Intelligent Photoelectric Sensor Module Utilizing Light for Communication and Energy Harvesting

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Optical wireless communication presents an alternative to traditional radio frequency channels. We introduce a concept of an intelligent photoelectric sensor module equipped with a light interface for data transmission. The paper describes the arising quality challenges of the received signal in light communication for miniature devices and proposes the possible solutions.

1 Introduction

With increasing popularity of wireless radio frequency (RF) communication technologies in all kinds of electronic devices the issue of electromagnetic interference between those, which operate on unlicensed 2.4 GHz band, become essential. The alternative for the RF approach is to encode transmitted data in light pulses of LED, which is able to switch light intensity levels at a very high rate. This method is called Optical Wireless Communication (OWC).

Apart from the fact, that the optical spectrum contains hundreds of terahertz of license free bandwidth, communication by means of light offers a set of advantages. At low power levels it is intrinsically safe and does not pose a health threat as long as eye safety regulations are fulfilled. It can be harmlessly used in environments where RF emission is forbidden or restricted, e.g. chemical and nuclear plants [1]. This paper aims to analyse the specific design aspects of a light communication channel for miniature devices, in particular for autonomous sensor modules. The main factors degrading the signal quality are considered and the possible solutions for its improvement are proposed.

2 Concept

In this paper we present a possibility of OWC for an autonomous sensor module, which is able to take measurements and emit information by external wake up. The power autonomy of the module is intended to be achieved by energy harvesting, where the ambient optical energy is converted into electrical energy by means of a solar cell, which can be also used as a receiver of a light signal.

A matrix-like arrangement of several such modules comprises a wireless sensor network, which can be used as an individually adapted sensor system. As a read/write unit, a smart phone with an individually programmed app can be used to transmit a data signal through the built-in LED and to read the optical information from the modules through the built-in camera (Fig. 1).

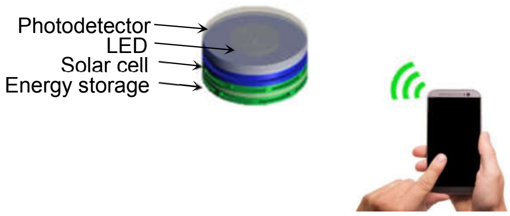

***Fig. 1** The concept of a fully-optical autonomous sensor module*

The size of each module is intended to be small-scale and mainly depends on the size of the solar cell used as a power supply.

3 OWC Challenges in Photoelectric Sensor Module Design

The design of OWC for an autonomous device of the small-scale size (1-3 cm in diameter), such as a photoelectric sensor module, imposes some specific constraints on the ability of the energy harvesting source to supply enough power during communication. Therefore, the device must consume as little power as possible during the whole communication process, minimizing the power necessary for modulation and demodulation, light emission and filtering and amplification of the received signal.

With respect to power consumption limitations and device dimensions miniaturisation, the following challenges are relevant for the implementation of OWC for an intelligent photoelectric sensor module.

3.1 Noise and Interference

In the context of energy harvesting for an autonomous sensor module, solar radiation is a very use-

DGaO Proceedings 2017 – *http://www.dgao-proceedings.de* – ISSN: 1614-8436 – urn:nbn:de:0287-2017-A015-6

submitted: 26.Jul.2017 published: 07.Aug.2017

ful energy source. However, within the framework of optical wireless communication it is also a source of noise, which has to be filtered on the receiver. Additional noise comes from artificial illumination sources, which are powered from alternating current (AC) at 50 Hz (in Europe) and therefore experience a voltage decrease 100 times a second (twice per line cycle), producing 100 Hz flickering. Such light changing intensity is also sensed by a photodetector and has to be filtered out (Fig. 2).

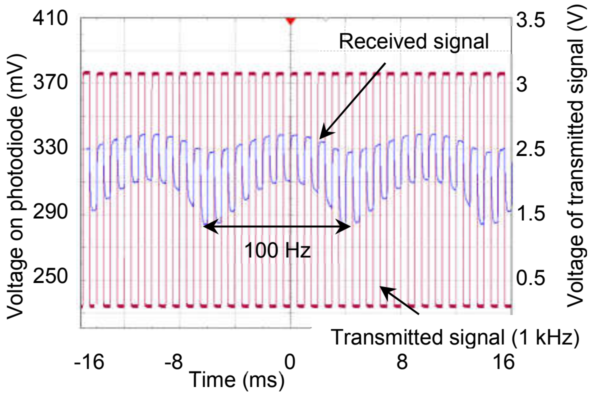

Fig. 2 *Behavior of received signal with the presence of interference from fluorescent lamp without filter*

This effect can be mitigated by using an electric circuit with a high-pass filter and transimpedance amplifier (TIA) included (Fig. 3). A high pass filter eliminates the DC component of light signals and reduces the effect of external illumination sources with a carefully adjusted cutoff frequency. The TIA is necessary for amplification the photodiode output to a usable voltage. Finally, a comparator digitalizes the amplified signal.

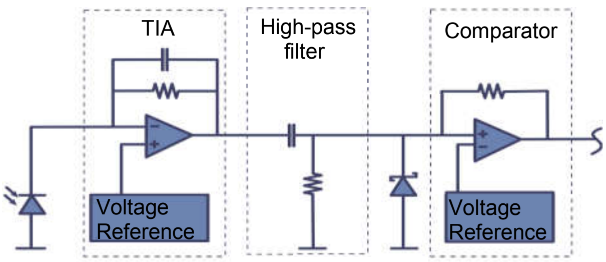

Fig. 3 *The concept of a fully-optical autonomous sensor module*

Power can be saved with the utilization of main components with ultra-low power consumption. For instance, TIA MAX4464 consumes only 750 nA at 1.8 V and comparator MCP6541 requires just 600 nA. Figure 4 illustrates the resulting received signal with the presence of fluorescent lamp interference after the circuit is applied.

Additional noise is induced in the photodetector by the signal and ambient light (shot noise) and in the electrical pre-amplifier stage (thermal noise). These depend on the photodetector area, on the

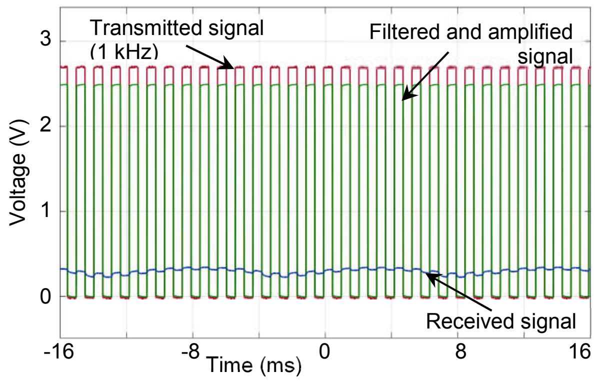

Fig. 4 *Behavior of filtered received signal with the presence of interference from fluorescent lamp*

room temperature and on the amount of ambient light and can usually be filtered out by a low-pass filter embedded in TIA.

3.2 Saturation of photodetector outdoors

Exposure of the photoelectric sensor to direct sunlight in outdoor environment can pose an issue of saturation of the photoelement. The photodiode saturates when the output photovoltage approaches the reverse bias voltage. Since a photodiode produces current, the saturation limit can be adjusted by changing the reverse bias voltage (within specification) or reducing the load resistance. Based on this principle authors of [2] designed an adaptive transimpedance amplifier, which changes its gain value according to the level of incident light. This could be a sufficient solution to the saturation issue of the photoelectric sensor. However, the possibility of implementing the electric circuit in mm-scale is still a challenging task, which is the next step of the current research.

4 Summary

In this article the concept of a photoelectric sensor module with a light interface for data transmission was presented and the challenges of optical wireless communication were discussed. The ambient light noise on receiver can be filtered out by low-power electrical circuit. Adaptive to the level of incident light transimpedance amplifier is a way to prevent the saturation of a photodetector outdoors.

This work was financially supported by the Lower Saxony Ministry for Science and Culture, Germany, within the framework of "Tailored Light" project.

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