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Software Design of SMD LEDs for Homogeneous Distribution of Irradiation in the Model of Dark Room

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Abstract. *This article describes wireless optical data networks using visible spectra of optical radiation with a focus on interior areas with direct line of sight LOS (line-of-sight). This type of network represents progressively evolving area of information technologies. Development of lighting technologies based on white power LED was the impulse for wireless optical data networks based on visible spectra of optical radiation development. Its basic advantage is the flexibility of users. Users do not have to stay on one place during the data sharing anymore. Wireless optical data networks represent an alternative solution for metallic and fiber networks [1], [2]. This paper deals with the software simulation of homogeneous distribution of optical irradiation in dark room model, carrying out in LightTools software. First, in previous simulations, the optical source composed from 9 SMD LED's type LW G6SP-EAFA-JKQL-1 was designed. In various simulations, various numbers and distributions of LED's were used. These were placed at the ceiling of a dark room. At last, the results of optical irradiation homogeneity are compared.*

Keywords

Homogenous distribution, LightTools software, simulation, SMD LED.

1. Introduction

In the beginning, the optical wireless link is described. This optical wireless link operates in visible spectra of optical radiation (380–780 nm). Next, the visible light communication (VLC) system operation principle is described, which allows line of sight (LOS) transmission and also non-LOS transmission between the transmitter and receiver. VLC transmitter consists of two main parts. From the control circuit and LEDs. The transmission medium is air. VLC receiver consists of receiving optical elements as photodiode, optical filter and others. VLC systems are sensitive to the sun and other types of radiation. White power LEDs are mostly used as a source [3]. To adjust the brightness of LEDs, various modulations are used, such as amplitude modulation (AM), pulse-width modulation (PWM), pulse-frequency modulation (PFM) and the bit angle modulation (BAM).

In the next part of the paper, photometric quantities are described. These are quantities related to electromagnetic radiation, which can be captured by the human eye.

The second part of this paper is focused on LightTools simulations. In the beginning, the model of a dark room was created. In this model, all the simulations were carried out. The appropriate 3×3 LED panel was designed. This LED panel was used as a basic simulation source. During the simulations was the number of basic 3×3 LED panels changed.

2. Optical Wireless Communication

Optical wireless communication (OWC) is a basic term for wireless communication with optical technology. OWC includes infrared (IR) communication for short distances and free space optics communication (FSO) for bigger distances. The visible light communication (VLC) is described by the technology, which uses visible light as an optical medium for data transfer and illumination. Nowadays, the LEDs with wavelengths from 380 to 720 nm are used. Silicon photodiodes with acceptable responses are also often used for receiving [4]. At the present stage of VLC research, the main focus is on its application in indoor areas. Channels used by VLC in indoor areas are adapted from IR communication. The difference between IR and VLC is in used different wavelengths. The infrared link is divided into four basic types according to existing light obstacles in the way of light and directivity of the transmitter to the receiver [5].

The basic types of link involve the direct line of sight (LOS) and the non-direct line of sight (non-LOS), the direct non-LOS and the non-direct non-LOS. Whether the link is direct or none direct depends on whether the transmitter is in the direction of the receiver. In the case of LOS or non-LOS it depends on whether there is an obstacle between the transmitter and receiver during the communication. In VLC system, it is very important non direct LOS due to the illumination of the environment, which could be aimed or direct. LOS system transfers the signal within one direction without any obstacles from the transmitter to the receiver. The area without any obstacles between transmitter and receiver is a condition [6]. If this condition is not followed, there is a decrease of signal quality. The size of the zone without obstacles depends on operating frequency and the distance from the transmitter to the receiver. The non-LOS system, unlike the LOS system, uses reflections from the elements in space and does not transmit a signal within one direct route, so it is also known as diffusion system. These systems operate regardless to obstacles or persons in the space. The disadvantage of this system is their reduced transmission capacity due to the complexity of the signal path [7].

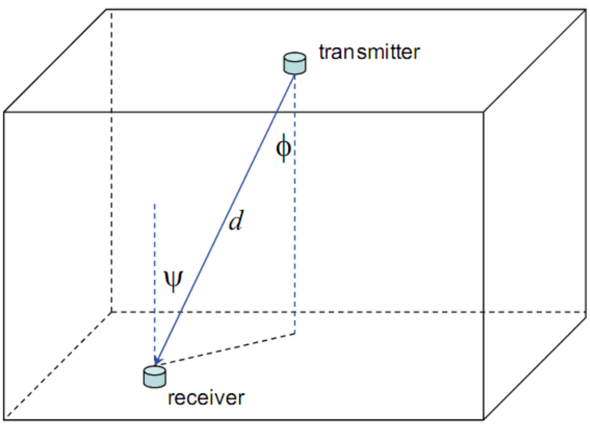


Fig. 1: Indoor, non direct LOS VLC link geometry.

In Fig. 1 is a simplified geometry in indoor area. This is non direct LOS link with the transmitter mounted on the ceiling and the receiver on the floor [8].

Received optical power is calculated in Eq. (1):

$$P = P_t \cdot \frac{m+1}{2\pi d^2} \cdot \cos^m(\phi) \cdot T_S(\psi) \cdot g(\psi) \cdot \cos(\psi), \quad 0 \leq \psi \leq \Psi_C, \tag{1}$$

where P_t is transmitted power of LEDs, ϕ is radiation angle to the axis perpendicular to the surface of the transmitter; ψ is angle of incidence to the axis perpendicular to the surface of receiver, d is the distance between LEDs and the detector surface. $T_S(\psi)$ is the transmission filter. $g(\psi)$ is the gain of concentrator. Ψ_C is the field of view concentrator, with a half angle is the half power. m is the serie of Lambert sources and it's given by the half angle of transmitter $\phi_{1/2}$ as:

$$m = \frac{-\ln_2}{\ln(\phi_{1/2})}, \tag{2}$$

where $m = 1$ in case of $\phi_{1/2} = 60°$ (Lambert transmitter). According to the axial symmetry of the Fig. 1 $\phi = \psi$. In front of the photodetector can be used optical filter and concentrator [9].

2.1. VLC Transmitter

The main parts of VLC transmitter are visible LEDs. The configuration of VLC link and VLC transmitter is shown in Fig. 2. The difference between VLC transmitter and conventional communication transmitter is that VLC transmitter has to be operating as transmitter and also lightening simultaneously.

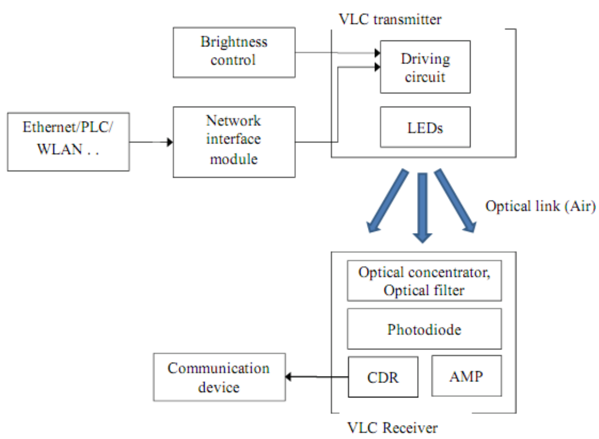
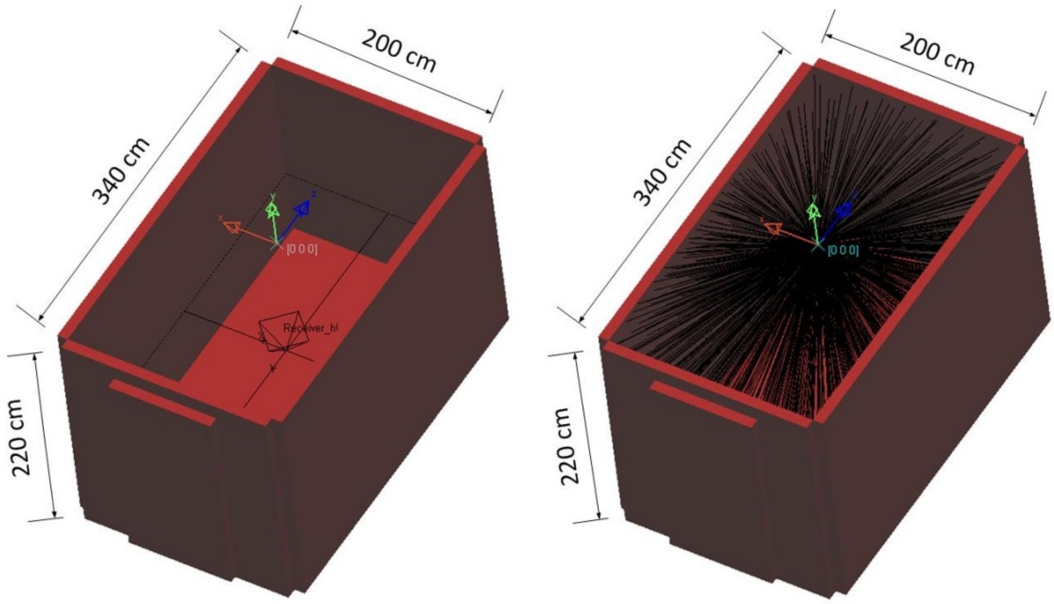


Fig. 2: Configuration of a VLC link. (CDR: clock and data recovery, AMP: amplifier, PLC: power line communication, WLAN: wireless LAN)[7].

VLC transmitter usually uses the visible LEDs as the modulation device for an optical carrier for visible light for communication. For LEDs data modulation, it must be taken into account the modulation bandwidth of visible LED light. LEDs with visible light are



(a) Before simulation (b) After simulation

Fig. 3: Scheme of a dark room in LightTools.

mostly diodes with high brightness and manufacturers did not evolve them for communication purposes. Although most of the LEDs with visible light used for lightning have modulation bandwidth of tens of megahertz. Despite this limitation, these diodes can be used for easy messages delivering.

VLC transmitter has to operate also as lightening. Requirements for interior lightening of office spaces are according to the ISO standards set to 200–1000 lx. LEDs with high brightness operate with high currency > 100 mA, which is an unusually high current compared to usual communication devices. Construction of VLC transmitter is a little bit difficult to maintain the level of illumination and data modulation for high brightness LEDs [10].

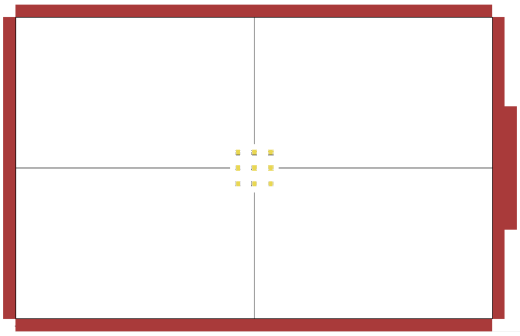
2.2. VLC Receiver

VLC receiver consists of receiving optical elements, including an optical concentrator and an optical filter, a photodiode, an amplifier and the signal recovery circuit (Fig. 2). VLC system is designed to utilize the direct detection of the photodiode. The optical concentrator is used to compensate for the high spatial attenuation due to beam divergence of LEDs for lighting large areas. Since the wavelength range is different from the infrared communication, the design parameters of the PLC system need to be changed according to the construction for infrared communication [11].

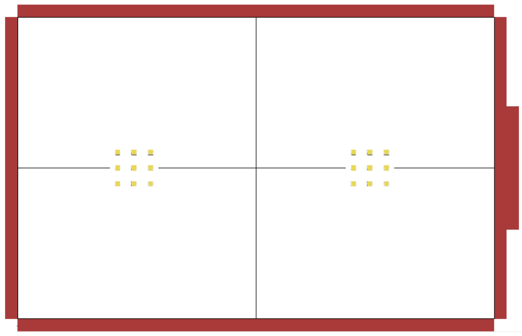
VLC system is sensitive to sunlight and other lighting and it is, therefore, important to use the appropriate optical filter to discard unwanted spurious components in the recovered data signal. Photodiodes with good sensitivity of visible light are p-type silicon-insulator-n-type photodiodes (Si PIN-PD) and silicon avalanche photodiodes (Si APD). Silicon photodiode operates in the range from 400 to 1200 nm, where visible light spectra are located, too [13]. There are many types of photodiodes with spectrum range wider than 200 MHz, which is more than with VLC LED transmitter. There are several types of amplifiers signals. Among them, a high-impedance amplifier and a transimpedance amplifier. High-impedance amplifier is easy to perform. Series resistor is connected to the anode of the photodiode and high input impedance amplifier senses the voltage across the series resistor and amplifies it. Transimpedance amplifier performs the conversion of current to voltage using a shunt resistor feedback about inverting amplifier [14]. In general, the noise of VLC receiver is similar to the noise of the receiver for the optical communication, for example, thermal noise of the load resistor and photodiode, excessive noise of the amplifier. The main components of the noise are sunlight and other light [12].

3. LightTools Software

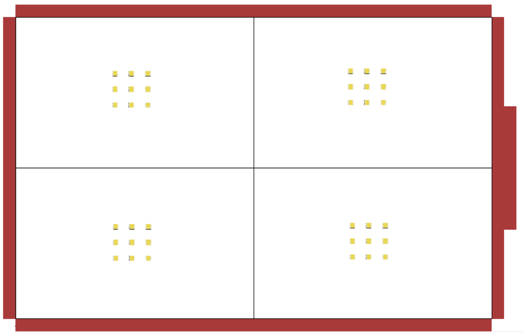
LightTools software provides an efficient modeling system with full optical accuracy and precision. Its unique design and analysis capabilities combined with ease of use allow lighting design according to predetermined specifications. Design and simulations are performed



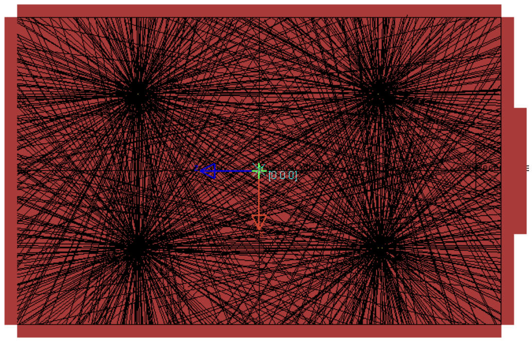
(a) One LED panel



(b) 2 LED panels

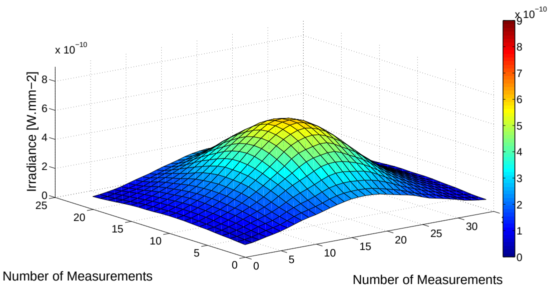


(c) 4 LED panels

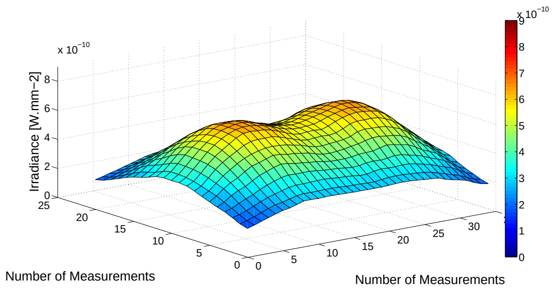


(d) Running simulations for 4 LED panels

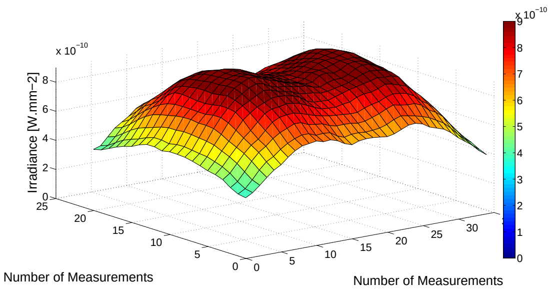
Fig. 4: Distribution of LED panels.



(a) One LED panel

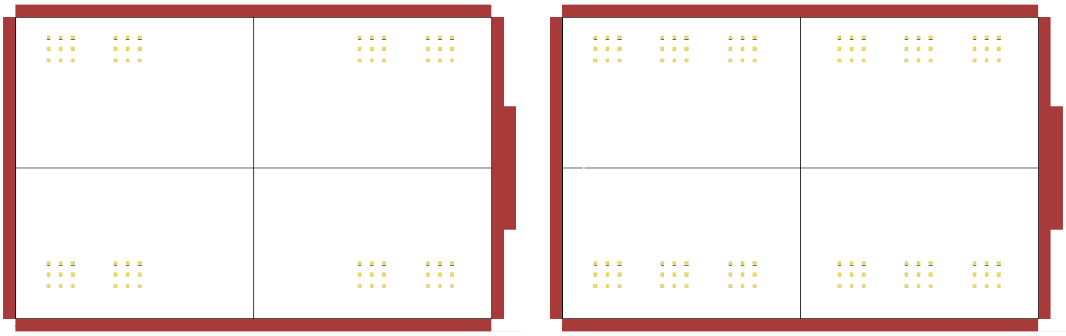


(b) 2 LED panels



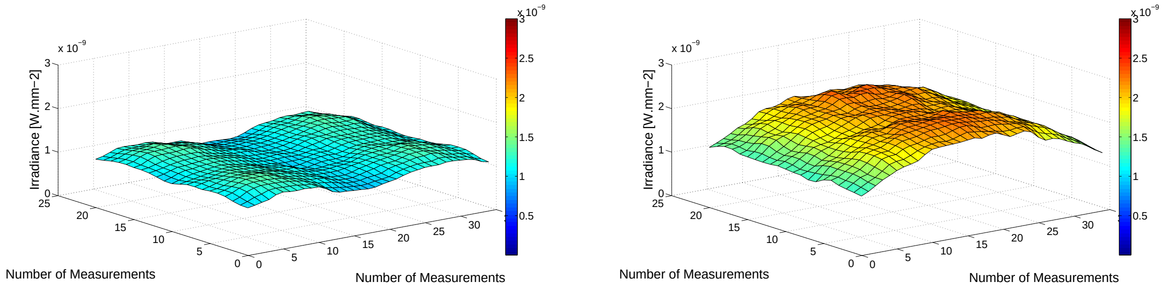
(c) 4 LED panels

Fig. 5: Optical power distribution.



(a) 8 LED panels (b) 12 LED panels

Fig. 6: Distribution of LED panels.



(a) 8 LED panels (b) 12 LED panels

Fig. 7: Optical power distribution.

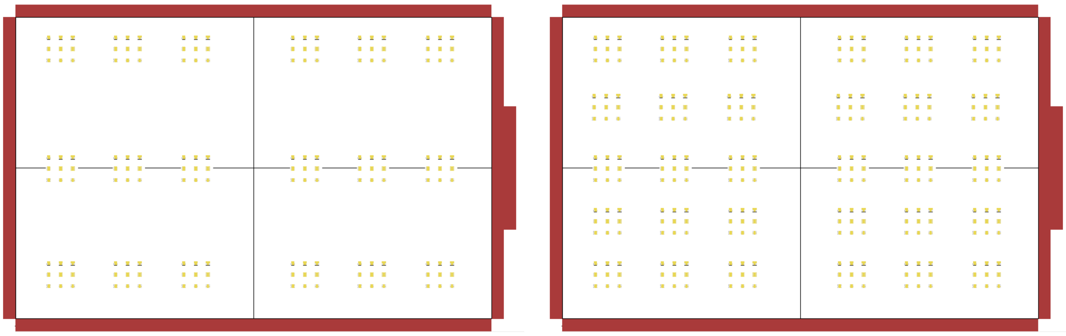
by inserting individual components directly into 3D models. These components may have variable size, position, and orientation. Monitoring rays give us a description of the optical behavior of the proposed system. This program is also able to calculate the total intensity distribution of light in the created object. It also allows the user to set a large number of optical surfaces for various geometric objects. In the software library, there is a great number of different optical sources, materials, and lenses, for which any of the selected optical surfaces can be used. The components that are not in the LightTools library can be imported from other programs [15]. In this paper, the model of a dark room is used (Fig. 3(a)). This model was created using the dimensions of the real laboratory at the Technical University. Each wall was measured at three points and from measured values the diameter was taken. In the center of the room, one LED panel of 3×3 LEDs is placed. In Fig. 3(b) the distribution of optical power in a dark room after running simulations can be seen .

4. Measurement and Result

The simulations were carried out in the LightTools software. As a basis for the simulation, it was necessary to establish the model of a dark room first; this is shown in the Fig. 3. This model is based on real measured values. The inner walls of the dark room are lined with a material that does not reflect light. In the room, there are no obstacles. Therefore the proposal was based on the assumption that the light is not reflected in the room, and therefore no reflectance value from the elements was observed.

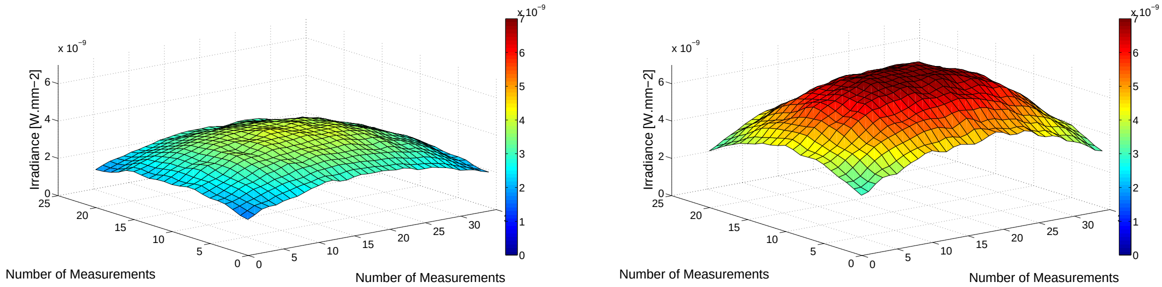
First, the suitable shape of LED panel was designed. For simplicity of shape and good emissivity the square panel shape was chosen. This panel was mounted in the middle of the ceiling of the room as shown in the Fig. 4(a). Then, the second panel was added. Each one of these panels was placed in the center of each half of the room, as shown in Fig. 4(b). In another configuration 2 LED panels were added and placed in the center of each quarter of the dark room, see Fig. 4(c). In Fig. 4(d) the visible light distribution of 4 LED panels can be seen after running the simulations.

The simulations results of the optical power distribution of the first three layout design are shown in Fig. 5(a), Fig. 5(b) and Fig. 5(c). Z axis was set in the range 0 to $9 \cdot 10^{-10}$ W·mm^{-2} for better presentation. The maximum optical power using one LED panel is in the middle of the room and its value is $6.022968 \cdot 10^{-10}$ W·mm^{-2}. The minimum value of the optical power is in the corner with a value



(a) 18 LED panels (b) 30 LED panels

Fig. 8: Distribution of LED panels



(a) 18 LED panels (b) 30 LED panels

Fig. 9: Optical power distribution.

$6.1360041 \cdot 10^{-11}$ W·mm^{-2}. The average value of optical power for one LED panel is $2.4822312231 \cdot 10^{-10}$ W·mm^{-2}. After adding another LED panel, the coverage of optical power at the edges of the room was improved, Fig. 5(b). The minimum value for this layout has a value $1.7329237 \cdot 10^{-10}$ W·mm^{-2}. The maximum value for the distribution of 2 LED panels just grew and was measured at two points with a value $6.4948348 \cdot 10^{-10}$ W·mm^{-2}. These points are located below each LED panels. The average value of optical power for 2 LED panels is $4.2094048263 \cdot 10^{-10}$ W·mm^{-2}. In the following simulations were added 2 LED panels as shown in Fig. 4(c). Results of a construction LED panels can be seen in Fig. 5(c). Again, increased minimum value was measured at the edge of the room. Its value is $3.9186581 \cdot 10^{-10}$ W·mm^{-2}. It also increased the maximum value of the $1.002408 \cdot 10^{-9}$ W·mm^{-2}. More important is that around the room begins to create homogeneously optical performance. The average value of optical power for 4 LED panels is $7.6249855811 \cdot 10^{-10}$ W·mm^{-2}.

In the next simulations, LED panels were added gradually. In Fig. 6(a) the distribution of 8 LED panels in the room edges can be seen . This shift to the room edges was chosen because of the best homogeneity of the optical power in the whole room. In Fig. 6(b) there is the scheme with 12 LED panels.

In this part of simulation, the z axis was set in the range 0 to $4 \cdot 10^{-9}$ W·mm^{-2}. In Fig. 7(a) the optical power distribution in the dark room with 8 LED panels can be seen . The maximum value of optical power is $1.3466686 \cdot 10^{-9}$ W·mm^{-2}. The minimum value of optical power is for the first time located not in the room corner, but in the middle of the longer room wall. Its value is $9.3246777 \cdot 10^{-10}$ W·mm^{-2}. In Fig. 7(a), there can be observed the increase of the homogeneous distribution of the optical power. The average value of the optical power with 8 LED panels is $1.16064346234 \cdot 10^{-9}$ W·mm^{-2}. In Fig. 7(b) are shown simulations results for 12 LED panels. The minimum value of the power increased to 1.2659695^{-9} W·mm^{-2} and again, it's placed in the middle of the longer room wall. The maximum power for this distribution is $2.3353532 \cdot 10^{-9}$ W·mm^{-2}. The average value of the optical power for this concept is $1.91278655224 \cdot 10^{-9}$ W·mm^{-2}.

In the last part of simulations, 18 and 30 LED panels were used. In Fig. 8(a) is shown the configuration for 18 LED panels and in Fig. 8(b) is the configuration for 30 LED panels.

In this part of simulation was z axis set in the range 0 to $7 \cdot 10^{-9}$ W·mm^{-2}. In Fig. 9(a) the optical power distribution for 18 LED panels can be seen. The maximum optical power value is $4.107196 \cdot$

10^{-9} W·mm^{-2}. The minimal optical power value is $1.7347025 \cdot 10^{-9}$ W·mm^{-2}. The average optical power value is $3.12255773034 \cdot 10^{-9}$ W·mm^{-2}. Again, the increase in average optical power in the room can be observed. The optical power distribution for 30 LED panels is shown in Fig. 9(b). The maximum optical power value is $7.2107355 \cdot 10^{-9}$ W·mm^{-2}. The minimal optical power value is $2.8400082 \cdot 10^{-9}$ W·mm^{-2}. The average optical power value is $5.40594893265 \cdot 10^{-9}$ W·mm^{-2}.

5. Conclusion

Recently, the wireless optical networks for indoor spaces operating in visible spectral range (VLC) are coming to the fore. The reason is the development in semiconductor lighting technology mainly in case of white power LEDs (Light Emitting Diodes). The white power LEDs are divided into two categories. The first one is using blue chip (450 nm) and yellow luminophore, known also as YAG (Yttrium, Aluminium, Garnet), or $Y_3Al_5O_{12}$ or $Y_3Al_5O_{12}$:Ce_3 eventually deposited on this chip. The second category is using triple RBG chip (red, green and blue), where the resulting white light is produced by composition of these colors.

This work deals with an optical link for indoor wireless optical network used LED as source visible light communication. The first chapter introduces wireless optical network and its mathematical expression. As the radiation source, we used power LEDs. These are used for data transmission and at the same time of lighting. Transmission medium is air. Possibility to adjust the brightness of the LEDs allows for different modulation.

In the next section, simulations in LightTools were carried out in the LightTools software. The LED panels were placed on the ceiling of the model of a dark room. Then the number of LEDs panels was changed as well as their distribution on the ceiling of the room. The number of LED panels was gradually changed from 1, 2, 4, 8, 12, 18, 30 LED panels. The results show that the differences between the average values of the optical irradiance in the model of a dark room increase. For 1 LED panel, the average value $2.4822312231 \cdot 10^{-10}$ W·mm^{-2} and for 12 LED panels, this value increased 7.71 times. Value for 30 LED panels was even 21.78 times higher than for 1 LED panel. The simulations were done according to the input parameters of SMD LED type LW G6SP-EAFA-JKQL-1.

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