An Active Inductor Based TIA with Ambient Light Rejection for VLC Applications

Nasir A. Quadir, Muhammad A. Awan, Mohamed Abdallah and Bo Wang
Division of Information and Computing Technology
College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar
{NAbdulQadir, mawan, moabdallah, bwang}@hbku.edu.qa

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***Abstract*—Visible light communication (VLC) is becoming a popular technology for its attractive features of electromagnetic interference free, high-bandwidth, high security, and license-free operation. VLC receivers are getting a favorable amount of research interest as it is more convenient to manipulate low power signals than the large current signals in VLC transmitter. In this paper, a VLC receiver design is proposed, which uses an active-inductor-based peaking technique to enhance the modulation bandwidth of the receiver for various VLC applications. By employing the peaking technique, a -3 dB bandwidth of 80 MHz is achieved with 94 dBΩ of total transimpedance gain. The whole receiver consumes 3.2 mW of power consumption, which reduces to ~1.2 mW if the power consumed due to the termination resistor of 50 Ω is ignored. The ambient light rejection capability of the proposed design is 70 μA.**

***Index Terms*—Visible light communication, ambient light rejection, active inductor, transimpedance amplifier.**

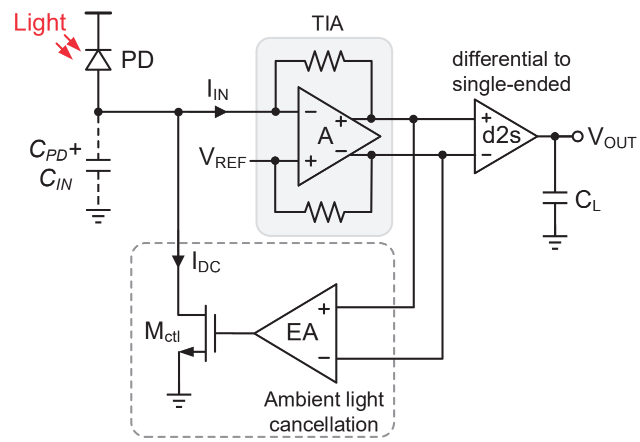

Fig. 1. The conventional system architecture of VLC receiver.

I. Introduction

Visible light communication technology (VLC) utilizes visible light as a medium of communication to transmit information. Recently, it has become a prevalent technology due to its attractive features such as electromagnetic interference free, high-bandwidth capacity, high security, and license-free operation, etc. [1]. With these exceptional attributes, VLC is seen as a solution to replace RF communication, especially in areas such as airplanes and hospitals that are sensitive to RF waves. Apart from that, VLC is also gaining popularity for different sets of the internet of things (IoT) applications where various light sources such as light emitting diode (LED) lights, displays, and signage could be utilized to pass on the information [2]–[4].

To design VLC suitable for low-cost applications, phosphorescent white LEDs are the preferred choice as signal transmitter with various circuit technique available to increase its bandwidth and ambient light rejection at the VLC receivers [5]–[7]. Manipulating weak signals at the VLC receiver does not incur a large power consumption as compared to improve signal strength at VLC transmitters by using high voltage and large current on LED drivers [8], thus attracting a fair amount of research interest. However, VLC receiver should incorporate two essential features. Firstly, we need to boost the modulated signal bandwidth to transfer the information at a higher rate than the -3 dB bandwidth controlled by the white phosphorescent LEDs. Secondly, rejection of ambient or background light is mandatory as it could saturate the receiver if not handled properly.

Generally, as shown in Fig. 1, VLC receivers utilize resistive feedback transimpedance amplifier (TIA) to convert the received optical signals to electrical voltage for further processing [9]–[11]. For bandwidth enhancement, a conventional equalizer consisting of RC source degeneration circuit through variable resistor and capacitor is employed [9], [10]. In [11], a negative feedback capacitance is generated to nullify the effect of photodiode capacitance that improves the speed of receiver. For ambient light interference rejection, an active feedback loop of error amplifier with a bypass transistor can be used to sink the unwanted DC current [9], [10], [12]. Whereas in [13] a floating active inductor is used to shunt the DC photocurrent. In [14], a logarithmic amplifier with a transistor is designed to cancel the background light variations.

In this paper, we propose a common-gate based TIA with an active inductor load to increase the modulation bandwidth beyond the limit set by the white LEDs used at the transmitter front, coupled with an error amplifier and bypass transistor to cancel the unwanted DC current for background/ambient light rejection. The proposed architecture can cancel the ambient photo-currents from 1 μA to 70 μA with a transimpedance gain of 94 dBΩ at an operating speed of 80 MHz. In the following, Section II introduces the detailed receiver design, with the simulation results presented in Section III, followed by a brief conclusion in Section IV.

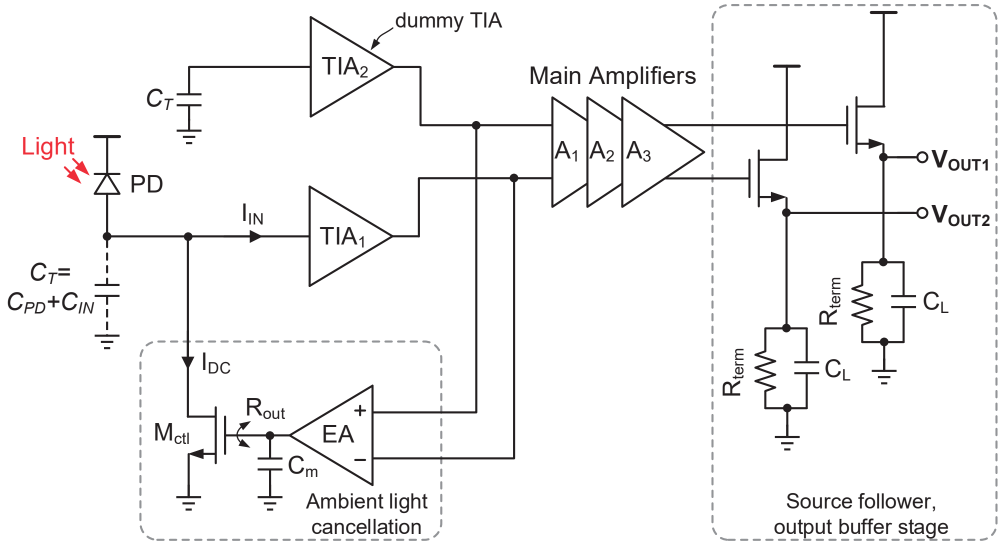

Fig. 2. Simplified block diagram of the proposed receiver with dummy TIA and ambient light cancellation.

II. Proposed Receiver Design

A standard VLC receiver is shown in Fig. 1, in which the optical signals from LED transmitter is converted into current through a photodiode, followed by a resistive feedback TIA and ambient light rejection circuitry. For low-cost applications, phosphorescent white LED is an attractive choice. However, it suffers from low modulation bandwidth (e.g., 2.2 MHz [9]). By applying a shunt peaking technique in the receiver to compensate for the above-mentioned insufficient bandwidth, the VLC's data rate could be increased [9], [10].

In this work, an active-inductor-loaded common-gate amplifier (due to its low input impedance) is used as the TIA to increase the modulation bandwidth of the receiver. Following the TIA, three differential amplifiers are designed to further boost the received signal amplitude. Common-drain amplifiers with a 50 Ω termination resistance and a 1 pF load capacitance are designed to drive the output. Fig. 2 shows the simplified system block diagram of the proposed receiver.

A. TIA Design

A conventional active inductor loaded common-source amplifier together with its small-signal model are shown in Fig. 3. The equivalent impedance Z_L looking into the drain of M_2 is given by

$$Z_L = \frac{1 + sC_{gs2}R_{ind}}{s^2R_{ind}C_a + s(C_{ds2} + C_{gs2} + R_{Ind}C_{gs2}g_{ds2}) + (g_{ds2} + g_{m2})} \quad (1)$$

where

$$C_a = C_{gs2}C_{ds2} \quad (2)$$

The RLC equivalent model of Z_L is shown in Fig. 3(c) and

$$R_{eq} = \frac{1}{g_{ds2} + g_{m2}} \quad (3)$$

$$L_{eq} = \frac{R_{ind}C_{gs2}}{g_{ds2} + g_{m2}} \quad (4)$$

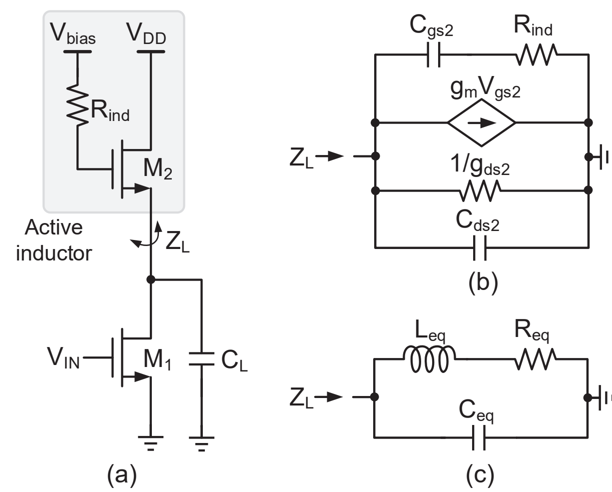

Fig. 3. (a) Conventional active inductor circuit level realization, (b) Detailed small-signal model of the active inductor, and (c) RLC equivalent model of the active Inductor.

$$C_{eq} = C_{ds2} \quad (5)$$

Therefore, the resonant frequency of this active inductor circuit is

$$\omega_0 = \sqrt{\frac{g_{ds2} + g_{m2}}{R_{Ind}C_{gs2}C_{ds2}}} \quad (6)$$

By carefully choosing or sizing the parameters in (6), one can achieve the required bandwidth extension. Referring to Fig. 3(a), the gate voltage of M_2 should be higher than the normal operating power supply to ensure that M_2 does not switch off when a large signal swing is present at its output (drain). To eliminate the usage of a higher power supply, the designed TIA uses the active inductor topology shown in Fig. 4 [15]. It has an active resistor formed by M_5 operating in its deep-triode region, through which the gate of transistor M_2 is

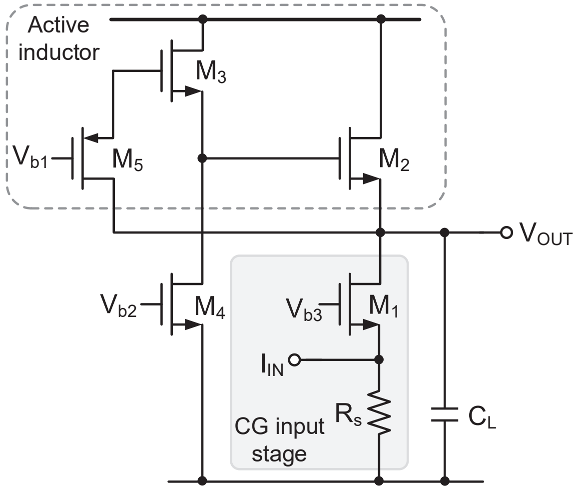

Fig. 4. Common-gate amplifier based TIA with active inductor load.

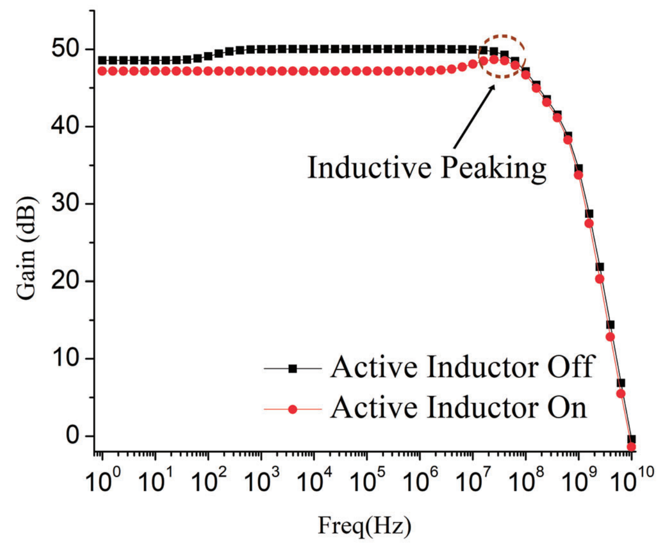

Fig. 5. TIA gain with and without active inductor functionality.

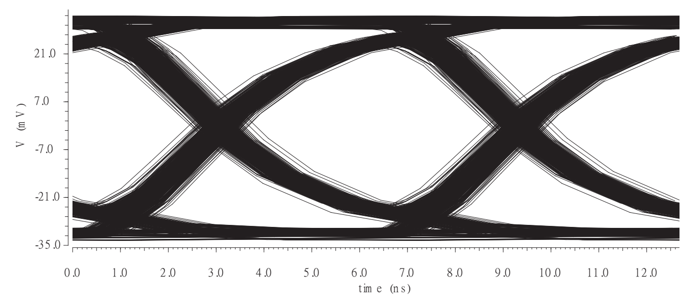

Fig. 6. Eye diagram at 2 μA modulation current and 70 μA of DC ambient light current.

coupled to its output via the source follower M_3. This design eliminates the need for a higher supply voltage and can operate at low voltage headroom. By tuning the gate voltage of M_5, the value of R_{Ind} changes, through which the active inductor inductance could be controlled as indicated in (4).

B. Ambient Light Rejection Block

Background light or ambient light interference causes unwanted DC photo-current, which adds to the photodiode signal current and saturates the receiver's output if they are not canceled. A high-pass filter is required to suppress this DC current. However, on-chip implementation of a high pass filter is costly due to the large values of capacitors and resistors. For this reason, an active feedback loop with the bypass transistor as shown in Fig. 2 is used in this design [9], [10]. The DC-offset compensation loop works by measuring the difference between the dc-levels of the two TIA (main and dummy) through an error amplifier, whose output is then fed to an NMOS transistor, which sinks the DC current generated by the ambient light [16].

III. Results and Discussion

In order to emulate the real operating condition, a 200 ps of rms jitter is introduced in the input source (pseudo-random bit sequence (PRBS) 2^7-1 signal). This signal is assumed to be originated from a LED transmitter source having a bit error rate (BER) of 1E-9 (IEEE 802.15.7 standard) [17].

Fig. 5 shows the effect of peaking introduced by the use of active inductor design (red dots) in the TIA. The active inductor introduces a zero in the system whose value is given by (4) thus increasing the -3 dB bandwidth of the system. The active inductor functionality can be turned off by turning M_5 off (Fig. 4). The -3 dB bandwidth of TIA is designed to incorporate the bandwidth losses due to the multi-stage amplifiers in the system given by (7) [18].

$$\omega_t = \omega_p \sqrt{2^{1/n} - 1} \tag{7}$$

where ω_t is the total bandwidth of the multi-stage amplifiers, ω_p is the bandwidth of the individual amplifier, and n is the number of stages. For the whole system to operate at 80 MHz, -3 dB bandwidth of the TIA is designed at 160 MHz with inductive peaking, which goes down to 100 MHz if the inductive peaking is not used. As we have discussed above, the phosphorescent white LED suffers from low modulation bandwidth (e.g. 2.2 MHz), making inductive peaking an important aspect of the design to increase the whole system bandwidth.

The simulated eye diagram of the receiver is presented in Fig. 6 (input modulation current of 2 μA) and Fig. 7 (an input modulation current of 20 μA) with the ambient light interference of 70 μA. We assume the signal is produced by 1-W LED as an ambient light source between the transmitter and receiver, with Vishay BPV10 silicon pin photodiode as the receiver photodiode. As can be seen, the eyes are wide open even if the ambient light interference is as high as 70 μA. Fig. 8 shows the eye diagram when M_5 in Fig. 4 is turned off, thus turning off the peaking functionality from the designed active inductor. Overall, an increase of 20% (horizontal) and 16% (vertical) eye opening is achieved when the peaking functionality of active inductor is on.

Table I is a benchmark of this design with the other VLC

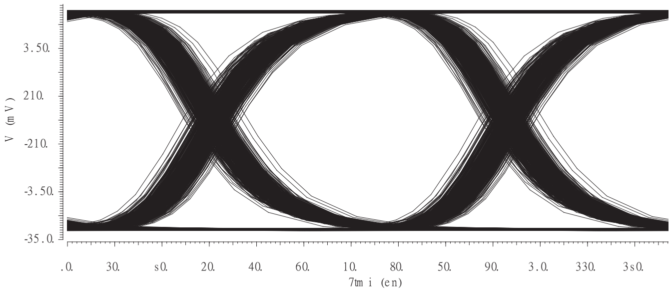

Fig. 7. Eye diagram at 20 μA modulation current and 70 μA of DC ambient light current.

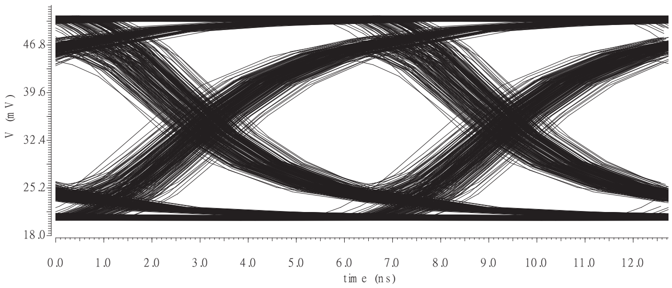

Fig. 8. Eye diagram when active inductor functionality is off at 2 μA modulation current.

TABLE I
PERFORMANCE COMPARISON WITH EXISTING VLC RECEIVER DESIGN

	[9]	[10]	[11]	This work
Data Rate (MHz)	25	25	3000	**80**
Technology (nm)	180	180	40	180
Power Dissipation (mW)*	2.2	2.2	1	**1.2**
Ambient Photocurrent DC (μA)	n/a	50	na	**70**
Transimpedance Gain (dBΩ)	128	124	89	94
Input Capacitance (pF)	7	7	0.5	**7**

*without including power consumed by the 50 Ω termination resistor.

receivers. The operating frequency of the proposed design is higher than the rest at the same process node. Our design also consumes less power (1.2 mW if the power consumption due to termination resistor of 50 Ω is ignored as is the case with the rest designs). The transimpedance gain is also comparable with the rest of the designs, even though the proposed design uses fewer gain stages with the same photodiode capacitance.

IV. CONCLUSION

In this paper, an active inductor-based peaking technique is proposed to enhance the receiver modulation bandwidth for VLC applications. By employing the peaking technique, a -3 dB bandwidth of 80 MHz is achieved with 94 dBΩ of total transimpedance gain. The whole receiver consumes 3.2 mW of power consumption with a resistive load of 50 Ω, which reduces to 1.2 mW if the power consumed due to the termination resistor of 50 Ω is ignored. The proposed design can reject and cancel the ambient light up to 70 μA, which is higher than other designs.

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