LiFi: TI High-Speed Products for Optical Wireless Communication

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LiFi is an emerging technology based on a wireless communication method: using visible light to transmit data. Since the LiFi debut in 2011, LiFi (also known by light fidelity) is the predominant light communication technology for bidirectional, high data rate transmission. LiFi is typically described as being implemented through existing luminaries, or light-emitting sources designed primarily for illuminating spaces. The high-level concept is to use visible light from an LED light bulb to communicate data by modulating the visible light at imperceptible frequencies to human vision. As light sources *flicker* faster than humans can see already due to supplied power, the idea is to *intentionally flicker* light sources to send data. Replacing a power supply-related frequency with a set modulation scheme turns (potentially) any standard light source into a data-transmitting node. The main idea of adapting luminaries into high-density data transceivers has attracted the attention of several industries, including industrial, medical, aerospace, defense, and communications. Some manufacturers are considering miniaturizing the systems to operate on personal electronics devices. Regardless of size or end application, the signal chain elements required are consistent.

The electronics hardware can be separated into two distinct functions: transmitter and receiver circuitry. Figure 1 shows the fundamental pieces of the signal chain for LiFi implementation.

RX Path

TI offers many high speed amplifiers already used in various TX/RX applications that are designed for both the transmit and receive signal chain of LiFi.

Key components of the receive path for LiFi include the photodiode, transimpedance amplifier (TIA), fully differential amplifier (FDA) (optional), and ADC. Various implementations or modulation schema can require certain filters across RX/TX.

Similar to light detection and ranging (LiDAR) circuits, LiFi RX circuits benefit from the wide-applicability and capability of TI's OPA85x family of operational amplifiers. Transimpedance amplifiers such as the OPA855 and OPA858 are high gain-bandwidth product (GBP) devices, capable of receiving small signals from photodiodes and providing amplification into an FDA or analog-to-digital converter (ADC). Table 1 shows a comparison of TI's-high speed operational amplifier designed for transimpedance applications, which are offered in various input types, bandwidths, and noise to suite a wide variety of applications. If footprint and integration are focuses of the design, TI's High Speed Integrated TIAs are listed in Table 2, which offer single chip solutions with additional features at the tradeoff of less configurations.

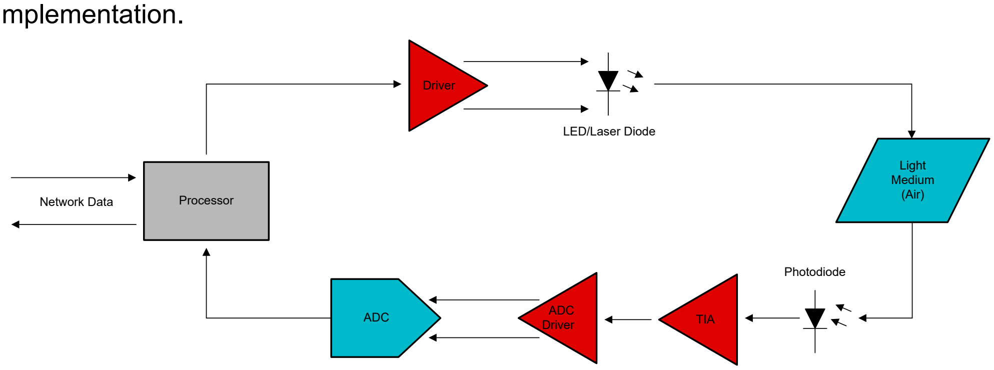

Figure 1. LiFi Signal Chain Block Diagram

When designing circuitry with transimpedance amplifiers, there are important parameters to be aware of: input capacitance, transimpedance gain (set by RF), and GBP. Two-Part E2E™ design support blog details the methodology and explanations behind transimpedance circuit design. The second part includes a TIA Calculator tool for processing the numbers associated with various TIA parameters, including how they affect each other. For more in depth analysis please see the *Transimpedance Considerations for High-Speed Amplifiers* application note.

In addition to the TIA, a fully-differential amplifier is often needed following a TIA to convert the single ended signal to a differential signal to drive differential input ADCs. An example would be a photodiode connected to an OPA859 transimpedance amplifier followed by the THS4541 fully differential amplifier to create the full analog front end driving a differential ADC. For more on Texas Instruments' Analog-to-Digital Converter products and solutions, please visit the ADC product page. With TIAs on the receive path, leveraging TI's experience in automotive LiDAR provides a validated family of TIAs to use with photodiodes for an RX signal chain.

Table 1. Discrete TIA Comparison

Part number	OPA855	OPA856	OPA858	OPA859	LMH6629
Input Type	Bipolar	Bipolar	FET	FET	Bipolar
VCC min (V)	3.3	3.3	3.3	3.3	2.7
VCC max (V)	5.25	5.25	5.25	5.25	5.5
Iq 25C max (mA)	19.5	19.5	24	24	16.7
GBW/BW (MHz)	8000	1200	5500	900	4000
Large signal BW (MHz)	850	110	600	400	390
Min. Stable Gain (V/V)	7	1	7	1	4
Slew Rate (V/us)	2750	350	2000	1150	1600
Vnoise (nV/√Hz)	0.98	0.9	2.5	3.3	0.69
Shutdown/Power Down	Yes	Yes	Yes	Yes	Yes
Ibias (typ) (uA)	-12	-15	+/- 0.4	+/- 0.5	-15
Vos (Max) (mV)	+/-0.2	+/-0.2	+/- 0.8	+/- 0.9	4.1
Vos Drift (uV/C)	0.5	0.7	+/- 2	-2	+/- 150
Package Option	WSON (DSG) | 8 (2 mm × 2 mm)	WSON (DSG) | 8 (2mm x 2mm)	WSON (DSG) | 8 (2mm x 2mm)	WSON (DSG) | 8 (2mm x 2mm)	WSON (NGQ) | 8 (3mm x 3mm)SOT-23 (DBV) | 5(2.9mm x 2.8mm)[FJ1]

Table 2. Integrated TIA Comparison

Part number	LMH32401	LMH32404	LMH34400
Total Gain	2 / 20 kΩ	20 kΩ	40 kΩ
TIA Gain Stage	1 / 10 kΩ	10 kΩ	12.2 kΩ
Iq per Channel (mA)	30	28	20
GBW/BW (MHz)	450 / 275	350	240
In (pA/√Hz)	9.2 / 2.1	2.3	2.4
Linear Input Current Range (uA)	0 to 700 / 0 to 72	0 to 72	0 to ~30
Integrated Current Clamp	100 mA 4 ns Recovery at 10 mA	100 mA 12 ns Recovery at 10 mA	100 mA 18 ns Recovery at 10 mA
Power Down Current (mA)	3.3	0.6	1.5
Ambient Light Cancellation (mA)	3	2.5	3
Output Multiplexing Supported	Yes	Yes	Yes
Channel Count	Single	Quad	Single
Package Option	VQFN (RGT) | 16(3mm x 3mm)	VQFN (RGT) | 28(5mm x 4mm)	SOT-5X3 (DRL) | 6(1.6mm x 1.6mm)

TX Path

Key components of the transmit path for LiFI include the digital-to-analog converter (DAC), modulation circuitry, DC bias (optional/choose how to implement), laser/LED driver, and laser diode/light source. As with RX, TX signal chains can require filters or additional elements to operate.

The laser and LED driver are components which need to be capable of high bandwidth operation and modulation, have high output current capabilities, and can drive the LED and laser diode load. TI's current-feedback amplifiers (CFAs) and differential driver ICs can drive the light sources in the LiFi transmit path. The OPA2675 dual-channel CFA is a wide band high-output current IC; the device can output current ±100 0 mA. The use of LEDs driven by differential-output amplifiers is documented in the G.9991 ITU standard for VLC/LiFi, Appendix I. The selection of LED driver depends on the number of channels, output drive required to modulate the LED, and the modulation scheme. Transmit circuitry for LiFi has been demonstrated to be as simple as catalog amplifiers and transistors modulating an LED On/Off using Manchester encoding, among other methods. While this lower bit rate approach is valid for small data throughput cases, the prevailing approach of orthogonal frequency division multiplexing (OFDM) signaling achieves far higher data throughput. OFDM signaling for LiFi enables parity with WiFi in data throughput, depending on the analog front-end (AFE) components as well as modulation schema. The transmit paths of LiFi are generally concerned with efficiency and light source considerations, such as modulation of LEDs and laser diodes versus power consumption and current requirement. Unlike dedicated LED driver or laser driver ICs, TI's CFA and line driver portfolio are already used in modulation techniques shared between PLC, DSL, WiFi, and LiFi. Many TI resources exist for using CFAs and line driver parts in wired communication systems with figures of merit that are used in wired communication systems design to validate circuit performance: multi-tone power ratio (MTPR) and out-of-band suppression (OOBS). While normally associated with DSL and PLC respectively, the similarities between the MAC and PHY layers of LiFi to wired PHY systems creates opportunity for adoption of TI CFAs into LiFi TX. For LiFi designs, the Bit-error rate (BER) and error-vector magnitude (EVM) are already known to the broader wireless communications field. MTPR and OOBS metrics are typically employed solely on wired systems. This distinction appears to disqualify these wired metrics from consideration here, however the approximation of a LiFi system's medium (air) as fiber-optic cabling allows for consideration of wired figures of merit, when applicable. TI amplifiers with original uses in DSL and PLC have data sheets showcasing relevant performance in the original wired applications. Adoption of high-speed amplifiers into LiFi can require the knowledge of TI engineers to assist in the design: TI's E2E™ Design Support Forum provides product family and IC-specific resources and forum posts to match the knowledge level of the investigating engineer. TI's analog and digital expertise, especially of wired and wireless figures of merit, provides reason for the adoption of TI CFA and differential driver products.

Characterizing TI CFAs, such as OPA2675, using wired communications metrics MTPR and OOBS enables a robust yet realizable method for testing the capabilities of TI high speed amplifiers in LiFi TX applications. While simulation and calculation allow for testing modulation schemes for BER and EVM, those metrics are not helpful when examining analog parts for the LiFi AFE. Evaluating ICs does not require the full development of a LiFi setup prior to analyzing IC performance. The use of MTPR and OOBS to qualify analog amplifiers for use in LiFi is a net-benefit to design engineers.

Table 3. CFA and Line Driver Comparison

Part number	OPA2675	THS6222
Type	LINE Driver	LINE Driver
Num Channels	2	1
VCC min (V)	4.5	8
VCC max (V)	13	32
Iq 25C max (mA)	16.5	19.5
GBW/BW (MHz)	730	250
Large signal BW (MHz)	230	190
Slew Rate (V/us)	3,000	5,500
Iout sourcing (typ) (mA)	1000	338
Vnoise (nV/√Hz)	2.4	2.5
Shutdown	Yes	Yes
Ibias (typ) (uA)	25	1
Vos (Max) (mV)	5	12
Vos Drift (uV/C)	3	40
Package Option	VQFN | 16(3 mm x 3 mm)	VQFN | 16(3 mm x 3 mm)

As LiFi matures into consumer and industry-facing products, Texas Instruments high speed amplifiers can be a consideration for design-in and testing. Many TI devices have varying packages and channel numbers; some devices are already available in bare-die for wire-bonding directly to the photodiode. TI's portfolio and product support are available to guide and assist the adoption of LiFi into the next high-security communications system, industrial control system, or RF interference-sensitive environment.

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