4 Transimpedance Amplifier Design

4.1 Introduction

The transimpedance amplifier (TIA) is without a doubt the most critical building block of the optical receiver. It converts the current generated by the photodiode into an output voltage. The design of this block involves many trade-offs between noise, bandwidth, gain and stability. This chapter tries to reveal all subtleties and challenges encountered during the design of low-noise high-bandwidth TIAs.

A summary of the TIA specifications regarding transimpedance gain, bandwidth, noise and overload currents is given in Section 4.2. Section 4.3 tackles the design of a TIA with shunt-shunt feedback. Design equations are derived for the transimpedance gain, bandwidth, open-loop gain, loop gain and the noise performance. Implementations published in open literature are discussed in Section 4.4. Two main topologies are distinguished: the TIA with common-source input stage and the TIA with regulated cascode input stage. Also some interesting work presented at ISSCC is described. Finally, the designs of three different TIAs, of which two are implemented in a 0.18 µm CMOS and one in a 90 nm CMOS technology, are explained more thoroughly in Section 4.5. These case studies clearly demonstrate the compromises to be made during the design of low-noise high-speed TIAs.

4.2 Performance Requirements

This section presents the main performance requirements for a TIA: high transimpedance gain, high bandwidth, low noise and high overload current.

Transimpedance Gain

The transimpedance gain of the TIA, $Z_{TIA}$, is defined as the ratio of the small-signal output voltage to the small-signal input current:
The transimpedance gain is specified either in units of $\Omega$ or $\text{dB}_\Omega$. The value $\text{dB}_\Omega$ is calculated as $20 \cdot \log_{10}(Z_{TIA}/\Omega)$. The transimpedance gain is a complex quantity, with frequency-dependent magnitude $|Z_{TIA}(f)|$ and frequency-dependent phase shift $\theta(f)$. The transimpedance gain at low frequencies is usually flat, and represented by $Z_{TIA,0}$.

The first reason for having a TIA with high gain is to create a signal with an amplitude large enough to drive the post-amplifier (PA). But there is an additional reason which might be even more important: noise. As the TIA is the first stage in the optical receiver (Fig. 2.1), the noise of the next stages like the PA will be suppressed by the TIA gain. So a lower transimpedance gain (for example to obtain a higher bandwidth (4.11)) cannot simply be exchanged for a larger post-amplification. The total gain remains constant, but the total input-referred noise of the receiver will increase.

**Bandwidth**

The upper frequency at which $|Z_{TIA}(f)|$ (4.1) has dropped 3 dB below its DC value, is defined as the TIA bandwidth, $BW_{TIA}$.

As discussed in Section 2.5, a limited bandwidth causes ISI and degrades the opening of the eye diagram. To receive data with a certain bitrate $R_b$, the bandwidth must be as high as possible to minimize the ISI. But on the other hand, Section 4.3.3 will demonstrate that a large bandwidth increases the noise picked up by the TIA. As a compromise between noise and ISI, a TIA bandwidth equal to $0.7R_b$ is commonly used [Raz03, Sâc05].

**Noise**

The input-referred current noise is one of the most critical TIA parameters. Often the noise of the TIA dominates all other noise sources and therefore determines the sensitivity of the receiver. The equivalent input-referred noise current is the current source that, together with the ideal noiseless TIA, reproduces the output noise of the actual noisy TIA. As stated before in Section 2.4.2 it is a fictitious quantity that cannot be observed in the actual circuit.

To determine the input-referred noise current, the noise power spectral density at the output for each noise source is calculated first. Typical noise sources are transistors, resistors and diodes. Assuming these sources are not correlated, they add up to form the total output noise power spectral density. The power spectral density of the input-referred noise current, $\frac{di_n^2}{TIA}$, can then be found by taking the frequency-dependent transimpedance gain into account: