Constant-bandwidth adaptive transimpedance amplifier

M.T. Sanz, J.M. García del Pozo, S. Celma and A. Sarmiento

A new CMOS transimpedance amplifier (TIA) with variable gain for optical fibre communication receivers is presented. The proposed configuration is realised in a low-cost digital 0.35 μm CMOS process fed from a single 1.8 V voltage supply. A 56–68 dBΩ transimpedance gain variation range is attained with 1 GHz bandwidth. The TIA shows 9 pA/$\sqrt{}$Hz input-referred spectral noise and only 6.9 mW power consumption.

Introduction: The high reliability and low cost of CMOS processes, as well as the possibility of integrating the optical receiver in a single chip, have led to extensive research into CMOS transimpedance amplifiers (TIAs). Cost-sensitive fibre-optic applications require high data transmission rates, e.g. 1.25 Gbit/s for Gigabit Ethernet 1000Base SX/LX. The dynamic range of TIAs can be extended by using adaptive transimpedance, but stability remains a concern [1]. In [2] a method to improve control of stability and bandwidth was reported. Here we propose a new structure which adapts the scheme in [2] from the Infrared Data Association (IrDA) standard to optical Gigabit Ethernet applications. The three-stage single-ended configuration in our proposal allows for a lower supply voltage (1.8 V against 3 V) and higher bit rates (1.25 Gbit/s against 100 Mbit/s).

Transimpedance amplifier: The proposed variable transimpedance amplifier is shown in Fig. 1. It consists of three stages based on the digital inverter with a second stage local feedback loop and a global shunt-feedback. Both the global and the local feedback loops are implemented with an NMOS transistor operating in the linear region: M_{GF} and M_{LF}, respectively. The gate terminal of these transistors is connected to a variable voltage V_C which controls the overall transimpedance gain without degrading the bandwidth and stability of the TIA.

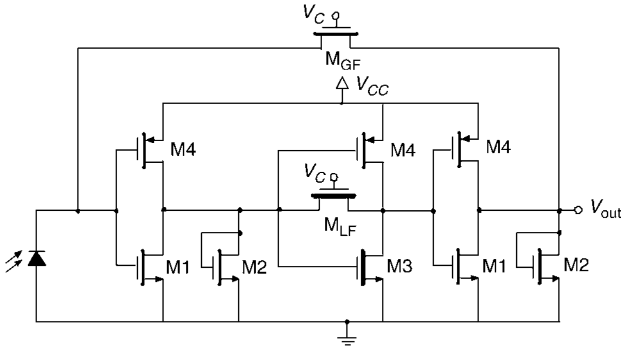

Fig. 1 *Adaptive transimpedance amplifier*

Special care must be taken to ensure the stability of the system, which is directly related to the open-loop gain. In fact, diode-connected transistors must be added to the first and third stage to keep the configuration stable [3]. To hold the common-mode voltage constant throughout the circuit, the width of transistor M3 is chosen to be $W_3 = W_1 + W_2$. Note that self-biasing operation avoids additional biasing circuitry. All inverter outputs exhibit the same voltage, 0.8 V.

The open-loop voltage transfer function of the amplifier is:

$$A(s) \simeq \frac{-g_m^2 r_O(g'_m R_{LF} - 1)}{g'_m + sC_O} \qquad (1)$$

where $g_m = g_{m1} + g_{m4}$, $r_o = 1/g_{m2}$, $g'_m = g_{m3} + g_{m4}$, R_{LF} is the equivalent resistance of M_{LF} and C_o is the dominant internal capacitance.

Assuming $g'_m R_{LF} >> 1$, the transimpedance gain is given by:

$$T_R(s) \simeq \frac{R_{GF} g_m^2 g'_m r_o R_{LF}}{s^2 C_O C_{PD} R_{GF} + s g'_m C_{PD} R_{GF} + g_m^2 g'_m r_o R_{LF}}. \qquad (2)$$

The DC transimpedance, the characteristic frequency and the quality factor are then given by:

$$T_R(s \to 0) \simeq R_{GF}, \quad \omega_o \simeq \sqrt{\frac{g_m^2 g'_m r_o R_{LF}}{C_O C_{PD} R'_{GF}}}, \quad Q \simeq \sqrt{\frac{C_O g_m^2 r_o R_{LF}}{g'_m C_{PD} R_{GF}}} \qquad (3)$$

If changes in R_{GF} are tracked by changes in R_{LF} both the bandwidth and the quality factor of the TIA remain constant, while the transresistance gain is continuously tuned through R_{GF}. Good tracking between R_{GF} and R_{LF} is achieved by using the same gate voltage V_C for transistors M_{LF} and M_{GF}, since both operate with the same drain-source voltage.

Simulation results: The circuit was implemented in a standard 0.35 μm CMOS process and the photodiode was modelled with a total capacitance CPD = 0.5 pF. Fig. 2 illustrates the frequency response of the TIA at $V_C = 1.6$ V and $V_C = 1.8$ V. As shown, a total variation range of 12 dBΩ is achieved with an almost constant bandwidth of 1 GHz. Controlling both feedback loops simultaneously keeps the bandwidth almost constant and prevents excessive peaking. If MFL is not tuned in the same way as M_{FG}, i.e. if no adaptive compensation is used, the transfer function suffers from peaking or from a drastic decrease in bandwidth, as represented by the dashed lines. Fig. 3 shows the eye diagram of the TIA at $V_C = 1.7$ V and 1.5 Gbit/s for $2^{31} - 1$ PRBS, 1 μA input pulse current. Note that a non-return-to-zero (NRZ) modulation format was considered. The eye closure is about 25% and the jitter is 55 ps. Table 1 compares the proposed TIA with previous implementations in CMOS processes. The TIA has an input-referred spectral noise lower than 9 pA/$\sqrt{}$Hz for all the transimpedance gain settings, thus meeting the low noise requirements for optical preamplifiers. It also exhibits the best figure of merit defined as Γ = (Bandwidth × Trasimpedance)/Power. Low-voltage low-power operation is confirmed.

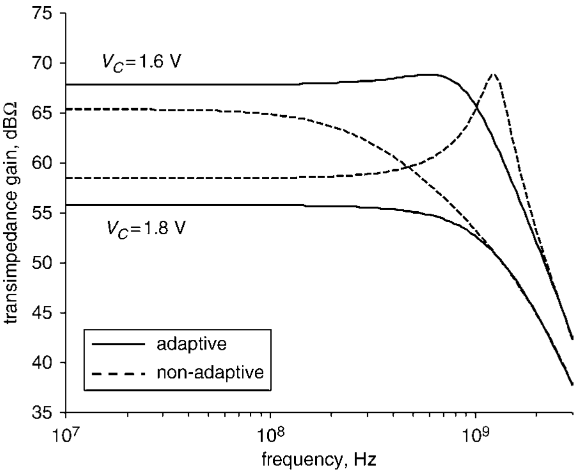

Fig. 2 *Frequency response of TIA at $V_C = 1.6$ V and $V_C = 1.8$ V*

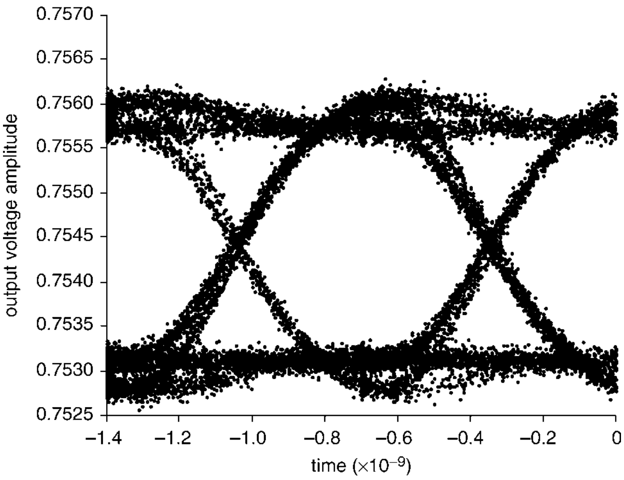

Fig. 3 *Output eye diagram of TIA at 1.5 Gbit/s for $2^{31} - 1$ PRBS, 1 μA input pulse current ($V_C = 1.7$ V)*

Table 1: Performance comparison of proposed TIA with other CMOS implementations

Main performance	[2]	[4]	[5]*	[6]	This work
CMOS process (μm)	0.35	0.6	0.25	0.18	0.35
Supply voltage (V)	3.0	5.0	2.0	1.8	1.8
Power consumption (mW)	8.0	85.0	72.0	43.0	6.9
Transimpedance (dBΩ)	54–86	58	48	57–66	56–68
−3 dB bandwidth (GHz)	0.07	0.95	1.50	2.1	1.00
Bit rate (Gbit/s)	0.1	1.25	2.5	3.0	1.25
Input referred noise (pA/$\sqrt{\text{Hz}}$)	6.7	6.3	9.0	9.8	5.6–9.0
Minimum Γ (GHzΩ/mW)	4.4	8.1	5.2	47.7	89.0
Photodiode capacitance (pF)	5.0	0.5	0.3	0.7	0.5

*TIA and postamplifier

Conclusions: A new transimpedance amplifier suitable for 1.25 Gbit/s optical links is presented. It provides a wide transimpedance variation range at a constant bandwidth and shows an optimal trade-off between power consumption, transimpedance gain and bit rate. Low-power low-voltage operation and low input-referred noise are further advantages of the proposed configuration. Finally, since this structure is process-independent, migration towards deep-submicron technologies could be considered for reaching higher transmission rates.

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