Biopotential Readout Front-End Circuits using Frequency-Translation Filtering Techniques

by

MA CHON TENG (WILSON)

(M-A8-6547-3)

Master of Science (M.Sc.)

in

Electrical and Electronics Engineering

2010

Faculty of Science and Technology
University of Macau

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A thesis submitted in fulfillment of the
requirements for the degree of

Master of Science
in
Electrical and Electronics Engineering

Faculty of Science and Technology
University of Macau

2010

Approved by: _____

Supervisor: Dr. Mak Pui In

_____

Co-Supervisor: Dr. Mang-I Vai

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Date: _____

Abstract

Measuring bio-potential signals, such as Electroencephalogram (EEG), Electrocardiogram (ECG), and Electromyogram (EMG) against various contaminating signals in portable biomedical monitoring systems is of great challenge in minimizing the power consumption while maintaining a high performance. This thesis investigates the most critical component in the biopotential acquisition system: the **readout front-end (RFE)** for obtaining high quality biopotential signal.

The first section is the introduction of the AC couple chopped instrumentation amplifier (ACCIA), which is improved from the conventional current feedback instrumentation amplifier by applying AC-coupling and chopper stabilization techniques. Thus, it is capable of filtering the differential DC electrode offset between the biopotential electrodes, and achieving low-noise and high-CMRR.

The second section will describe two different function filter designs that are befitted to the ACCIA. The first one is the powerline notch filter for rejecting the powerline interference. Capacitor area for realizing the notch's time constant is reduced by 1000 times compare to direct circuit method by utilizing the frequency-translation property of the chopper stabilization, which has been the technique of flicker-noise reduction, but is now extended to reject also the powerline interference fully within the ACCIA. Secondly, a chopper-stabilized response-translating lowpass filter (RT-LPF) is proposed, which can achieve an ultra-low cutoff down to 1.4-Hz. Similarly, it spreads the frequency-translation property to translate the bandpass filter characteristic to perform lowpass filtering. The implementation is further optimized by using a power-and-area-efficient Nauta cell as the operational transconductance amplifier (OTA). Simulation results show that the RT-LPF achieves 1.4-to-15-Hz cutoff tuning, –40-dB/decade stopband attenuation with low power consumption.

The final section presents the entire design of the RFE. The front stage ACCIA is improved by applying the 50/60-Hz powerline notch filter and the thin- and thick-oxide transistors selection technique. Following the ACCIA there is a spike filter, which is clocked accurately to suppress the chopping spikes. In the last stage, there is a gain-BW-controllable amplifier, which further boosts the gain and enables different biopotential signal measurements through simple logic controls. Simulation results showed that the RFE can successfully eliminate the differential electrode offset up to ±50 mV, while achieving 140-dB CMRR and 51.4-nV/√Hz input-referred noise spectral density. The entire RFE consumes 35.5-μA in 3-V when the powerline notch filter is activated, which can rejects the powerline interference for more than 40-dB.

Acknowledgments

Firstly, I would like to acknowledge my honorable supervisor Dr. Pui-In Mak and co-supervisor Dr. Mang-I Vai for their great support and guidance during the courses of my B. Sc and M. Sc. studies at UM. I wish to express my gratitude to them for leading me to this most challenge biomedical and microelectronic area. And I acknowledge Dr. Peng-Un Mak for being my oral defense examiner. Also, I specially thank Prof. R. P. Martins, Dr. Wan Feng, Mr. Sio-Hang Pun and Dr. R. F. Yazicioglu for their valuable discussion.

In addition, I am very grateful to my colleagues in Analog and Mixed Signals VLSI and Biomedical Engineering Laboratory: Dr. Sai-Weng Sin, Mr. U-Fat Chio, Mr. He-Gong Wei, Ms. Yan Zhu, Mr. Kim-Fai Wong, Mr. Ka-Fai Un, Mr. Li Ding, Mr. Chi-Hang Chan, Mr. Hou-Lon Choi, Mr. Si-Seng Wong, Mr. Jin-Tao Li, Mr. Chio-In Ieong, Mr. Pedro Antonio Mou, Mr. Chang-Hao Chen and Mr. Tan-Tan Zhang for the fruitful collaboration we had during the design of this project. Furthermore, I would like to thank Mr. Fan Ng for his technical support.

Finally, I would like to give my thanks to my dearest parents and girlfriend for their supports and understandings in these years.

This work is partly funded by the University of Macau Research Committee and the Macau Science and Technology Development Fund (FDCT).

Chon-Teng Ma (Wilson)

June 2010

Symbols and Abbreviations

β	Loop gain
1/f	Flicker noise
A	Open loop gain
A_v	Close loop gain
A_{CM}	Common-mode voltage gain of an op-amp
A_{DM}	Differential-mode voltage gain of an op-amp
C	Capacitance
C_{ext}	External Capacitor
C_{ox}	Gate oxide capacitance per unit area
f	Frequency
$f_{c,1/f}$	Flicker noise corner frequency
f_{center}	Center frequency
f_{chop}	Chopper frequency
$f_{stopband}$	Rejection bandwidth
f_{HP}	High-pass cut-off frequency
f_{LP}	Low-pass cut-off frequency
g	Conductance
g_m	Transconductance
g_{mb}	Body effect transconductance
I_{bias}	Bias currents
I_D	Drain current
k	Boltzmann's coefficient, load capacitance relation, number of stages, error correction coefficient
K_n	Gain factor of n-channel metal oxide semiconductor
K_p	Gain factor of p-channel metal oxide semiconductor
L	Channel length
LC	Product of inductance and capacitance
r_o	Output resistance
R	Resistance
R_{on}	On-resistance
RC	Product of resistance and capacitance
RC	Product of resistance and inductance

T	Temperature / Period
U_T	Thermal voltage
V	Voltage
V_{DD}	Positive supply voltage
V_{ds}	Drain-source voltage
V_{gs}	Gate-source voltage
V_{in}	Input voltage
V_{ref}	Reference voltage
V_{th}	Threshold voltage
$\overline{v_{in,thermal}^2}$	Input-referred thermal noise
$\overline{v_{in,flicker}^2}$	Input-referred flicker noise
W	Channel width
Φ	Phase
AC	Alternating Current
ACCIA	AC couple chopped instrumentation amplifier
ADC	Analog-to-digital converter
BW	Bandwidth
CBIA	Current balancing instrumentation amplifier
CHS	Chopper stabilization technique
CM	Common mode
CMFB	Common mode feedback
CMOS	Complementary metal oxide semiconductor
CMRR	Common mode rejection ratio
CSF	Chopper Spike filter
DC	Direct current
ECG	Electrocardiogram
EEG	Electroencephalogram
EMG	Electromyogram
FFT	Fast Fourier transform
GM	Transconductance
GBW	Gain bandwidth
HPF	High-pass filter
IA	Instrumentation amplifier
ISSCC	International Solid-State Circuits Conference
JSSC	Journal of Solid-State Circuits
LPF	Low-pass filter

NEF	Noise efficiency factor
MOS	Metal oxide semiconductor
NEF	Noise efficiency factor
NMOS	n-channel metal oxide semiconductor
OTA	Operational transconductance amplifier
PMOS	p-channel metal oxide semiconductor
PSD	Power spectral density
PSRR	Power supply rejection ratio
RFE	Readout front-end
RMS	Root mean square
RGC	Regulated cascode current sources
RT-LPF	Response-translating lowpass filter
SC	Switched capacitor
T&H	Track and hold
THD	Total harmonic distortion
VGA	Variable gain amplifier

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