

ABSTRACT

Title

Photoplethysmogram (PPG) Analog Front-End (AFE) Circuit with Ambient Light Cancellation Loop

Theory / Description

Simulation Software: eSim Version 2.5

Photoplethysmography (PPG) is a non-invasive optical technique used to measure blood volume changes in microvascular tissue. The raw optical response from a photodiode consists of a small AC cardiac signal riding on a $5\mu\text{A}$ DC offset.

This project implements a multi-stage Analog Front-End (AFE) circuit in eSim:

- **Transimpedance Amplifier (TIA) Stage:** Converts the photocurrent input I_1 into an equivalent voltage signal V_{TIA} with a high transresistance gain.
- **High-Pass Filter Network:** Eliminates DC baseline wander using a passive RC network ($C_3 = 100\text{ nF}$, $R_4 = 3.18\text{Meg}$).
- **Gain Stage:** Amplifies the filtered AC cardiac signal to provide a full-scale output (V_{OUT}) suitable for microcontroller ADCs.

Circuit Diagram (When the Current source was used for Transient Analysis, current source parameter was: SINE(5uA 0.05uA 1Hz))

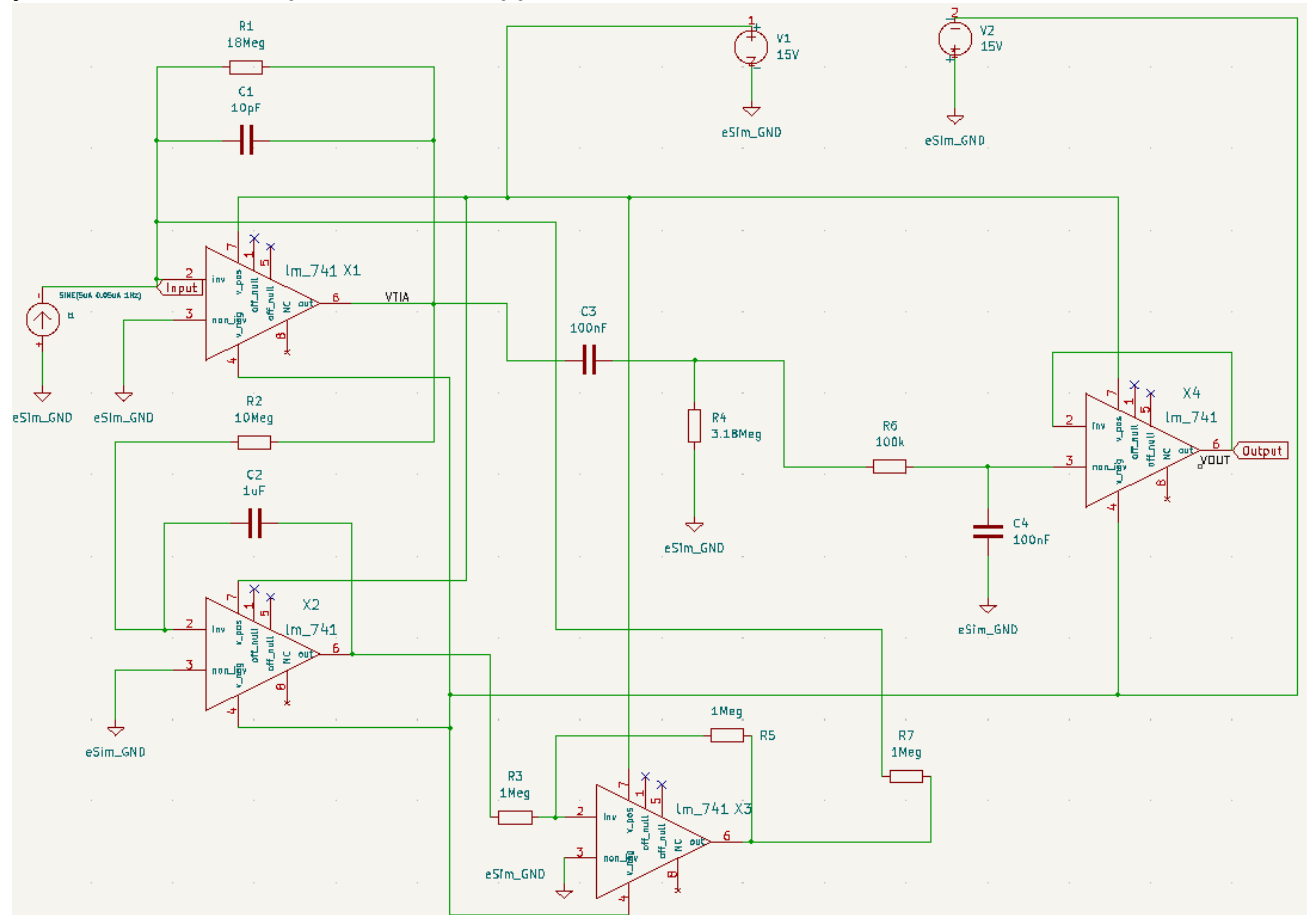


Figure 1: Multi-stage PPG Analog Front-End schematic implemented in eSim, featuring TIA stage, active DC cancellation, and output gain stage.

Alternatively for AC analysis for Frequency response was done for Current source parameter: SINE(5uA 0.05uA 1Hz) AC 1.

Results / Output

- **Input & Transimpedance Node (V_{IN}):** Demonstrates the converted voltage waveform at the TIA input node proportional to the input AC photocurrent riding on the DC offset.
- **Filter & Stage Output (V_{OUT}):** Produces a phase-inverted, amplified output signal demonstrating a peak-to-peak swing of $0.86 V_{PP}$ (ranging from +20 mV down to -800 mV) across a 5s transient analysis.
- **Frequency Response (Bode Plot):** Demonstrates an active band-pass characteristic with peak transimpedance gain ($\sim 139 \text{ dB}\Omega$) around the 1 Hz cardiac target frequency, rolling off below 0.5 Hz to eliminate DC drift and above 16 Hz to suppress high-frequency noise

The following plots illustrate the Input Node Voltage and Output Voltage during transient analysis, followed by the frequency response plot obtained from AC analysis.

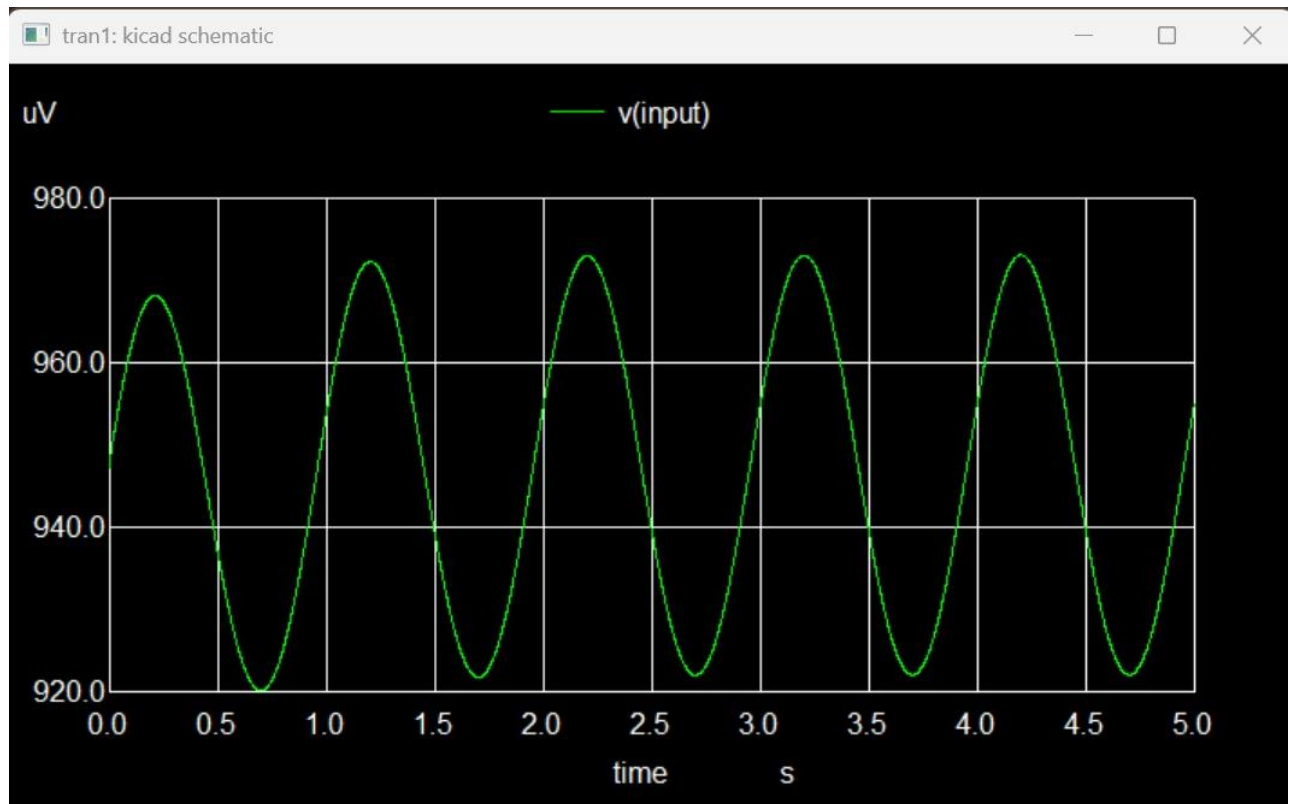


Figure 2: Transient analysis waveform at input node (V_{IN}).

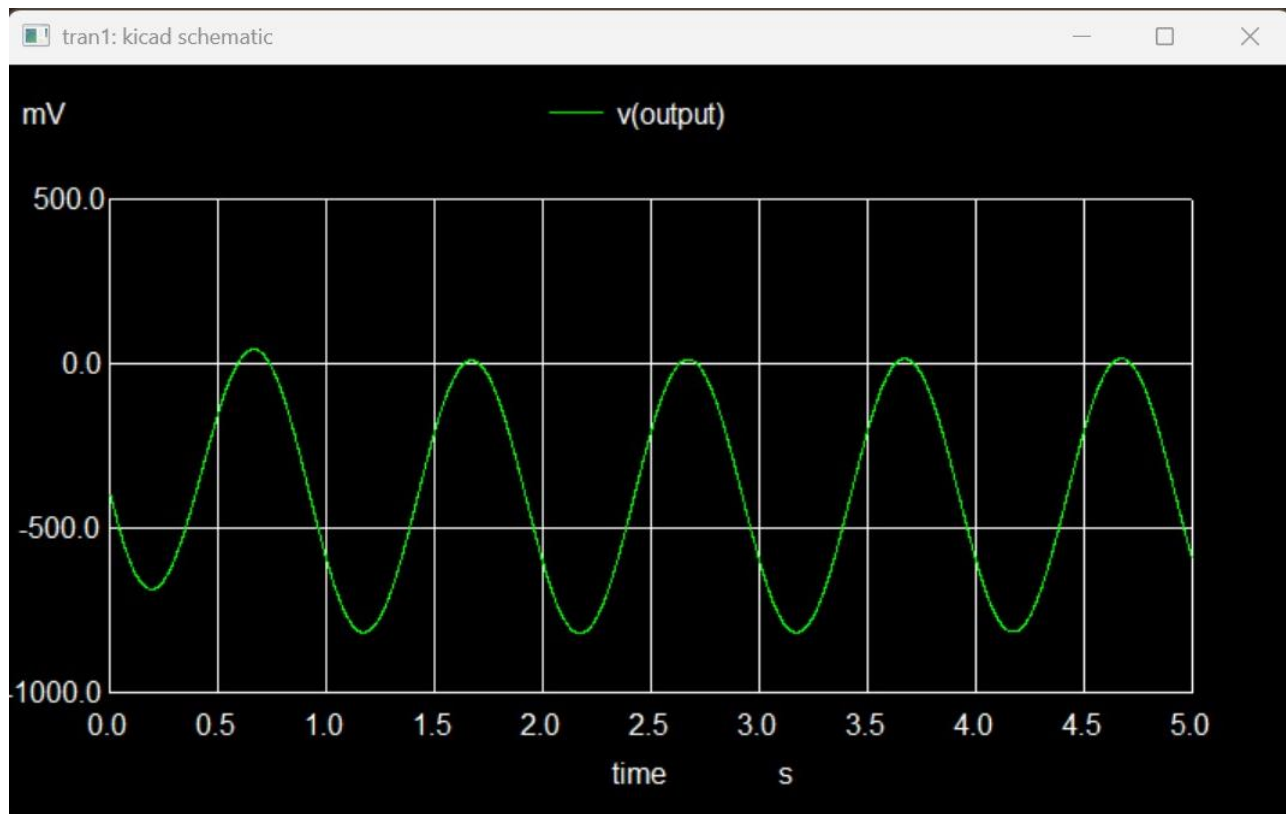


Figure 3: Transient analysis waveform at output node (V_{OUT}) showing 1.42 V_{pp} swing.

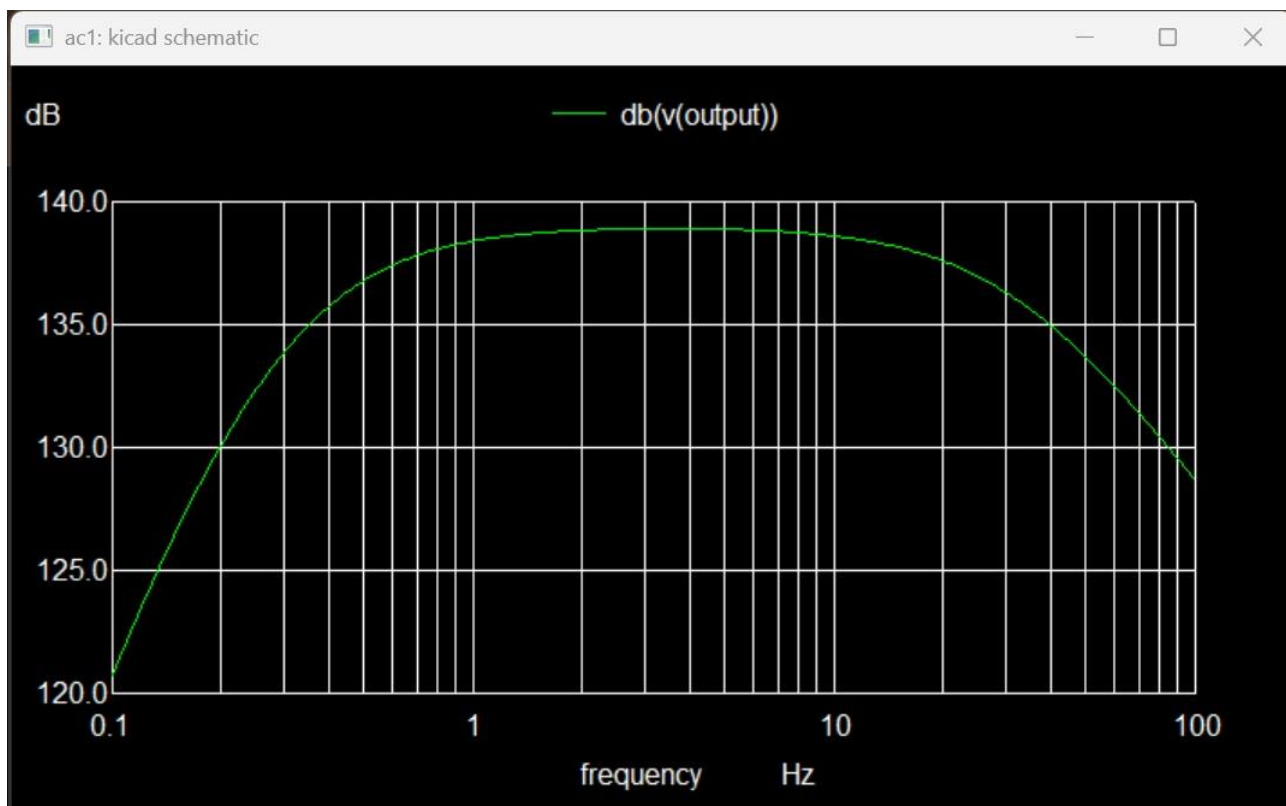


Figure 4: Bode magnitude plot illustrating 139 dBΩ peak transimpedance gain and band-pass profile.

References

1. eSim Open Source EDA Tool, FOSSEE, IIT Bombay.
2. John G. Webster, *Design of Cardiac Pacemakers*, IEEE Press, 1995.
3. Texas Instruments, *Analog Front-End Design for Pulse Oximeter Applications*, Application Report.
4. B. Lin, M. Atef, and G. Wang, "14.85 μW Analog Front-End for Photoplethysmography Acquisition with 142-dB Ω Gain and 64.2-pA_{rms} Noise," *Sensors*, vol. 19, no. 3, p. 512, Jan. 2019