Simultaneous EEG and Electrode–Skin Impedance Monitoring for Long-Term Ear-EEG

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Abstract

Wearable ear-EEG can enable long-term sleep monitoring at home, but signal quality depends on electrode-skin impedance (ESI). Conventional systems often check impedance only before recording, although ESI can drift during 1-2 hour or overnight recordings. This project proposes a shared-channel TSMC 65 nm CMOS AFE that records EEG and estimates ESI through the same input path for continuous contact-quality monitoring.

Introduction

Longitudinal sleep studies need EEG that is comfortable for repeated or overnight recordings. Scalp-EEG is accurate but uncomfortable and difficult to set up; ear-EEG is less obtrusive and more suitable for home sleep monitoring.

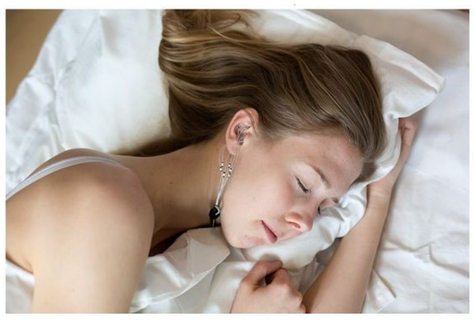
For sleep staging, biomarkers, and artifact rejection, the signal quality must be known during the whole recording. Therefore, EEG and ESI should be measured simultaneously, not only before EEG starts.

Traditional Scalp-EEG



- Uncomfortable
- Difficult to set up

Ear-EEG



- Less obtrusive
- More user-friendly
- More suitable for long-term sleep monitoring

Candidate sleep biomarkers

- **Sleep and pain:** Long-term ear-EEG can reveal how sleep quality, deep sleep, and nighttime awakenings are related to changes in pain levels.
- **MCI and Alzheimer's disease:** Changes in sleep spindles, slow waves, and sleep fragmentation may provide useful biomarkers for early detection and long-term monitoring.

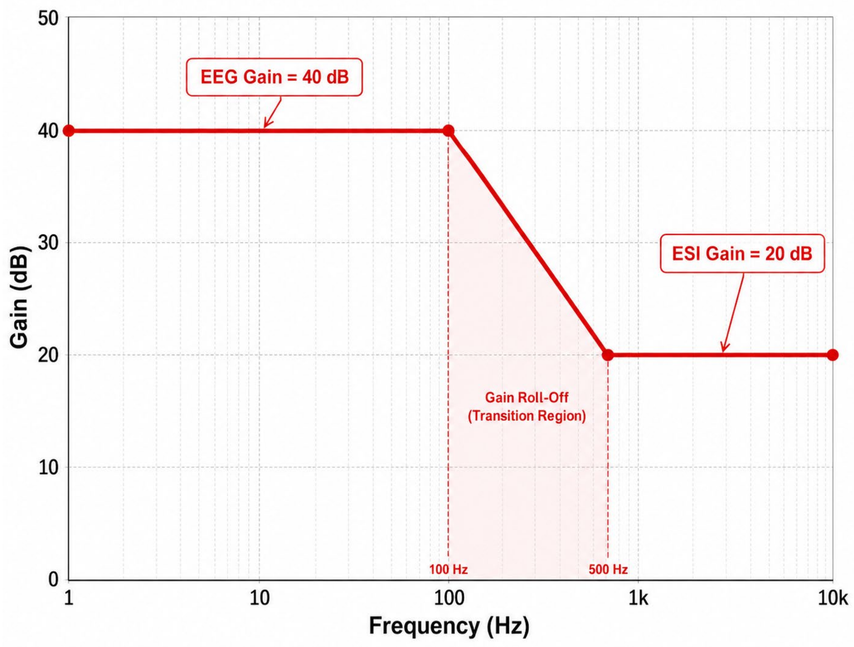
Challenges and Limitations

Why continuous ESI matters:

- ESI changes during sleep due to motion, sweat, skin hydration, and electrode pressure.
- A pre-recording impedance check can miss later contact changes.
- Poor contact can create artifacts larger than the neural EEG signal.
- Artifacts may be confused with true changes in sleep stage or biomarkers.
- Simultaneous EEG + ESI gives a real-time contact-quality marker for each channel.

Frequency-Selective Gain Concept

The same input channel provides high gain for low-frequency EEG and lower gain at the injected-current frequency for ESI estimation. This keeps impedance monitoring aligned with the exact EEG channel being recorded.

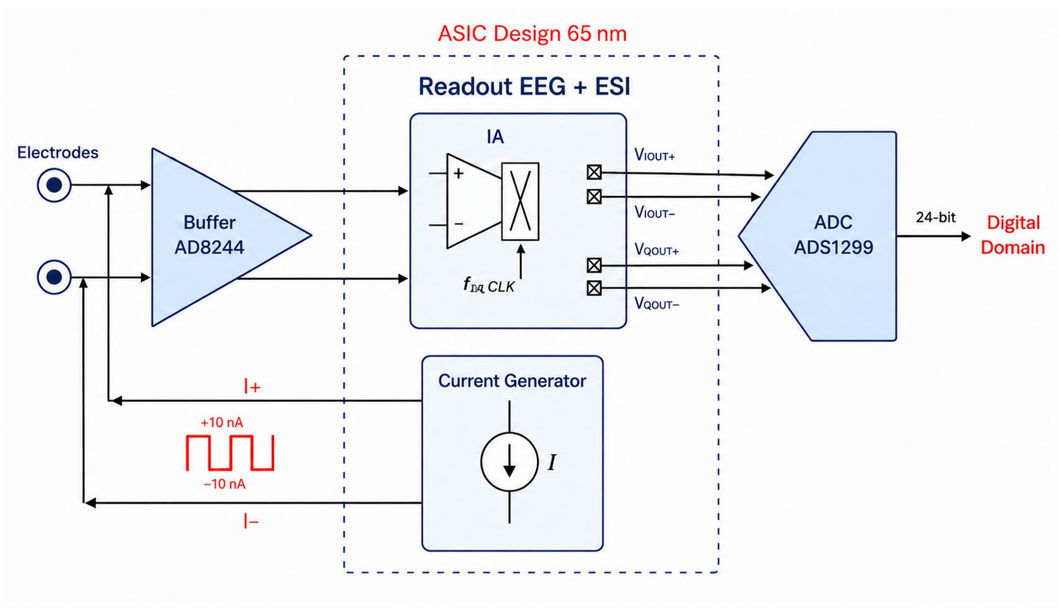


Proposed single-channel gain profile for simultaneous EEG and ESI.

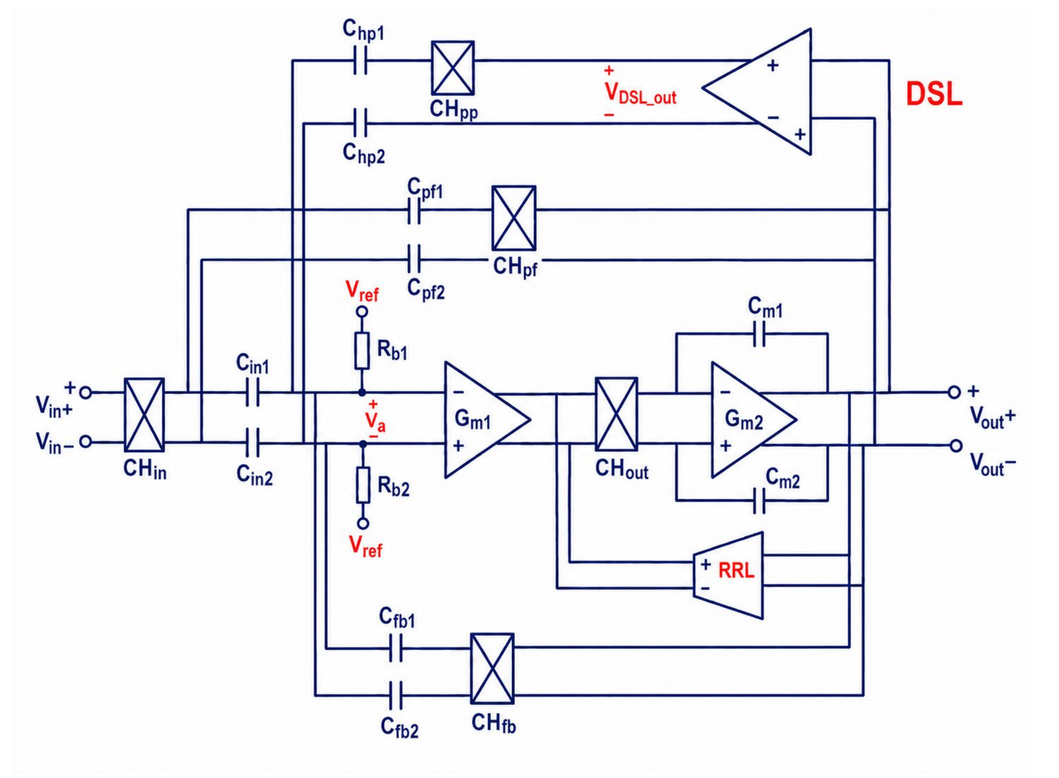
Methods

All circuit layouts have been completed, and the design is currently undergoing post-layout simulation and pre-tapeout verification. The AFE uses the same electrodes and input path for low-frequency EEG acquisition and higher-frequency ESI estimation.

A programmable AC current is injected through the electrode interface. A frequency-selective gain profile keeps high gain for EEG (1-100 Hz) and lower controlled gain at the ESI frequency, preventing saturation while preserving EEG sensitivity.



System-level architecture of the proposed EEG/ESI readout.



Readout EEG + ESI Architecture

Performance Comparison

Comparison between representative low-noise neural/biopotential AFEs, a commercial T&W solution, and the target specifications of this work.

System specs	Das[1]	Luo[2]	Ha[3]	Park[4]	T&W	This Work
IRN (0.5-100 Hz)	1.75 µVrms	0.65 µVrms	0.44 µVrms	0.36 µVrms	0.8 µVrms	**<0.8 µVrms**
Zin @ 50 Hz	400 MΩ	100 MΩ	1 GΩ	2 GΩ	>2 GΩ	**>2 GΩ**
CMRR @ 50 Hz	84 dB	102 dB	N/A	>80 dB	86 dB	**>80 dB**
EOV rejection	N/A	±350 mV	±350 mV	N/A	±250 mV	**±250 mV**
Power / channel	82 µW	105 µW	23 µW	3.8 µW	90 µW	**<20 µW**

Conclusion

The proposed shared-channel architecture enables simultaneous EEG and ESI recording for long-term ear-EEG, allowing electrode-contact changes to be tracked during sleep monitoring and helping distinguish neural activity from contact artifacts. All layouts are now complete, post-layout simulations are in progress, and tape-out is scheduled for **7 July 2026**, followed by chip measurement and validation.

References

[1] V. R. Das et al., low-noise CMOS instrumentation amplifier for low-power biosensors, MWSCAS, 2014.
[2] D. Luo, M. Zhang, and Z. Wang, low-noise chopper amplifier for neural signal acquisition, IEEE JSSC, 2019.
[3] U. Ha et al., EEG-NIRS multimodal SoC for anesthesia depth monitoring, IEEE JSSC, 2018.
[4] Y. Park et al., 3.8-µW chopper-stabilized amplifier with high input impedance, IEEE JSSC, 2022.

Funded by the European Union