An automatic threshold-converged CMOS optical receiver for high-definition digital audio interfaces

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Abstract: This paper proposes an automatic threshold converged CMOS optical receiver employing a threshold convergence technique to reduce pulse width distortion and design complexity in high-definition digital audio interfaces. A threshold concentrator is introduced at the receiver, in order to improve digital audio quality by aligning various logic thresholds of the input signals into a constant one. Simulation results demonstrate that the designed optical receiver in a 0.18- μm CMOS technology can successfully reduce pulse width distortion within -2% and circuit complexity.

Keywords: threshold convergence, optical receiver, pulse width distortion

Classification: Integrated circuits

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1 Introduction

The intrinsic desire for cost-effective multimedia home-networks has created a tremendous demand for CMOS optical receivers. In these networks, optical receivers for digital audio interfaces should recover data with a wide frequency range and a wide dynamic range, for applying to high-definition digital audio interfaces, such as super-audio compact disc (SACD) and digital video disc (DVD)-audio [1]. Moreover, pulse width distortion (PWD) which directly determines the digital audio quality must be kept low. In addition to PWD, both silicon cost and power consumption also must be kept low because they determine the competitiveness in the market.

An automatic-threshold control (ATC) has been introduced at the receiver to meet these requirements [2, 3]. However, present ATC technique does not thoroughly satisfy the requirements because it suffers from dc-offset and requires reset circuitry [4]. The dc-offset in ATC circuit results in PWD, which in turn increases the bit error rate (BER). Although offset cancellation techniques can reduce the dc-offset, they increase circuit complexity. In addition, ATC technique requires a reset signal internally or externally to discharge the holding capacitor before receiving new data with different power. The generation and application of the reset signal significantly complicates the system design.

In this paper, a CMOS optical receiver employing a threshold convergence method is proposed to reduce PWD and circuit complexity for high-definition digital audio interfaces.

2 Circuit description

Fig. 1 (a) shows a block diagram of the proposed optical receiver, containing a photo detector (PD), a transimpedance amplifier (TIA), a threshold concentrator, a replica bias circuit (reference), and a limiting amplifier (LIA). Since the PD and the TIA generate current and voltage signals with various logic thresholds depending upon the optical wave length and the sender power, direct application of a fixed reference to the LIA results in PWD, especially at high speed as shown in Fig. 1 (b). In order to overcome this problem, a threshold concentrator is introduced at the receiver, which detects input signals with various logic thresholds and generates output signals with a constant one. The threshold convergence technique is similar to an ac-coupling technique, but does not require a huge ac-coupling capacitor to remove dc-components, because it does not block the dc-components of the input signals.

Fig. 2 (a) presents schematic diagrams of the proposed concentrator and the replica bias circuit. In the concentrator, the first stage consisting of transistors M_1 and M_2 performs the extraction process with an equivalent resistor-capacitor (RC) circuit and a level shifter. The voltage averaging in a RC circuit allows the threshold difference of the output signal proportional to the threshold difference of the input signal. Consider the output voltages produced by the RC circuit in response to the two input pulses with differ-

Fig. 1. (a) Proposed optical receiver (b) Raw and aligned data.

ent height of V_{H1} and V_{H2} ($V_{H1} > V_{H2}$) and with a same period as shown in Fig. 2 (b). Since the average voltage of the output signal $V_x(t)$ can be described as

$$V_{x,avg}(t) = \frac{V_x(t_L) + V_x(t_H)}{2}, \quad (1)$$

where $V_x(t_L)$ and $V_x(t_H)$ are the voltages at logic ‘low’ and ‘high’, the RC circuit will provide the following average voltages of the output signals:

$$V_{x1,avg}(t) = \frac{V_{x1}(t_L) + V_{x1}(t_H)}{2} = \frac{V_{H1}}{2}, \quad (2)$$

$$V_{x2,avg}(t) = \frac{V_{x2}(t_L) + V_{x2}(t_H)}{2} = \frac{V_{H2}}{2}. \quad (3)$$

Also, the average voltages of the input signals can be written as

$$V_{i1,avg}(t) = \frac{V_{i1}(t_L) + V_{i1}(t_H)}{2} = \frac{V_{H1}}{2}, \quad (4)$$

$$V_{i2,avg}(t) = \frac{V_{i2}(t_L) + V_{i2}(t_H)}{2} = \frac{V_{H2}}{2}. \quad (5)$$

Using Eqs. (2)-(5), we can write

$$V_{i1,avg}(t) - V_{i2,avg}(t) = V_{x1,avg}(t) - V_{x2,avg}(t) = \frac{V_{H1} - V_{H2}}{2}. \quad (6)$$

Eq. (6) can be rewritten by

$$V_{i1,avg}(t) - V_{x1,avg}(t) = V_{i2,avg}(t) - V_{x2,avg}(t). \quad (7)$$

This result shows that we can obtain the signals with the constant threshold voltage after subtracting the threshold voltages of the output signals from those of the input signals. In other words, the proposed concentrator aligns

signals with the different thresholds into signals with same threshold as shown in Fig. 1 (b).

Although the proposed concentrator performs threshold convergence, it still requires a fixed reference to generate a clear reshaping signal fed the LIA. Thus, a replica bias circuit shown in Fig. 2 (a) is designed to provide a desired reference, where it adds a low-pass filter to detect the bottom-level of the input signal in the front side. In the same manner as the concentrator, we have an output signal $V_{o,LPF}(t)$ with a height of $V_{H2}(=0)$ after a voltage step with a height of $V_{H2}(> 0)$ passes through a low-pass filter. Using Eq. (6), we can also write

$$V_{i1,avg}(t) - V_{i2,avg}(t) = V_{x1,avg}(t) - V_{x2,avg}(t) = \frac{V_{H1}}{2}. \quad (8)$$

This results shows that the output voltage of a replica bias circuit is equal

Fig. 2. (a) Schematic diagrams of concentrator and replica bias circuit (b) Simulated results of concentrator and replica bias circuit.

to the threshold voltage of proposed concentrator.

Fig. 2 (b) shows an example of simulated results of the concentrator and the replica bias circuit, where $V_i(t)$, $V_x(t)$ and $V_o(t)$ are the input voltage, the voltage at node x and the output voltage of the concentrator, respectively.

Fig. 3. Simulated results against various optical powers
(a) Transient response (b) Pulse width distortion.

3 Simulation results

The proposed optical receiver which consists of a PD, a common drain TIA, a concentrator, a replica bias circuit and a LIA was designed in a 0.18- μm CMOS technology. To measure the transient response and the pulse width distortion (PWD), 20 Mbit/s pseudorandom bit sequences (PRBS) of 2^9-1 data were applied to the receiver. Fig. 3 (a) shows a transient response at the output of the concentrator, which represents precise threshold convergences and a fast response time of 400 ns with alternating power levels from the highest (−14 dBm) to the lowest (−28 dBm). Fig. 3 (b) shows the simulated PWD against the received optical power. The results are compared with the PWD of a commercial ATC-based optical receiver [5]. With the proposed receiver, PWD is obtained −2% when the optical input power varies from −28 dBm to −14 dBm while that of conventional one is within +5% ~ −3%. These results show that the threshold convergence method is more effective than automatic-threshold control. The maximum power dissipation of the proposed circuit is 0.92 mW at a supply voltage of 1.8 V.

4 Conclusion

We presented a cost-effective and reliable CMOS optical receiver with a threshold convergence technique for high-definition digital audio interfaces. A threshold concentrator was designed to reduce pulse width distortion and circuit complexity. The proposed optical receiver can improve digital audio quality by threshold convergence of the input signals.

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