









intensities of RGB LEDs [8]. The disadvantage of the multi-carrier techniques is in their high implementation complexity and in increased power requirements.

## VLC CHALLENGES IN PHOTOELECTRIC SENSOR MODULE DESIGN

The design of VLC for an autonomous device of a small-scale size (1-3 cm in diameter), such as photoelectric sensor module, imposes some certain constraints on the ability of the energy harvesting source to supply enough power during communication. It is important to notice that in the case of sensor node the maximum amount of reading cycles per second is more relevant than the rate of transmission of any single sensor reading (data rate). Therefore, the device must consume as little power as possible on a full-scale of whole communication process, minimizing power, which is necessary during modulation and demodulation (1); light emission (2); filtering and amplification the received signal (3).

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

### Noise and Interference

In the context of energy harvesting for autonomous sensor module the solar radiation is a very useful energy source. However, within the framework of wireless light communication it is a source of noise, which has to be filtered in the receiver. Additional noise comes from artificial illumination sources,

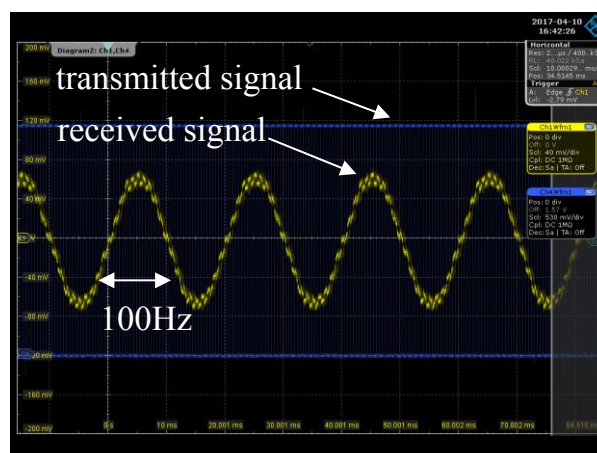


Fig.3. Behaviour of received signal with the presence of interference from fluorescent lamp without filter

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 100Hz flickering. Such light changing intensity is also sensed by a photodetector and has to be filtered out (Figure 3). This effect can be mitigated by using an electrical high pass filter. However, the complete elimination of the interference component presents a significant challenge and requires very precise adjustment of the filter parameters. Figure 4 illustrates the resulting received signal without (a) and with (b) presence of fluorescent lamp interference.

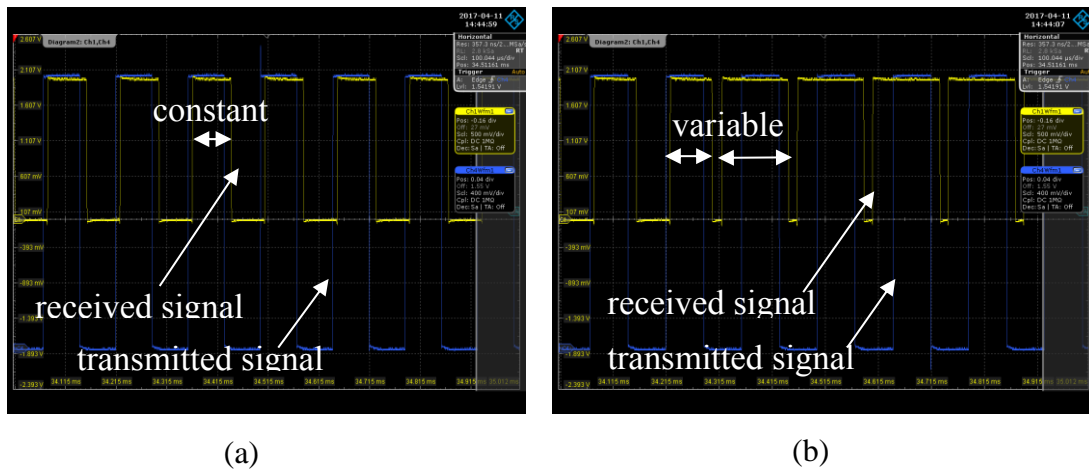


Fig.4. Behaviour of received signal without (a) and with (b) the presence of interference from fluorescent lamp with filter

Additional noise is induced in the photodetector by the signal and ambient light (shot noise) and on electrical pre-amplifier stage (thermal noise). They depend on the photodetector area, on the room temperature and amount of ambient light and can usually be filtered out by a low-pass filter.

### Saturation of photodetector outdoors

An exposure of the photoelectric sensor under direct sunlight in outdoor environment can pose an issue of saturation of the photoelement. Photodiode saturates when the output photovoltage approaches the reverse bias voltage. Since photodiode outputs a current, the saturation limit can be adjusted by modifying the reverse bias voltage (within specification) or reducing the load resistance [9]. Based on this principle authors of [10] designed an adaptive transimpedance amplifier, which changes its gain value according to the level of incident light. This can be a good solution of the saturation issue of the photoelectric sensor in case of possibility of implementing the electric circuit in mm-scale.

## Spatial Communication

Several autonomous photoelectric sensor modules can comprise a wireless sensor network, where each node communicates with its neighbors by means of light. In this scenario unlike for RF communication the position of every node requires precise adjustment and preliminary simulation for each application, since the quality of the transmitted signal is very sensitive to incident and to irradiation angle (Figure 5) and the inter-channel interference can occur. Such ray-tracing simulation and path loss calculation example was given in [7] for modelling a light-communication-based cellular network in aircraft cabin. Another challenging task in spatial communication of sensor nodes involves implementation of MIMO (Multi-Input Multi-Output) transmission. Compared to RF systems, which have multiple spatial paths that

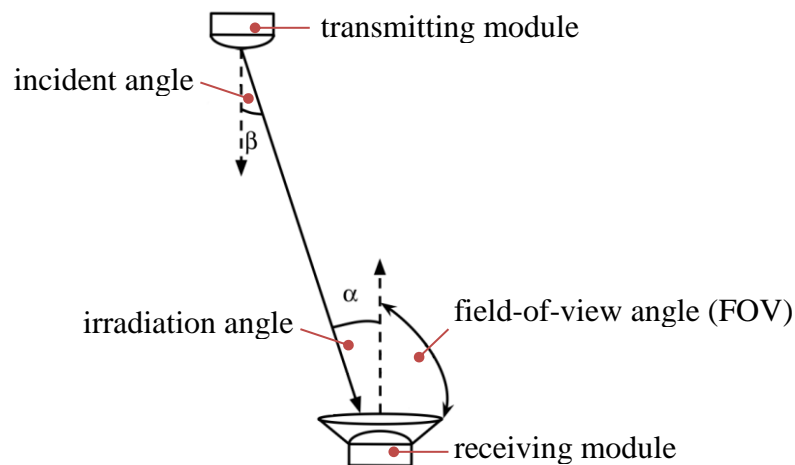


Fig.5. Incident and irradiation angles in spatial communication between two autonomous sensor nodes

diverse in nature, in VLC such diversity gains are limited, since the paths for transmitters and emitters are very similar and can interfere with each other. A solution can be in utilization of an image sensor as a photodetector instead of a single photodiode. A specific advantage of the image sensor is its ability to spatially distinguish light sources, since massive number of pixels is available

## CONCLUSION

In this study the challenges of visible light communication were analysed with respect to its implementation in fully-optical autonomous sensor module, which is capable of self-powering, taking measurements and communicating with environment by means of light. The VLC for such application was chosen

as an alternative to RF for the environments, where electromagnetic waves are unwanted or unsuitable. The general issues of the VLC link design, such as noise and interference on the receiver, saturation of photodetector, limited spatial path diversity in wireless sensor network, were identified and the possible solutions were proposed. To sum up, the design of a network of autonomous sensor modules communication in terms of light is an demanding task, however, a lot of research in VLC field is bringing new sophisticated ideas, which are likely to follow in near future.

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