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Photo detector IC for Blu-ray-Disc applications: a realization applying efficient design methodologies

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Abstract. A high-speed photo detector IC for application in Blu-ray/DVD/CD drives is presented. Bandwidths for the highest gain of 254 MHz and 221 MHz for 405 nm (Blu-ray) and 635 nm (DVD) wavelengths, respectively, were achieved by applying novel design methodologies. The combination of this outstanding speed performance with its low power dissipation of 192 mW at 5V supply and the low noise power of −72 dBm at 300 MHz makes it the best in literature reported optical transceiver IC for Blu-ray and Blu-ray/DVD/CD multi drives. Beside the excellent performance results, the usage of the novel design methodologies gave us an increased design efficiency with 25% compared to earlier similar design processes.

1 Introduction

In 2008 the Blu-ray Disc won the competition for the distribution media of high-definition video data. Since the data storage density of Blu-ray Discs is about one order higher compared to DVDs and in consequence much higher data rates have to be transferred, high-speed electronics is needed to read, write and rewrite the discs.

In this work a photo detector IC (PDIC) with the capability of converting high-frequency blue and red laser light into electrical signals for data reading and writing is presented. The PDIC development had to face extreme requirements of signal amplifier bandwidth with a large dynamic range at the same time. The maximum possible rotation speed of recent Blu-ray Disc drives corresponds to a 12x readout speed and maximum data rates of 432 Mbit/sec, which requires 3 dB bandwidths larger than 200 MHz for the whole amplifier chain at all gains. In previous works maximum 3 dB bandwidths for either, DVD (260 MHz in Sturm, 2005) or Blu-ray applications (204 MHz in Ko, 2009) are reported. But especially for BD/DVD multi drives a PDIC with high bandwidths for multiple wavelengths is indispensable. We combined three novel design and optimization methodologies within the design process of the presented 12x-PDIC to achieve this sophisticated goal.

The PDIC was fabricated in a 0.6 µm BiCMOS process (XFAB, 2010) using integrated PIN-photodiodes with sensitivities of 0.26, 0.42 and 0.40 A/W for wavelengths of 405 nm, 635 nm and 780 nm (CD), respectively. With the implemented 8 gains one can adjust the high dynamic sensitivity between 28.0 and 0.2 mV/µW. Furthermore the device is featured by an overall power consumption of only 192 mW for a 10-channel system as depicted in Fig. 1.

2 Architecture of the photo detector IC

The schematic diagram in Fig. 1 gives an overall architecture overview of the PDIC. The PIN photodiode array is formed by 12 single diodes, divided into 4 center diodes (A-D) for beam focusing and data transfer and 8 satellite diodes (E-L) for tracking control of the laser beam. The diode array is followed by a 10-channel programmable (8 gains) 4-stage amplifier chain. The 6 amplifier chains A-D, RFp and RFn need to be high-speed for transmitting data up to 500 Mbit/sec. The 4 channels S1–S4 operate at lower speed and the connection to the input diodes E-L is reconfigurable via a mode decoder.

Each amplifier chain consists of a current amplifier (CAp, CAn) followed by a constant transimpedance amplifier (TIA) and a buffer amplifier (VA). Applying a 2-stage current amplifier with distributed gain control ensured high-speed operation and stability for all gains within the large dynamic range. For the differential channel RFp–RFn the diode currents A-D are summed up. Gain and mode decoder can be

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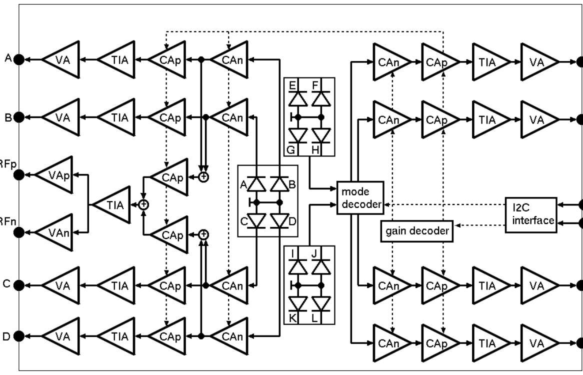

Fig. 1. Architecture overview of the complete 12x-PDIC.

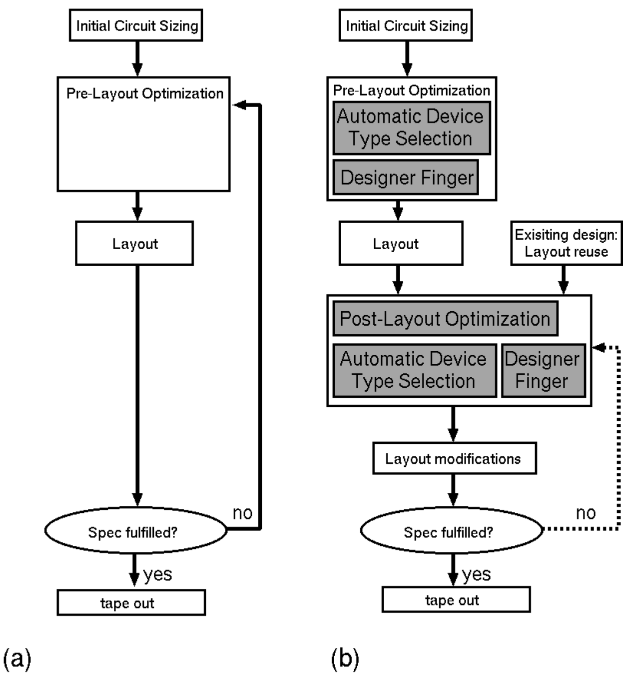

Fig. 2. Design flow within the 12x-PDIC development: **(a)** conventional optimization loop, **(b)** novel design flow applying post-layout optimization, automatic device type selection and Designer Finger.

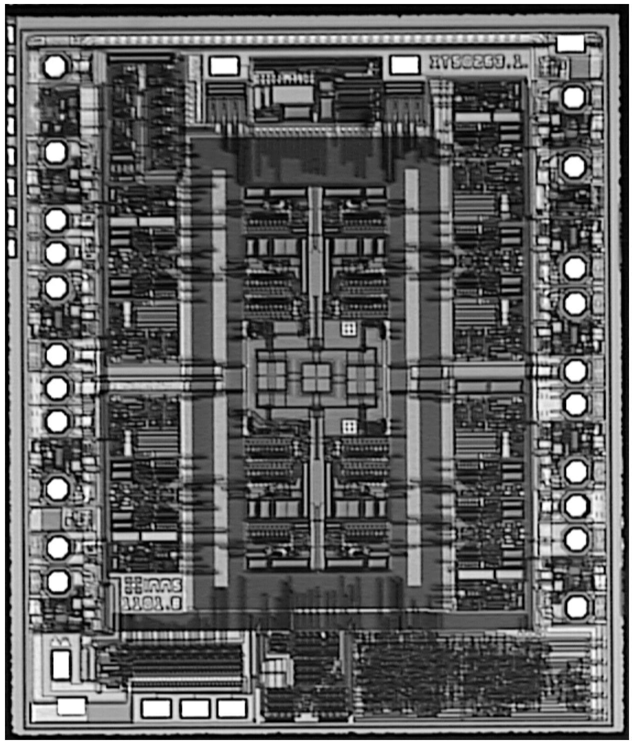

Fig. 3. Chip photograph of the PDIC.

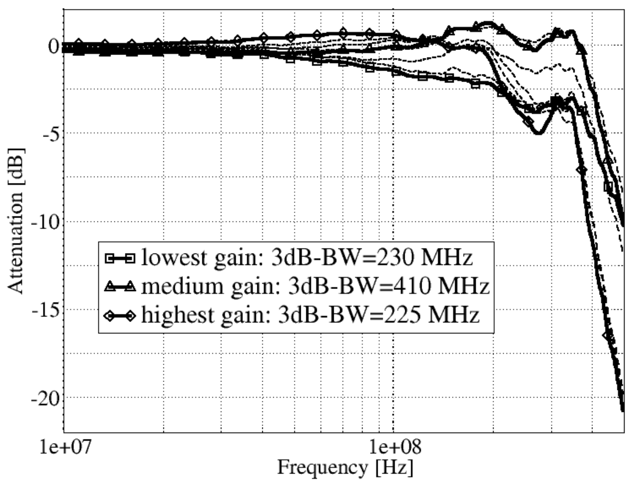

Fig. 4. Frequency response of an example high-speed channel for all 8 gains: curves for lowest, medium and highest gain are highlighted as bold lines.

configured via an I^2C interface. The presented PDIC is optimized with respect to signal bandwidth, sensitivity and noise for the high-speed channels to meet the challenging requirements of Blu-ray applications.

3 Novel methodologies for circuit optimization

Since almost ten years our group develops successfully optical transceiver ICs starting from CD and DVD applications up to today's Blu-ray drives. Raised requirements on amplifier chain bandwidths due to higher data rates made new design methodologies indispensable. We implemented a combination of three novel methods within the overall design process. In Fig. 2 the difference between the conventional design and optimization flow and the novel flow including all three methodologies for efficient optimization is shown. The proposed flow in Fig. 2b is suitable for complete design processes beginning from the initial topology selection and circuit sizing as well as for cost saving reuse of existing

Table 1. Simulated and measured performances of the presented 12x-PDIC.

Parameter	Simulated value	Measured value
sensitivity [mV/µW]		
· Blu-ray, highest/lowest gain	28.02/0.22	27.89/0.22
· DVD, highest/lowest gain	–	43.66/0.34
3 dB bandwidth [MHz]		
· Blu-ray, medium/highest gain	454/276	369/254
· DVD, medium/highest gain	454/276	355/221
Peaking [dB]	0.27	0.73
Slew rate rise/fall [V/µs]	133/−204	145/−135
Offset voltage [mV]		
· Mean value (108 channels)	1.39	1.0
· Standard deviation	–	3.3
Power dissipation @ Vdd=5V [mW]	190	191.7
Noise power (single-ended RF channel) @ 300 MHz [dBm]	−78	−77

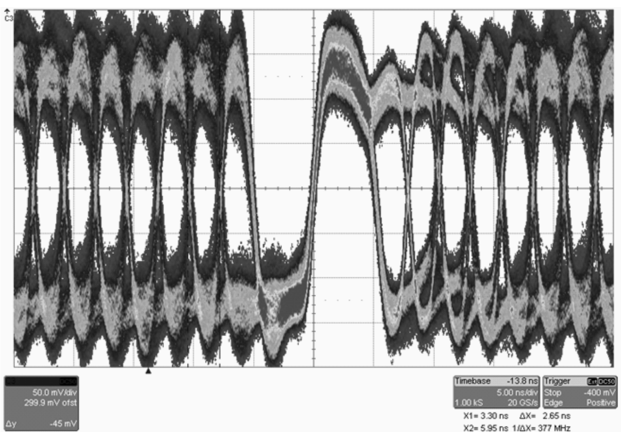

Fig. 5. Eye diagram in 12x-mode with an eye width of 2.5 ns (data rate = 400 Mbit/sec).

designs and layouts up to fulfilled specifications. The base for the design within this work ranged from existing low-speed sub designs including layouts (e.g. VA blocks) to completely new designed blocks (e.g. CAp, CAn). Combining layout reuse with the methodologies automatic device type selection (ADTS) and post-layout optimization (PLO) for the buffer amplifier VA for the fast channels A-D, RFp and RFn was very successful in terms of circuit performance and design efficiency. The post-layout 1 dB bandwidth of the single block VA could be increased from 220 MHz to 630 MHz. Furthermore, the discrepancy between pre- and post-layout performance was significantly reduced due to the intrinsic parasitics estimation of the PLO method. The layout reuse allowed a cost saving of 90% in the layout process for this particular block. Both, the PLO and ADTS methodology, are described in detail in (Reich, 2010) and (Dimov, 2008), respectively. The third novel methodology Designer Finger (Krausse, 2008) was successfully applied to the TIA. Its 1dB bandwidth was increased from 260 MHz to 385 MHz with a remaining peaking < 1 dB.

The presented methodologies are easy to implement into common design and optimization environments – within the presented design process Cadence 5.1 (Cadence Virtuoso, 2008) and WiCkeD analog circuit optimizer (MunEDA, 2008) were used.

4 Experimental results

Before PDIC characterization the laser spot characteristics was measured using a beam profiler. The full width at half maximum (FWHM) parameter was determined to 3.4 µm and 6.6 µm at wavelength of 405 nm and 635 nm. A very good focused laser beam was used for determining the photo diode sensitivity and homogeneity of this sensitivity. The measured sensitivity of the integrated PIN diode was 0.26, 0.42 and 0.40 A/W for wavelengths of 405 nm, 635 nm and 780 nm, respectively, which fit well with the simulated values.

A chip photograph of the fabricated 12x-PDIC is shown in Fig. 3. In Table 1 the simulated and measured key performances of the PDIC are listed. Intending high frequency operation, the buffer amplifier outputs have been matched with an integrated output resistance, since the downstream low-capacitive flexible PCB is specified with a load of 2 pF || 110 Ω. Within the measurement setup the load resistance was 110 Ω, whereas the load capacitance was slightly higher than the one for simulations. This fact helps the reader to understand the significant discrepancy in simulated and measured performances. However, considering the strong influence of

Table 2. Comparison of published PDIC realizations for DVD and Blu-ray drives.

Parameter		(Sturm, 2005)	(Seidl, 2005)	(Ko, 2009)	This work
Highest Sensitivity [mV/μW]	Blu-ray	–	–	12.3	27.9
	DVD	100	186	–	43.7
3 dB bandwidth [MHz] (high gain)	Blu-ray	–	–	204	254
	DVD	260	145	–	221
Offset voltage [mV]		n.a.	6.0	n.a.	3.3
Noise power	[dBm]	n.a.	–66.0	–89.8	–77.0
	@Freq. [MHz]	n.a.	200	120	295
Power dissipation [mW]		300	163	140	192
Number of channels		10	10	6	10

every small parasitics due to the measurement setup at high operation frequency, the achieved agreement between simulated and measured performances is superb.

In Fig. 4 the small-signal response of one high-speed channel for all gains with blue light illumination (wavelength = 405 nm) is shown. A mean 3 dB bandwidth of 254 MHz with 0.73 dB peaking was determined by measuring 25 high-speed channels on 5 PDIC devices. Furthermore, a medium gain mean 3 dB bandwidth of 369 MHz with 1.28 dB peaking was measured. For red light (wavelength = 635 nm) laser source the highest gain mean 3 dB bandwidth was determined to 221 MHz.

The eye diagram in Fig. 5 shows the highest gain measurement with 400 Mbit/sec pseudorandom data input, which is sufficient for the focused Blu-ray application. The limit for the realized 12x-PDIC is bound to 500 Mbit/sec data rates, since rise and fall times of about 2 ns were determined within experiments.

The statistical distribution of the measured offset voltage with a mean value of 1 mV and 5.8 mV standard deviation was achieved for measuring 108 channels. By applying the internal offset compensation the standard deviation improves to 3.3 mV. A power consumption of 192 mW is state-of-the-art among PDICs for DVD and Blu-ray drives.

The comparison with earlier publications of PDIC realizations in Table 2 substantiates the outstanding performance of the presented PDIC. It is state-of-the-art for optical transceiver ICs for fastest DVD drives with respect to bandwidth, sensitivity, noise and power dissipation. It is the best known PDIC for Blu-ray drives with the maximum 12x speed, since we achieved a 3 dB bandwidth larger than 250 MHz for the first time. All other known publications suffer from the fact, that they are characterized for either, DVD or Blu-ray. In contrast our PDIC for Blu-ray/DVD/CD multi drives shows excellent performance for both, the fastest DVD and Blu-Ray applications.

5 Conclusions

A high-speed 10-channel photo detector IC for Blu-ray, DVD and CD storage drives has been presented. The implementation of novel design methodologies within the overall design flow was the base for a successful IC realization in a 0.6 μm-BiCMOS technology meeting the requirements of Blu-ray applications with up to 500 Mbit/sec data transfer rates. The 12x PDIC with 8 programmable gains features a power consumption of 192 mW and a maximum transimpedance of 214 kΩ resulting in 28 mV/μW sensitivity. For the highest gain 3 dB bandwidths of 254 MHz and 221 MHz were achieved for wavelengths of 405 nm (Blu-ray) and 635 nm (DVD), respectively. The presented PDIC is the best known device for 12x speed Blu-ray drives and Blu-ray/DVD/CD multi drives. Furthermore its performance is state-of-the-art for DVD applications.

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