VLC Transmitter with Plastic Optical Fibers for Indoor Free Space Optic Networks

Jan VITASEK, Petr SISKA, Stanislav KEPAK, Jakub CUBIK, Radek POBORIL and Jan LATAL

Department of Telecommunications, Faculty of Electrical Engineering and Computer Science, VSB–Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava, Czech Republic.

jan.vitasek@vsb.cz, petr.siska@vsb.cz, stanislav.kepak@vsb.cz, jakub.cubik@vsb.cz, radek.poboril@vsb.cz, jan.latal@vsb.cz

Abstract. *This article deals with the construction design of optical transmitter for indoor Free Space Optic (FSO) networks. This optical transmitter will be able to provide the lighting and communication at the same time. Thanks to special solution in spectral characteristic of transmitted light it is necessary to use two LEDs radiation sources. The light beams of these LEDs have to be spatially overlapped in crisscross direction and then the transmitter can realize both functions. There is described a construction of optical transmitter with plastic optical fibers which merges two LED beams together and provide lighting and communication at the same time.*

Keywords

Illumination, indoor FSO, LED, plastic optical fiber, transmitter, Visible Light Communication VLC.

1. Introduction

The most important parameters of communication for normal user are high data rate and mobility. Radio wireless networks could realize these two parameters, therefore they became so successful. However, user demands on data rate continuously increase; therefore it is necessary to find other solutions and improvements. In this field optical links begin gradually more and more establish, because they are able to provide high data rate and mobility is also possible. Visible Light Communication (VLC) is a promising example of optical technology, which could be used in indoor spaces. VLC holds attention in academia and industry thanks to large progress in development of LEDs. Current LED features are at the level, which enables them gradually replace classical illumination sources (incandescent light bulbs and fluorescent lamps). Moreover, LEDs could be modulated at high bit rates in comparison to classical illumination sources. Therefore LED features directly challenge using them for illumination and communication at the same time.

The advantage of optical communication is high data rate, no legislative restriction, no interferences with radio links, small size, low power consumption and data safety. On the other side, it is necessary to keep limits of optical power for human eyes and to square up with optical noise.

2. Current Indoor Free Space Optic Networks

Indoor FSO networks could be divided according to the line of sight between transmitter and receiver and according to directivity of transceivers [1]. The other classification is according to used optical spectrum, which is more important and more interesting for this article. Presently, the infrared (IR) light or visible light are used for communication indoor [2]. IR transmission is defined by several standards with different bit rates. The highest bit rate according to IrDA association is 16 Mb$\cdot$s^{-1} [1]. Using visible light for communication has several advantages, which have been mentioned above. Moreover, VLC also provides illumination. Several experiments have been done, when the bit rate greatly exceeds 100 Mb$\cdot$s^{-1} [2]. This is substantially more than IR can provide. This is also the reason, why using of white light for illumination and IR for communication is not advantageous. In addition, stricter optical power limits hold for IR. As expected, VLC also has a disadvantage. This disadvantage is white light emitting LED.

3. Current Visible Light Communication VLC

White LEDs are key elements for Visible Light Communication VLC. White light creation is not simple issue, which reflects in VLC features. Presently, VLC uses the whole emitted spectrum of white LED for data transmission.

There exist two main methods, how to create a white light using LEDs. The first method uses more color light sources; the other method uses a blue light source and a suitable wavelength converter, e.g. yellow phosphor [3] [4]. The first type of white LED consists of three light sources (blue, green, red) which are supplied in correct proportion. This method is more complex and more expensive [2], but enables to create any other color. VLC needs power LEDs for a sufficient coverage of required space by light. The forward current of power LED is up to 700 mA [5]. If power LED should provide illumination and communication at the same time, it has to be modulated fast enough. But quite high forward current can limit the modulation rate thanks to switching on and off [6].

The other type of white LED consists of a blue light emitting chip. A portion of blue light excites a yellow phosphor (Yttrium Aluminium Garnet $Y_3Al_5O_{12}$), which creates yellow light. Mixing of blue and yellow lights creates a white light. The modulation rate is limited by slow response of phosphor. This method is simpler and cheaper.

Thanks these limitations we proposed a new type of transmitter for indoor FSO networks which uses only a part of visible spectrum for data transmission. The part of original spectrum emitted by white LED is purposely suppressed by optical notch filter. The suppressed part is then replaced by light from another LED which will be modulated. Both these LEDs create together original white light. The advantage is, that white power LED emits continuously, therefore the disadvantages of high current switching or phosphor delay do not appear. The useful data will be transmitted by a narrow spectral LED, which replaces the suppressed part. It will be supplied by lower forward current and therefore it can be modulated faster. The problem is how to merge two optical beams from the power LEDs spatially together. The aim of this article is not a description of new VLC method, it has been described in [7] and [8]. The aim is a solution of problem how to spatially merge two optical beams together into one beam.

Nowadays, VLC is very interesting area for research, many calls and project are aimed at improving and searching new possibilities of VLC.

4. Spatial Merging of Beams from LEDs

The one solution of this problem has been found and presented in [9]. We have thought out, set and measured still another solution. The basis of beams merging are again parabolic reflectors [10], which were set to the power LEDs and beamsplitter 50T/50R. The beamsplitter 50T/50R merges two optical beams in power and spatial properties correctly and it creates original white light. The disadvantage of beamsplitter 50T/50R is a deflection of a half of optical power. In [9], a mirror was used to parallel direction of beam.

The basis of this type of optical transmitter is two plastic optical fibers [11]. The plastic optical fibers were chosen thanks to their large diameter. The diameter of cladding is 10 mm; the diameter of core is 8.6 mm. Other optical properties are summarized in Tab. 1. The light which passed through beamsplitter would be very difficult to couple in classical optical fiber and the loss of optical power would be great.

Tab. 1: Optical properties of plastic optical fiber.

Title	Symbol	Value
Core Diameter	d_1	8.6 mm
Outer Diameter	d_2	10 mm
Refractive Index: Core	n_1	1.492
Refractive Index: Cladding	n_2	1.343
Numerical Aperture	NA	0.65
Spectral Trans. Range	$\Delta\lambda$	380–750 nm

The first beam from beamsplitter's output is coupled into the first plastic fiber; the other beam from other beamsplitter output is coupled into the other plastic fiber. For coupling beams into plastic fibers two achromatic lenses AC254-030-A-ML [12] were used. The lens is achromatic doublets for visible part of spectrum. The diameter of lens is 25.4 mm; focal length is 30 mm. All important parameters of achromatic lens are written in Tab. 2.

Tab. 2: Important parameters of achromatic lens.

Title	Symbol	Value
Lens Diameter	D	25.4 mm
Focal Lenght	f	30.0 mm
Back Focal Lenght	f_b	22.9 mm
Radius of Curvature	R_1	20.9 mm
Radius of Curvature	R_2	-16.7 mm
Radius of Curvature	R_3	-79.8 mm
Center Thickness	t_{c1}	12.0 mm
Center Thickness	t_{c2}	2.0 mm
Edge Thickness	t_e	8.8 mm

When the light is coupled into plastic optical fibers, the ends of plastic fibers could be suitable located on the ceiling of room and perform the best light coverage of room. For suitable coverage two fibers will not be sufficient, therefore another light dividing into more fibers is supposed, which ensures required coverage. The ends of fibers will be specially modified for effective room coverage. In this article the coupling from beamsplitter into plastic optical fibers is solved. The scheme of optical transmitter is in Fig. 1.

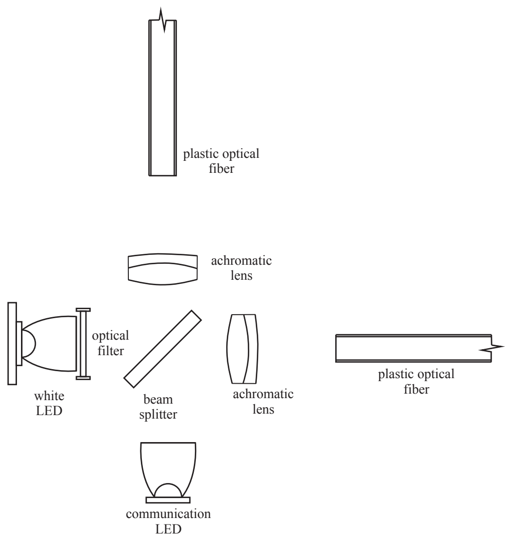

Fig. 1: Scheme of optical transmitter.

The construction of this transmitter depends on the correct placing of plastic fibers inputs for the utmost light coupling. For this purpose a simulation in software LightTools was done and its results were verified in laboratory on transmitter prototype which was set from optical components on optical table.

5. Simulations in LightTools

Software LightTools enables modelling of various optical systems. Its unique design and analyzing features combined with its simple way of operation, its support of a quick design and optimization make obtaining of results according to the predefined conditions possible. This software includes a large component library. It is possible to change many parameters. The results are very precise [13].

In software LightTools the optical transmitter with plastic optical fibers was created, as shown in Fig. 2. The target of simulation was to find out whether it is possible to couple the beams from beamsplitter into plastic fibers. The important element is achromatic lens which collimates the beam in its focus. Thanks to the software LightTools it was possible to simulate how small beam spot the achromatic lens creates and in what distance from the end of lens it is. In this place, the inputs of plastic fibers were placed for the best light coupling.

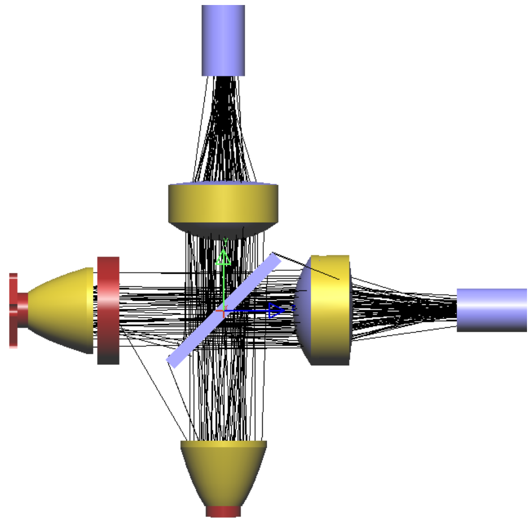

Fig. 2: Simulation in LightTools.

In software LightTools a measuring plain was created. This measuring plain was placed in distance 18 mm from the end of achromatic lens and the simulation was run. The evaluative criterion was a Full Width at Half Maximum (FWHM). A target was to find such distance in which a beam spot is the narrowest. The results calculated by simulation are summarized in Tab. 3. From this table it is obviously that the narrowest beam spot is in distance 24 mm from the end of achromatic lens.

Tab. 3: Simulation of the narrowest beam spot.

Distance [mm]	**FWHM$_x$** [mm]	**FWHM$_y$** [mm]
18	8.59	8.59
19	8.54	8.54
20	8.47	8.48
21	8.41	8.41
22	8.40	8.41
23	8.39	8.39
24	**8.37**	**8.38**
25	8.41	8.41
26	8.44	8.43
27	8.49	8.48
28	8.53	8.54
29	8.59	8.59
30	8.66	8.65

Further it was simulated in LightTools how much of optical power reaches the core of plastic optical fiber and how much reaches the cladding. The software calculated that 96.6 % of optical power, which passed through the lens, reaches the core in the first one way, in the other one way it was 96.4 % of optical power.

6. Measurement in Laboratory

The simulation in software LightTools showed that it is possible to set an optical transmitter with plastic optical fibers. In laboratory on optical table, the optical transmitter was constructed. The scheme is in Fig. 2. The constructed transmitter is consonant with transmitter which was created in software LightTools.

It was measured in which distance from the end of achromatic lens the spot of merged beam is the narrowest. For this purpose a measurement was done, its aim was to measure the beam spot in several distances from the end of achromatic lens and to find in such way the distance in which the beam spot is the narrowest. Two motorized linear translation stages and powermeter with photodetector were used to measurement.

Beam profiles were measured in several distances from the end of achromatic lens. The powermeter was placed in distance 18 mm from the end of achromatic lens. Powermeter moved in transverse direction with step 1 mm. In this the beam profiles were measured in the range from −15 mm to 15 mm. Then the powermeter was moved in distance 19 mm from the end of achromatic lens and the beam profile was measured again. In this way the beam profiles were measured up to distance 30 mm from the end of achromatic lens. For each distance a graph of relative optical power was set to measure FWHM. The measured results are summarized in Tab. 4. It is obviously from this table that the narrowest beam spot was in distance 24 mm from the end of achromatic lens. This result is consonant with the simulation in LightTools which is summarized in Tab. 3. The profile of beam spot in y-axis direction was also measured in distance 24 mm. FHWM_y was 8.99 mm in this distance.

Tab. 4: Measurement of the narrowest beam spot.

Distance [mm]	$\mathbf{FWHM}_x$ [mm]
18	9.42
19	9.35
20	9.25
21	9.18
22	9.13
23	9.11
24	**9.04**
25	9.13
26	9.18
27	9.25
28	9.35
29	9.54
30	9.73

7. Conclusion

The simulation and the real measurement of optical transmitter with plastic optical fibers investigated above all the coupling of light beams into plastic fibers by achromatic lenses. The simulation showed that the beam could be focused to couple into plastic optical fiber, because the beam spot is enough narrow. The LightTools calculated how much percent of optical power couples into optical fiber. The measurement found the position in which the optical power is the greatest. After that the measurement of beam profiles behind the achromatic lens was done.

The simulation measured narrower FWHM than the measurement. It is given by higher precision of simulation in comparison to measurement. The important is that the narrowest beam spot is in distance 24 mm from the end of achromatic lens. Simulation and measurement agreed well.

The simulation and the measurement showed that it is possible to set an optical transmitter with plastic optical fibers. This transmitter is not finished yet, further it is necessary to deal with distribution of light coupled into plastic optical fibers.

Other next step is a construction of modulator with suitable modulation and line code for bit rate testing. It seems that OOK with Manchester coding should be interesting for this VLC transmitter.

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About Authors

Jan VITASEK was born in Opava. In 2009 he finished M.Sc. study at Brno University of Technology, Faculty of Electrical Engineering and Communication. In 2014 he finished Ph.D. study at Department of Telecommunications, VSB–Technical University of Ostrava. His interests are Free Space Optics, indoor Free Space Optics networks and visible light communication. He is a member of SPIE. He is engaged in project dealing with VLC.

Petr SISKA was born in 1979 in Kromeriz. In 2005 he completed his M.Sc. studies at VSB–Technical University of Ostrava. Three years later he completed his Ph.D. studies. He is currently employed at the Department of Telecommunications. He is interested in optical communications, fiber optic sensors and Distributed Temperature Sensing systems.

Stanislav KEPAK was born in 1987 in Ostrava. In 2009 he received Master's degree in the field of Telecommunications. He is currently Ph.D. student, and he works in the field of optical communications and fiber optic sensor systems.

Jakub CUBIK was born in 1986 in Olomouc. In 2011 he received Master's degree in the field of Telecommunications. He is currently Ph.D. student, and he works in the field of optical communications and fiber optic sensor systems.

Radek POBORIL was born in Valasske Mezirici. He received his M.Sc. degree from the VSB–Technical University of Ostrava, Faculty of Electrical Engineering and Computer Science in 2013. Currently in a Ph.D. student, he focuses on optical technologies and especially on WDM/TDM PON.

Jan LATAL was born in Prostejov. In 2008 he was awarded his M.Sc. degree at VSB–Technical University of Ostrava, Faculty of Electrical Engineering and Computer Science, Department of Electronics and Telecommunications. He is currently Ph.D. student, and he works in the field of Wireless Optical Communications, Optical Communications and Distributed Temperature Sensing Systems.