Outline

The content of this thesis, presented in a very concise form, covers three different topics as follows.

Since filtering in telecommunications is envisaged, Chapter 2 is entirely dedicated to the telecommunications field. The first section is a brief description at basic level (due to size constraints) of telecommunications standards, covering frequencies up to 5 GHz. The interest in this regard are the frequency allocation and attenuation requirements for particular applications since these represent key aspects for the RF filtering design. Other standard specifications regard different transceiver blocks, like the modulation scheme which becomes important for the power amplifier design but also the low noise amplifier. An overview of the wireless transceiver architectures is presented in the second section. Since hundreds of papers and tens of books have been reported in literature covering the transceiver architectures and design, an overview of RF transceivers is beyond the scope of this thesis. Only a concise, clear and up to date review of RF transceivers in a form that synthesizes the relevant information from a great number of sources but also describe the current multi–standard trend is given.

Chapter 3 covers the gyrator concept and is intended to be a ‘state of the art’ regarding the concept of ‘transistor only simulated inductor’. All TOSI architectures reported in literature and mentioned in this thesis envisage applications in the GHz range thanks to their frequency capability. These capacitorless simulated inductors represent promising architectures for RF filtering applications and not only, since their successful use in implementing CCOs, LNAs and bandpass amplifiers has been reported in literature.

A more detailed insight into CMOS simulated inductors is provided in Chapter 4 where the TOSI frequency behavior is addressed. The main contributions for this research are presented in this final chapter.

A final conclusion is drawn at the end of this thesis in Chapter 5.