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Post-Amplifier Design

5.1 Introduction

The purpose of the post-amplifier (PA) is to amplify the relatively small signal from the transimpedance amplifier (TIA) to a level sufficient for reliable operation of the clock and data recovery circuit (see also Fig. 2.1). The required swing at the output of the PA is typically several 100 mV peak-to-peak. Two types of PAs can be distinguished: the limiting amplifier (LA) and the automatic gain control (AGC) amplifier. An LA is an amplifier with no special measures to prevent the output signal from clipping or limiting. For very small input signals, the amplifier operates in the linear regime, and the output voltage is proportional to the input voltage. For larger signals, clipping occurs and the output voltage remains constant. An AGC amplifier consists of a variable gain amplifier and an automatic gain control mechanism that keeps the output swing constant over a wide range of input swings. Whereas the LA starts to distort for large input signals, the AGC amplifier reduces its gain and thus manages to stay in the linear regime. Which PA should be used, depends on whether the application allows nonlinear distortion or not. The LA is generally easier to design and its performance is often superior to an AGC amplifier realized in the same technology. On the other hand, the linear transfer function of the AGC amplifier preserves the signal waveform and permits analog signal processing of the output signal. The LA severely distorts the input signal when operating in the limiting regime, causing much of the information in the input to be lost. This chapter deals with the design of the LA. For further information regarding AGC amplifiers for optical communication circuits, the reader is referred to [Rei89, Mol94, Wu04, Sac05, Lia06].

Section 5.2 discusses the main LA specifications, of which the most important are a high gain and a high bandwidth. Next, some recently published LAs are summarized in Section 5.3 together with a short history of the Cherry-Hooper topology. The design of a fully differential LA is addressed in Section 5.4. The optimal number of gain stages for maximal gain-bandwidth is calculated. Design equations for the CMOS Cherry-Hooper stage and the
capacitive source degenerated stage are derived. Also a basic offset compensation scheme is proposed. Finally, Section 5.5 presents two different case studies which analyze the design of respectively a four-stage LA and five-stage LA with offset compensation in 0.18 µm CMOS.

5.2 Performance Requirements

While the TIA specifications determine the primary performance of the optical receiver, such as the sensitivity and the overload limit, the PA specifications have less impact. However, insufficient PA specifications may degrade the overall receiver performance. This section defines the main PA requirements regarding gain, bandwidth, noise, input dynamic range, input offset voltage, input capacitance and jitter.

Gain

Figure 5.1 shows a fully differential PA together with its input and output voltages. The differential input voltage $v_{in}$ is the difference between the two single-ended input voltages $v_{in,p}$ and $v_{in,n}$. Similarly, the differential output voltage $v_{out}$ is the difference between the two single-ended output voltages $v_{out,p}$ and $v_{out,n}$.

The voltage gain of the PA, $A_{PA}$, is defined as the ratio of the small-signal differential output voltage to the small-signal differential input voltage:

$$A_{PA} = \frac{v_{out}}{v_{in}} = |A_{PA}(f)|e^{j\theta(f)}. \quad (5.1)$$

The higher this value, the more output signal is produced for a given input signal. The gain is specified either on a linear scale or in dB. The gain is a complex quantity, with frequency-dependent magnitude $|A(f)|$ and frequency-dependent phase-shift $\theta(f)$. The mid-band gain is usually flat, and represented by $A_{PA,0}$. For amplifiers with differential outputs, the gain can be measured single-endedly ($v_{out,p}$ or $v_{out,n}$) or differentially ($v_{out} = v_{out,p} - v_{out,n}$). It is important to specify in which way the gain is measured, as the differential gain is 6 dB higher than the single-ended gain.