Low power, Low noise Chopper Amplifier for EEG Acquisition

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Outline

Motivation
System Overview
Analog Front End
Digital End
Integration Simulations
Project Management
Conclusion & Future Work

Motivation

Low frequency signals (0.5-150 Hz)
Low amplitude signals (5μV – 100μV)
Noise levels (1μV – 3μV)
Need to separate signal and noise and produce an amplified signal. SOLUTION: Chopper Stabilized Amplifier

Objectives

To design a chopper stabilized amplifier system using the AMI 0.5 μm process. Components of the system include:

- Bias Circuitry
- Input EEG signal and Vref (freq = 150 Hz, 10 μV)
- Chopper modulator with fmod = 2 kHz
- Fully Differential Op-Amp
- Chopper Demodulator
- Low Pass Filter (to separate noise and signal)
- Level Shifter
- Analog-Digital-Converter

CRITERIA: POWER, AREA, PORTABILITY

Motivation

EEG measurements commonly used in medical electronics: Reads scalp electrical activity generated by the brain structures
When brain cells are activated, local current flows are produced
EEG signals are used to:
- Monitor alertness, coma and brain death
- Locate areas of damage/head injury/stroke/tumor
- Monitor human and animal brain development

EEG Acquisition System-Analog Frontend

Chopper Stabilized Amplifier
Level Shifters

Analog Mux
Third Order GMC Filter
Analog Front End: Mux and Mod

- Analog Mux
- Chopper Modulation

Gain = 65 dB
Phase = 69
Power = 113 uW
Input referred noise = 52 nV/√Hz

Analog Front End: Amplifier

Gain = 65 dB
Phase = 69
Power = 113 uW
Input referred noise = 52 nV/√Hz

Analog Front End: Amplifier

Input Referred Noise = 800 nV/√Hz

Input Referred Noise = 59 nV/√Hz

Analog Front End: Demodulator/Filter

GMC Power Consumption = 350 uW

ADC: Comparator

External Clock = 300kHz
Internal Clock = 400kHz
R-DAC

Differential input = 2V

C-DAC

SAR block

Differential input = 2V

Conclusion

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal</th>
<th>Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Consumption</td>
<td>150 µW</td>
<td>112 µW</td>
</tr>
<tr>
<td>CMRR</td>
<td>80 dB</td>
<td>106 dB</td>
</tr>
<tr>
<td>ICMR</td>
<td>-1.3 – 3.3 V</td>
<td></td>
</tr>
<tr>
<td>OCMR</td>
<td>-1.3 – 3.3 V</td>
<td></td>
</tr>
<tr>
<td>PSRR</td>
<td>-48 dB</td>
<td></td>
</tr>
<tr>
<td>Gain Bandwidth</td>
<td>-19 MHz</td>
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</tr>
<tr>
<td>Gain</td>
<td>65 dB</td>
<td>65 dB</td>
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<tr>
<td>Phase Margin</td>
<td>Stable, 69°</td>
<td></td>
</tr>
<tr>
<td>Fchop</td>
<td>2 kHz</td>
<td>2 kHz</td>
</tr>
<tr>
<td>GMC Filter Power</td>
<td>350 µW</td>
<td></td>
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<tr>
<td>ADC, max DNL</td>
<td>1.5 LSB</td>
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<tr>
<td>ADC, Power</td>
<td>250 µW</td>
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Appendix

Bias Circuitry

- Implemented Bandgap reference circuit
- Circuit based on thermal voltage self-biasing topology
- Provides high degree of supply voltage independence

Bias values required:
- 1.65 V for opamp
- 1 V for GMC
- 1.5 V for GMC
- 1.85 V for DAC
- 1.72 V for comparator
Hand Calculations for current sources

\[ I = \frac{V_{in}}{R_{load}} \]

Gain: 80 dB
GBW: 19.51 MHz
Phase: 61.22 degrees

Opamp Characteristics

ICMR: 1.3 – 3.3 V
OCMR: 1.3 – 3.3 V
The value correlate with hand calculations, as per transistor we have a 0.65 V drop for the 0.5 um process

Opamp Characteristics

Common Mode Rejection Ratio: 106 dB

Opamp Characteristics

Power Consumption

Opamp power: 3.3 V x 33.9 uA = 111.87 uW
## Opamp summary

<table>
<thead>
<tr>
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<th>Simulated</th>
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</thead>
<tbody>
<tr>
<td>Power Consumption</td>
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<td>CMRR</td>
<td>80 dB</td>
<td>106 dB</td>
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<tr>
<td>OCIR</td>
<td>1.3 – 3.3 V</td>
<td>1.3 – 3.3 V</td>
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<tr>
<td>Gain Bandwidth</td>
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<td>39 MHz</td>
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<tr>
<td>Gain</td>
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<tr>
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