Circuit Simulation Project

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Title of the circuit: Design and Simulation of a Programmable Transimpedance Amplifier Using eSim

Theory/Description: Transimpedance Amplifiers (TIAs) form the core of optical receivers and LiDAR front-ends, where they convert extremely small photodiode currents into usable voltage signals. A key limitation of conventional fixed-gain TIAs is their inability to handle the wide dynamic range of input optical power—they either saturate on strong signals or fail to resolve weak ones. This project proposes the design and simulation of a Digitally Programmable Variable-Gain TIA to overcome this constraint.

The circuit employs a high-speed operational amplifier with a switched feedback network. Instead of a single feedback resistor, the design uses multiple parallel branches, each composed of a resistor R_n and a MOSFET switch. Digital control signals selectively enable these branches, dynamically adjusting the effective transimpedance gain according to

$$V_{out} = -I_{in} \times R_F.$$

This allows the TIA to maintain sensitivity across varying optical input levels without compromising output linearity.

A major focus of the simulation is stability analysis. The photodiode's parasitic capacitance C_{PD}, combined with large feedback resistances, introduces a pole in the loop response that can cause oscillations. To ensure stability, appropriate compensation capacitors C_F are calculated and placed in the feedback path to introduce a zero that counteracts this pole. A Butterworth-type response is targeted using the approximation:

$$C_F \approx \sqrt{\frac{C_{PD}}{2\pi \cdot GBP \cdot R_F}}.$$

The final simulation set includes transient analysis for photocurrent pulses, AC analysis for stability and bandwidth verification, and gain-bandwidth characterization across multiple

digital gain settings. Results will highlight the fundamental trade-off in TIAs: higher gain provides better sensitivity but reduces bandwidth. This validates the effectiveness of the programmable TIA architecture in handling wide dynamic-range photodiode signals.

Circuit Diagram(s):
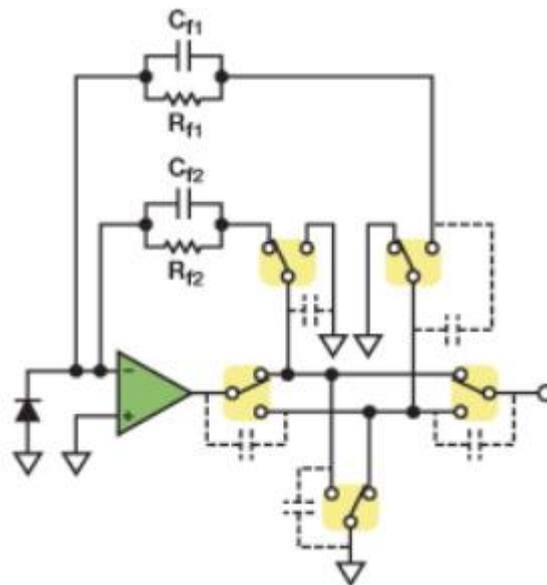
Programmable TIA with SPDT switches.

Results: The simulation results will primarily highlight the transient behaviour of the TIA, showing that the output voltage V_{out} accurately follows the applied photocurrent pulses. The transient plots will clearly illustrate the dynamic gain switching, as digital control signals activate different feedback branches (R_{Low} vs. R_{High}), resulting in distinct output amplitude levels.

Stability verification will be confirmed through a critically damped step response characterized by minimal overshoot and the complete absence of ringing. This behaviour validates the correct selection of compensation capacitors C_F, demonstrating their effectiveness in counteracting the photodiode's parasitic capacitance C_{PD}.

Additionally, AC analysis will verify the expected gain bandwidth trade-off, where higher feedback resistance produces increased gain but a lower 3dB cutoff frequency. The resulting Bode plots will align with theoretical predictions, confirming the inverse proportionality between transimpedance gain and bandwidth.

Source/Reference(s):

1. L. Orozco, "Programmable-Gain Transimpedance Amplifiers Maximize Dynamic Range in Spectroscopy Systems," *Analog Dialogue*, vol. 47, no. 5, May 2013. [Online]. Available: Analog Devices.
2. Texas Instruments, "Transimpedance Considerations for High-Speed Amplifiers," Application Note SBOA122, Nov. 2009.