

Whitepaper

Low-Power Optical Wireless Communication Near-Field Transceiver

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Abstract:

Wireless connectivity enables flexible operation of mobile devices and sensor systems. Low-power optical wireless communication (LP-OWC) complements radio frequency (RF) technologies with energy-efficient, reliable, and spatially confined links that reduce interference and spectrum congestion. This article introduces LP-OWC, its properties, implementation, and potential applications, and compares it with established RF technologies such as near field communication (NFC) and Bluetooth Low Energy (BLE).

1. Introduction

LP-OWC uses light to transmit data with low energy consumption. It is particularly suited to dense, secure, and interference-sensitive communication environments.

Fundamentals

At the transmitter an optical emitter such as a light-emitting diode (LED) or a laser diode (LD) is used. LDs generally enable higher data rates but at the expense of increased system complexity, higher cost, and additional eye-safety requirements. At the receiver, a photodetector, typically a photodiode (PD), converts the incident optical signal into an electrical signal. This signal is amplified for further processing. Optics are used to shape the emission profile of the emitter and to focus the incident light onto the PD.

Properties

LP-OWC typically operates in line of sight within spatially defined light cones. Although this limits mobility, it enables low crosstalk, deterministic latency and throughput, and high channel capacity in dense environments. The technology is particularly attractive where RF communication is restricted, spectrum is congested, or power and reliability requirements are stringent.

LP-OWC uses non-ionizing optical wavelengths in a vast, largely unlicensed frequency range and is therefore typically

subject to fewer spectrum-allocation constraints than RF technologies.

LP-OWC complements rather than replaces RF technologies. It combines high data rates, low latency, and high transmission efficiency over short distances, enabling wireless links that are independent of RF interference.

Standardization

Infrared OWC was standardized from the Infrared Data Association (IrDA) since the 1990s. The Infrared Physical Layer (IrPHY) specified data rates are between 2.4 kbps and 1 Gbps [2]. However, only Serial Infrared (SIR, 115 kbps), medium infrared (MIR, up to 1.6 Mbps) and fast infrared (FIR, 4Mbps) and very fast infrared (VFIR, 16Mbps) were available in the past and UFIR (96 Mbps) and Giga-IR (1 Gbps) never achieved widespread adoption. SIR transceivers have found widespread use, particularly in remote controls, which benefit from their low power consumption. Today, commercially available IrDA transceivers are largely limited to low-speed SIR devices, such as remote controls, represented in Table 1 by the Vishay TFBS4652 [1]. Consequently, commercially available IrDA solutions are typically limited to approximately 115 kbps, which limits the performance of modern internet of things (IoT) devices.

In recent years, additional standards for optical wireless communications have been introduced, including IEEE 802.15.13, IEEE 802.11bb, and ITU-T G.9991. The ITU-T standard G.9991 defines high-speed optical links with data rates of up to Gbps. However, the use of computationally complex Optical Orthogonal Frequency Division Multiplexing (OFDM) schemes, such as Direct Current-biased OFDM (DCO-OFDM), typically results in significantly higher power consumption in the range of Watts, as shown in a previous study (IPMS GigaSpot) [3].

2. Fraunhofer IPMS Li-Fi TinySpot

Over the past years, Fraunhofer IPMS has developed several Li-Fi communication platforms, including the ultra-low power Li-Fi TinySpot depicted in Figure 1.



Figure 1: Fraunhofer IPMS: Li-Fi TinySpot.

Table 1 compares the Li-Fi TinySpot with a commercial IrDA transceiver (Vishay TFBS4652) and a professional grade high-speed LP-OWC transceiver (Li-Fi GigaDock®, shown in Figure 2) [4]. Both listed alternatives are complementary to each other in terms of maximum data rate. The IrDA transceiver features SIR standards with 115 kbps at a range of one meter and the Li-Fi GigaDock® up to two digits Gbit/s at lower centimeter distances. In between, there is a lack of LP-OWC alternatives that can reach a one-meter distance for handheld applications, which was a main driver behind the development of the Li-Fi TinySpot.

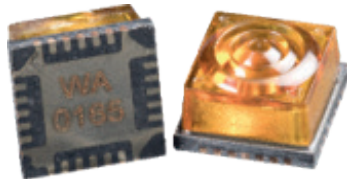


Figure 2: Fraunhofer IPMS: Li-Fi GigaDock®

Li-Fi TinySpot has a footprint of 15 mm × 21 mm and consumes 17 mW over a range exceeding one meter. For systems that prioritize energy savings, power consumption can be reduced to about one third with a moderate reduction in range. In this adjusted configuration, Li-Fi TinySpot consumes less power per bit than the IrDA reference while providing up to 200 times the data rate at a similar range.

Li-Fi GigaDock® is smaller than Li-Fi TinySpot and is well suited to space-constrained or rotary applications. The higher data rates of both Li-Fi modules shorten transmission time compared with the IrDA module, allowing the interface to remain active for less time and reducing average power consumption in duty-cycled systems.

Parameter	Li-Fi TinySpot	Vishay TFBS4652	Li-Fi GigaDock®
Max Data Rate	Up to 20 Mbps	0.1 Mbps	Up to 10 Gbps
Range	Typ. 1 m	Typ. 1 m	Up to 10 cm
Power Consumption	Min. 5 mW, Typ. 17 mW (range depending)	7 mW	100 mW
Size (h × w × d)	15 mm × 21 mm × 3.3 mm	6.8 mm × 1.6 mm × 2.7 mm	5 mm × 5 mm × 3.1 mm
Interface	SPI / UART (SIR, MIR, FIR, VFIR)	SIR (UART)	LVDS
Cost	Low-medium	Very low	Medium

Table 1: Low-Power Optical Wireless Technologies for different data rates and ranges: Li-Fi TinySpot, IrDA SIR TFBS4652 and Li-Fi GigaDock® [1].

3. Comparison to RF

Table 2 compares Li-Fi TinySpot with RF-based technologies including NFC, BLE, Long Range Wide Area Network (LoRaWAN), Zigbee, and Z-Wave [5-15]. Each technology offers distinct strengths and is therefore suited to different application requirements.

Li-Fi TinySpot provides the highest throughput among the compared technologies, with a data rate roughly an order of magnitude higher than BLE and substantially higher than Zigbee, Z-Wave, NFC, and LoRaWAN. At the same time, its energy per bit is among the lowest in the comparison. Among the compared technologies, Li-Fi TinySpot occupies a distinct operating range: it combines approximately one meter of coverage with 20 Mbit/s, whereas NFC targets much shorter, low-data-rate interactions and RF technologies trade higher range or networking capabilities for lower throughput.

Unlike NFC, Li-Fi TinySpot supports communication over approximately one meter, while avoiding the additional range and networking capabilities of conventional RF technologies where these are not required. This combination makes it particularly suitable for direct device-to-device links that periodically transfer larger data volumes, such as measurement data, firmware, or images. The high throughput shortens transmission times and allows the communication interface to return to a low-power state quickly. Its spatially confined optical link also enables clear device assignment and the parallel operation of neighboring links. Li-Fi TinySpot can therefore handle high-throughput local links while RF technologies provide wide-area connectivity.

In contrast, LoRaWAN prioritizes communication range over throughput. It enables communication over several kilometers to tens of kilometers, but this capability comes at the expense of data rate. BLE, Zigbee, and Z-Wave occupy the middle ground, providing moderate throughput and communication range, with BLE generally offering the highest throughput of the RF-based technologies. A further distinction is the communication medium. Li-Fi TinySpot does not use the RF spectrum and is therefore unaffected by RF interference or spectrum congestion. However, it requires a line-of-sight connection, whereas RF technologies provide omnidirectional coverage and greater flexibility in device positioning.

4. Applications and Requirements

LP-OWC supports a broad range of industrial, medical, and mobile applications, particularly where low power consumption, RF independence, or robust short-range communication is required. Representative application fields include:

Energy-Efficient Connectivity for Mobile and IoT Devices

LP-OWC provides low-power connectivity for battery-operated systems such as autonomous guided vehicles (AGVs), drones, wearables, sensor nodes [15], and IoT devices. Low transceiver power can extend battery life and reduce heat generation in energy-constrained applications.

Self-Sufficient Optical Sensor Nodes

LP-OWC can also enable self-sufficient optical sensor nodes [14]. The Fraunhofer IPMS Li-Fi Power over Light (Li-Fi PoL) system combines data communication with optical power transfer [16]. Energy can be supplied by a reader during data acquisition or harvested from ambient light, depending on the application.

Optical Links for Galvanic Isolation

LP-OWC can act as a wireless “optocoupler,” enabling contactless transmission over distances ranging from centimeters to several meters while maintaining complete galvanic isolation. This enables applications requiring electrical isolation across both small gaps and extremely high potential differences, including high-voltage systems with isolation distances corresponding to several thousand kilovolts [17, 18].

Communication in Harsh and RF-Restricted Environments

Optical wireless communication remains reliable in environments where RF technologies are limited by electromagnetic interference (EMI), regulatory restrictions, or safety requirements. As a result, LP-OWC is particularly well suited for aerospace [19], military [15], medical, and other EMI-critical applications where dependable wireless communication is essential.

Dense Sensor Networks

LP-OWC supports many parallel links without adding to RF spectrum congestion, making it suitable for dense industrial sensor and monitoring networks. Its communication energy can be approximately one twentieth of that required by BLE, with greater savings compared with Wi-Fi-based systems.

Rotating Machinery and Industrial Equipment

In rotating systems, optical wireless links can replace mechanical or inductive slip rings for data transmission across moving interfaces. Eliminating physical contact reduces wear and maintenance while improving long-term reliability [4].

Parameter	TinySpot (Li-Fi)	NFC	BLE	LoRaWAN	Zigbee	Z-Wave
Max Data Rate	Up to 20 Mbps	Typ. 424 kbps (RFID), up to 53 kbps (NFC)	Typ. 1 Mbps, recently up to 2 Mbps	Typ. 50 kbps	Up to 250 kbps	Up to 200 kbps
Stability	Highly stable under unobstructed line-of-sight	Highly stable at very short range	Generally stable, but throughput can be reduced by fading, multipath propagation, and RF interference	Generally stable, but latency and packet loss depend on channel occupancy	Stable, possible degradation in crowded 2.4 GHz environments	Generally stable due to sub-GHz operation
Energy-per bit	5 nJ/bit	Typ. 220 nJ/bit (RFID), 950 nJ/bit (NFC)	Typ. 100 nJ/bit Research down to 3.5 nJ/bit for TX	Typ. 9667 nJ/bit	Typ. 102 nJ/bit 109.2 nJ/bit	Typ. 100 nJ/bit Up to 1000 nJ/bit
Range	Typ. 1 m; more with increased power	Typ. <10 cm	Typ. 10 m to 30 m with long range PHY up to 240 m	5-15 km	Typ. 10 m to 100 m	Typ. 30-50 m, up to 150 m
Coverage	Line-of-sight	Very low	omnidirectional	omnidirectional	omnidirectional	omnidirectional
Robustness: dirt and dust	low	high	high	high	Depending on application	Depending on application
Robustness: metallic environments	Not critical	Can be tailored to the environment	Strong influence	Strong influence	Medium influence	Small influence
Interference in highly crowded RF environment	No interference	Does not apply	Moderately susceptible to interference and packet collisions in dense deployments	Prone to interference	Moderate susceptibility to interference in crowded 2.4 GHz environments	Less prone to interference
Movement	Restricted by the line-of-sight	Not possible, typ. 100ms to reconnect	Very low influence	No influence	Low influence	Very low influence
Cost	Low-medium	low	Very low	Medium	Low	Low-medium
Size	Small	Transmitter relatively large	Very small	Medium	Small	Small

Table 2: Technology Comparison between Li-Fi (Li-Fi TinySpot as reference), NFC, BLE, LoRaWAN, Zigbee and Z-Wave [5-15].

5. Implementation

LP-OWC transceivers can be integrated into embedded platforms through standard digital interfaces, often without dedicated communication controllers.

For low- and medium-rate applications, standard microcontroller interfaces such as Universal Asynchronous Receiver/Transmitter (UART) or Serial Peripheral Interface (SPI) are typically sufficient. Depending on the optical front end and modulation scheme, data rates of up to several tens of Mbit/s are possible at low power consumption [10].

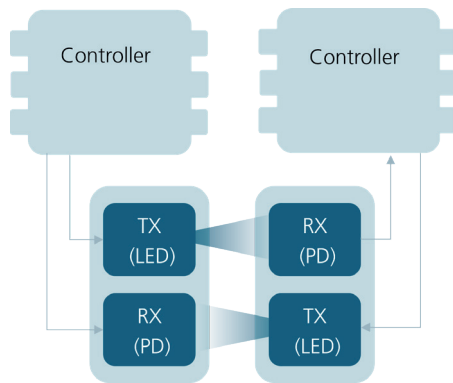


Figure 3: Implementation with two microcontrollers

6. Fraunhofer IPMS Li-Fi Competencies

Fraunhofer IPMS develops Li-Fi technologies for a broad range of data rates, transmission distances, and power requirements. The portfolio includes ultra-low-power links for mobile devices and sensors, long-range industrial gigabit links, and compact high-speed transceivers for real-time communication. Further solutions address rotary, underwater, space, and military applications, as well as combined optical data and power transfer. These technology platforms are continuously advanced to meet evolving requirements for energy efficiency, form factor, robustness, and system interfaces.

Beyond providing individual transceiver technologies, Fraunhofer IPMS supports customers from feasibility assessment and application-specific design through prototyping and system integration. Existing Li-Fi solutions can be tailored to the optical, electrical, mechanical, and environmental requirements of a target application and integrated into customer hardware and higher-level systems.



Figure 4: Fraunhofer IPMS: The Li-Fi TinySpot was developed as part of the “CommUnity” project from the Leistungszentrum Mikro-Nano.

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The Fraunhofer-Gesellschaft, based in Germany, is the world's leading organization for application-oriented research. With its focus on future-relevant key technologies and the utilization of the results in business and industry, it plays a central role in the innovation process.

The Data Communication and Computing (DCC) division has been developing top-notch optical wireless communication solutions for over 15 years now. The competencies range from analog- and digital design, high-frequency circuit design, optic design to software- and system design. This enables the expert team to develop tailored solutions at the highest technical-scientific level.

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