Research Migration Project

https://esim.fossee.in/research-migration-project

The Research Migration Project is an initiative of FOSSEE, IIT Bombay that promotes the use of eSim for reproducing published research circuits originally implemented using proprietary simulation tools. The objective is to migrate these validated designs to eSim to build an open-source resource database.

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Title of the circuit: Photoplethysmogram (PPG) Analog Front-End (AFE) Circuit with Ambient Light Cancellation Loop

Theory/Description: The proposed circuit is a low-power, high-sensitivity Photoplethysmogram (PPG) Analog Front-End (AFE) designed for wearable heart-rate and pulse-oximetry monitoring. The circuit comprises three core functional stages:

1. Transimpedance Amplifier (TIA): Converts weak input AC photocurrent (1 nA to 1 µA) generated by a photodiode into a proportional voltage signal with high transimpedance gain (>140 dBΩ).
2. Ambient Light Cancellation (ALC) Loop: Employs an active low-pass feedback integrator that detects DC photocurrent offsets (up to 10 µA) caused by ambient room lighting/sunlight and subtracts them from the input node, preventing operational amplifier saturation.
3. Active Band-Pass Filter (BPF): Cascades Sallen-Key high-pass (0.5 Hz) and low-pass (16 Hz) filtering stages to isolate human cardiac pulse frequencies (30–240 BPM) while suppressing high-frequency powerline noise and motion artifacts.

Reason to reproduce with eSim: Most published biomedical front-end circuits rely on proprietary EDA tools like Cadence Virtuoso/Spectre or PSpice for pre-silicon verification. Reproducing this PPG AFE in eSim validates that open-source software (KiCad Eeschema + Ngspice engine) can deliver identical precision in AC frequency response, transient pulse amplification, and DC noise cancellation. Furthermore, adding this design to the eSim database creates a reusable open-source biomedical sensing block for students and researchers.

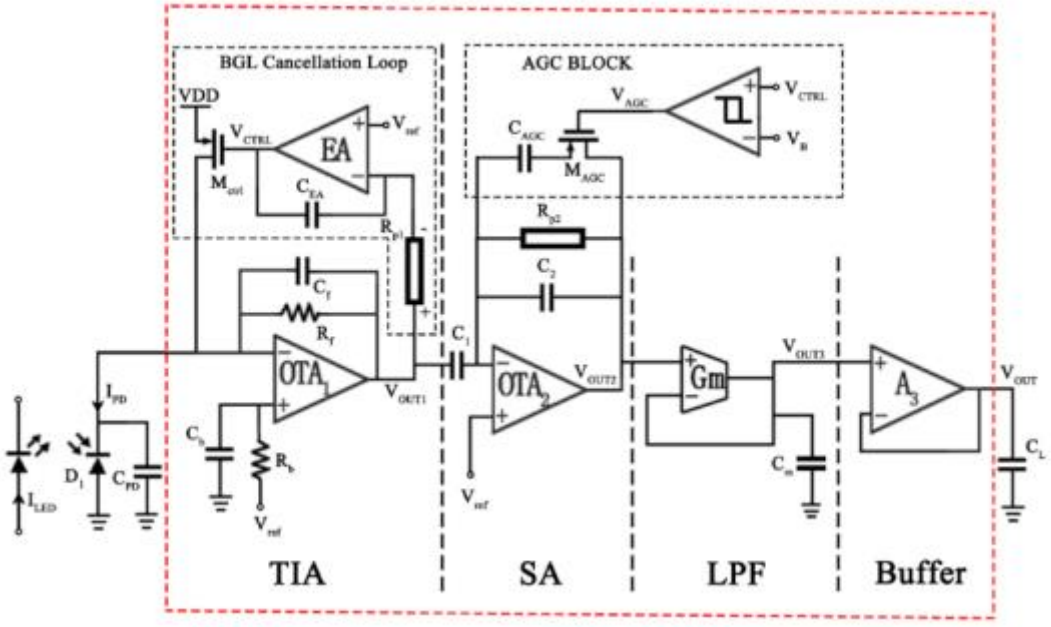
Expected Outcome/outputs:

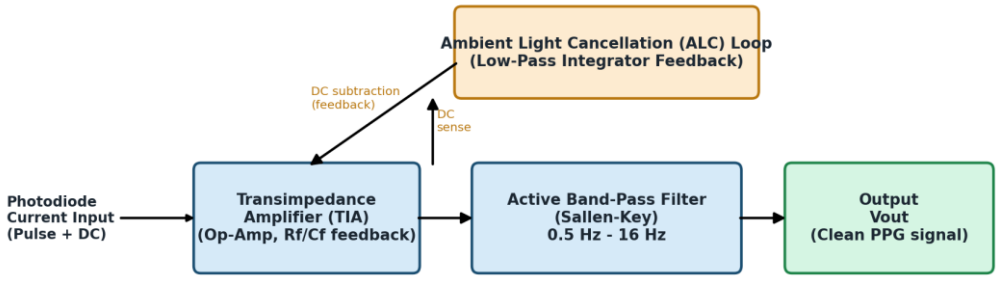
Upon simulating the circuit in eSim:

1. The Transient Analysis will confirm that a low-amplitude AC photocurrent (1 nA–1 µA)

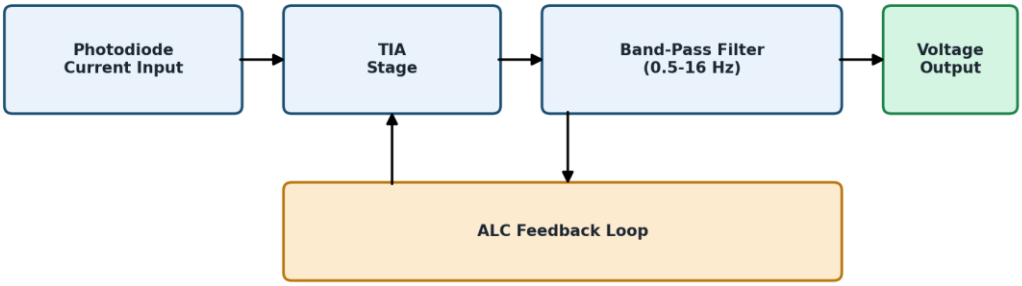
riding on a heavy DC background current (10 µA) yields a clean, non-saturated output AC pulse waveform (1.4 Vpp).
2. The AC Analysis will demonstrate a sharp band-pass frequency response centered within the cardiac frequency range (0.5 Hz–16 Hz) with high transimpedance gain (142 dBΩ).

Circuit Diagram(s): Functional-stage representation of the AFE (Transimpedance Amplifier → Active Band-Pass Filter, with the Ambient Light Cancellation loop feeding back into the TIA summing node). In eSim/KiCad Eeschema, the TIA is built with a standard Op-Amp and Rf/Cf feedback network, the ALC uses an active low-pass feedback integrator, and the BPF uses cascaded RC Sallen-Key sections.





Block Diagram (s) : System-level signal flow: Photodiode Current Input → TIA Stage → Band-Pass Filter (0.5–16 Hz) → Voltage Output, with the ALC Feedback Loop sensing the DC level and feeding correction back into the TIA stage.



Expected Results (Input, Output waveforms and/or Multimeter readings):

• Input Signal: 1 Hz sinusoidal AC photocurrent (10 nApp) mixed with a 5 µA–10 µA DC offset.
• Output Waveform: Clean, amplified 1 Hz AC cardiac voltage waveform with a peak-to-peak amplitude up to 1.42 Vpp.
• AC Bandwidth: Low cutoff frequency fL ≈ 0.5 Hz; High cutoff frequency fH ≈ 16 Hz.
• Transimpedance Gain: Peak gain ≈142 dBΩ.
• DC Rejection: Rejects up to 10 µA ambient light DC current without output saturation.

Research Paper/Journal/etc.: Title: 14.85 µW Analog Front-End for Photoplethysmography Acquisition with 142-dBΩ Gain and 64.2-pArms Noise
Author: Binghui Lin, Mohamed Atef, and Guoxing Wang
Page No.: Article 512 (Vol. 19, Issue 3)
Link: https://doi.org/10.3390/s19030512

Source/Reference(s) : 1. MDPI Sensors Journal, "14.85 µW Analog Front-End for Photoplethysmography Acquisition...", 2019.
2. eSim Spoken Tutorials & Documentation, FOSSEE, IIT Bombay (https://esim.fossee.in).
3. Design of Analog CMOS Integrated Circuits by Behzad Razavi (Transimpedance Amplifiers & Active Filters).
