LETTER *Special Section on Analog Circuit and Device Technologies*

A 500-MHz and 60-dBΩ CMOS Transimpedance Amplifier Using the New Feedforward Stabilization Technique

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SUMMARY This paper describes a method of extending the signal frequency bandwidth while increasing the stability of a CMOS transimpedance amplifier (TIA). The TIA consists of three inverting amplifiers in a series, and a high-pass filter plus a non-inverting amplifier that are connected to the last two inverting amplifiers stated above in parallel. The TIA is fabricated using a 0.35 μm CMOS process and realizes stable conversion of 60-dBΩ from the photodiode current to the output voltage with more than 500 MHz of signal frequency bandwidth and 60 mW of power consumption from a 3.3 V supply voltage.

key words: *TIA, feedforward, CMOS, wideband*

1. Introduction

A transimpedance amplifire (TIA) is the key component in optical fiber communication. Its role is to convert the input photodiode current to the output voltage, and therefore, a constant conversion gain over the wide frequency range is needed.

The commonly used circuit topology for the TIA is a common source configuration with a feedback resistor across the input and the output of the TIA [1]. A configuration with multiple stages of amplifiers in a series is preferable to obtain the constant conversion gain, especially in the case of CMOS, because the voltage gain becomes large. However, this causes stability problems when the full feedback is applied by connecting a resistor between the input and output terminals. One way to improve the stability problem is to use a regulated cascode circuit as a first stage of the TIA [2], [3]. This reduces the influence of the input capacitor, however, the TIA's voltage gain remains low because the regulated cascode circuit acts only as a current buffer.

In the present paper, we propose a new feedforward technique to obtain both a sufficient voltage gain and the stability suitable for CMOS implementation. Section 2 introduces the configuration of the proposed TIA. Section 3 shows our experimental results and Sect. 4 concludes this study.

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2. The Feedforward TIA Configuration

The proposed TIA consists of three inverting amplifiers and a high-pass filter plus a non-inverting amplifier as shown in Fig. 1. The input signal current produced by the photodiode (PD) flows into a feedback resistor Rf and is converted into the signal voltage at the output. In contrast to the conventional TIA, the proposed system has two paths, one through the three inverting amplifiers (A1, A2 and A3), and another is the feedforward path which consists of the first stage amplifier A1, a high-pass filter (C4 and R4), plus a non-inverting amplifier A5.

In order to obtain constant transimpedance, the total voltage gain of the three amplifiers shown in Fig. 1 should be large. However, the stability degrades due to the poor phase margin, as can be seen in Fig. 2. Without any phase compensation, the TIA oscillates. The feedforward path in Fig. 1 can have a large voltage gain at high frequencies and

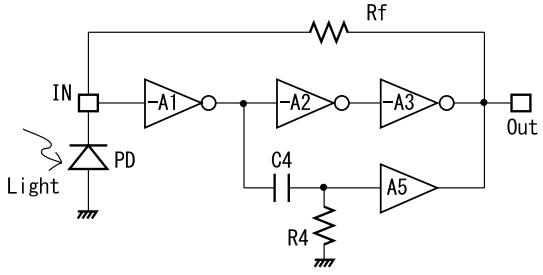

Fig. 1 Block diagram of the proposed TIA.

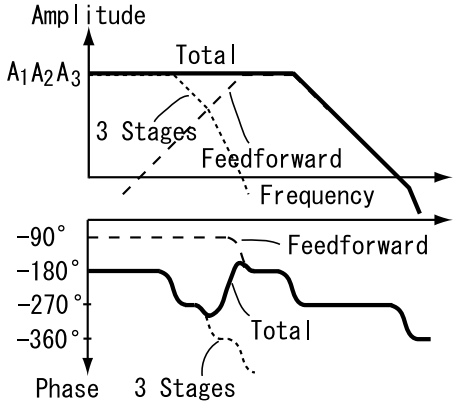

Fig. 2 Voltage gain and phase frequency characteristics of the proposed TIA.

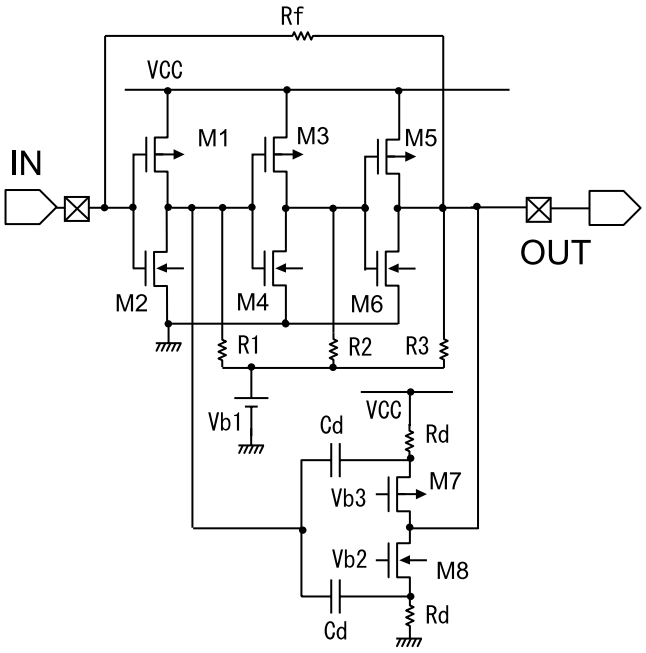

Fig. 3 The complete TIA circuits.

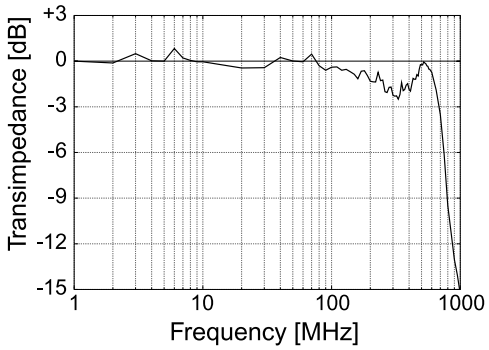

Fig. 4 Frequency characteristics of the transimpedance of the TIA (Transimpedance: 0 dB=60-dBΩ).

a phase leading in 90 degrees in contrast to that of the three inverting amplifiers at low frequencies as seen in Fig. 2. As the voltage gain and the phase of the feedforward path take over those of the three inverting amplifiers at high frequencies, the phase of the TIA is recovered and the TIA becomes stable while keeping the voltage gain high, as seen in Fig. 2.

Figure 3 shows the actual implementation of the TIA shown in Fig. 1. Each of three amplifiers is a CMOS inverter. Each amplifier has a load resistor (R1, R2 or R3), so that each has a moderate voltage gain. The total voltage gain $(-A_1A_2A_3)$ becomes 35 dB when the feedback is applied. The feedforward path consists of two amplifiers and a high-pass filter. A high-pass filter is formed by a capacitor Cd, the parallel connection of a source resistor Rd and a source impedance of a MOS transistor. In high frequency regions, the feedforward path dominates. Although the high-pass filter modifies the voltage gain frequency characteristic of the two amplifiers, it begins to decrease by −40 dB/decade when the signal frequency exceeds the cutoff frequency of the high-pass filter. In order to maintain stability, the voltage gain of the feedforward path should be less than unity at the cutoff frequency of the high-pass filter. In our design, the −3 dB cutoff frequency of the high-pass filter was chosen to be 1.1 GHz. The non-inverting amplifier has a complementary common gate configuration with transistors M7 and M8 where the input signal is applied through the sources of the MOS transistors. The voltage gain of the non-inverting amplifier is 26 dB, and the total voltage gain of the feedforward path becomes 46 dB. In the circuit shown in Fig. 3, the non-inverting amplifier has a high voltage gain, and a large frequency bandwidth for the feedforward path. In order to obtain the stability in the frequency region where the voltage gain of the three-inverting-amplifier and that of the feedforward path become almost equal, the flat part in the voltage gain of the feedfoward path should be larger than the voltage gain of the three-inverting-amplifire at its second pole frequency. Otherwise, the efficient phase compensation is lost. This means that the gain of the feedforward path ($A1A5$) should be larger than that of three-inverting-amplifier ($A1A2A3$).

3. Experimental Results

The circuit in Fig. 3 is fabricated using a 0.35 μm CMOS process. Figure 4 shows the frequency characteristics of the transimpedance of the TIA with a 1 KΩ feedback resistor. The conversion gain is 60-dBΩ, the supply voltage is 3.3 V and the total current consumption is 20 mA. The input is an InGaAs photodiode with a light wavelength of 1550 nm. The output voltage level is measured using a spectrum analyzer. In this system, the light of the laser diode is modulated by the RF signal simply by changing the current flowing through the laser diode. Therefore, the frequency bandwidth of the signal is limited to 500 MHz and the data at frequencies of more than 500 MHz in Fig. 4 should not be considered reliable. However, Fig. 4 shows that the frequency bandwidth of the TIA is more than 500 MHz, that no oscillation is observed, and that the three inverting amplifiers take a dominant role in the frequency characteristics up to 300 MHz while the feedforward path takes over at frequencies of more than 300 MHz. The small dip in Fig. 4 indicates that there is a slight mismatch for the frequency characteristics of the two paths in the TIA. Cutoff frequency variation may occur due to variations in chip processing, however, it is partly possible to compensate for this by adjusting the bias voltages of M7 and M8 because the source resistances of these transistors change.

4. Conclusion

A 500 MHz and 60-dBΩ CMOS transimpedance amplifier was developed using a 0.35 μm process. It was verified that the use of the proposed feedforward path is effective and suitable to form a CMOS TIA.

Acknowledgement

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