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A Survey on Solar Cell based receivers used for Optical Wireless Communication

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ABSTRACT

As of now, the Radio Frequency (RF) Spectrum results in heavy spectrum congestion. The available bandwidth in case of RF spectrum is not enough to satisfy the demand. Optical wireless communication (OWC) evolved as an alternate choice to beat the RF spectrum congestion. OWC utilizes a broad range of unlicensed and unregulated spectrum. OWC indicates Optical Wireless Communication with the help of visible light (VL), infrared (IR), and ultraviolet (UV) rays as its various sources. Visible Light Communication (VLC) is used to both illuminate and communicate at the same time. There can be innumerous types of optical receivers being used for VLC reception with low bit error rate (BER). In this Survey paper, we have reviewed different types of OWC Receivers and their performance comparison. This summary can help researchers to identify the receiver which suits their research.

Keywords: Photodiode, Image Sensor, Solar Cell, Data Communication, Energy harvesting.

I. INTRODUCTION

In Contemporary communication systems, the foremost known frequency band is Radio Frequency (RF) band. Thanks to little interference within the frequency band and wide coverage. However, heavily congested RF spectrum alongside increasing wireless network traffic needs higher bandwidth and spectral relief [1]. The Optical Wireless Communication (OWC) is considered an alternative choice for the RF Communication. High data rate of 30 Gbps achieved by OWC that operates at 350nm to 1550 nm wavelength range [2]. OWC is classified into Visible Light (VL), ultraviolet (UV) and infrared (IR) ray communication.VLC is one of the Choices. It is a communication medium with the illuminating devices such as LED's and Laser Diodes. Developments in LED technologies has provided way to modulate LED at upper frequencies so that human eye is not able to sense modulation. Because LED's cost less, have high lifetimes and consume less power, in future LEDs are supposed to replace fluorescent lamps and incandescent lamps. This paves the way for the utilization of LEDs to both illuminate and communicate at the same time, thus making VLC a cost effective and efficient transmission solution [3].

II. OPTICAL WIRELESS COMMUNICATION

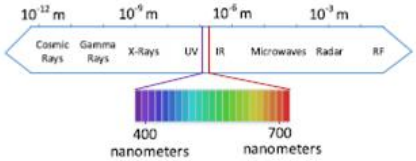

Fig 1. Electromagnetic spectrum and visible light region [3]

In Fig.1, the EM (Electromagnetic) spectrum is illustrated. OWC is divided into three portions i.e. Visible Light (VL), Ultraviolet (UV) and Infrared (IR) . VL (Visible light) portion indicates to the region where the wavelength is in between 400 nanometers and 700 nanometers. EM (Electromagnetic) Waves in the visible light wavelength are not harmful for humans. This is not the scenario with RF (Radio Frequency) communication. VLC systems don't interfere with the operation of the electronic devices.

In the case of the RF communication, huge transmitting powers create a health hazard. In the case of VLC, there are no restrictions on the transmitted power [4]. The visible light portion of the frequency spectrum is unlicensed / unregulated. Hence the cost of the technology drops [19]. This is a huge bandwidth. It is useful for a variety of applications. Infrared is extensively used in TV remote controls.

One of the crucial elements of an Optical Communication System is Optical Receiver. The

modulated light streams carrying data is input to the receiver. It determines the total system performance. The Optical receiver detects the input optical power and extracts the signal. The extracted signal is transmitted. At the same time, it should also satisfy system requirements such as the desired level of SNR (signal-to-noise ratio) and BER (bit error rate) [18]. Photodiode / Image sensor / Solar Cell is the major element of the optical Receiver. The optical receiver converts the optical signal into an electric signal. Then it amplifies the signal to a level so that it is processed by the electronics next to the amplifier.

III. PHOTODIODE, CAMERA / IMAGE SENSOR AND SOLAR CELL AS RECEIVER

PHOTODIODE BASED RECEIVER

For OWC systems, main elements of receiver are, PIN (Positive-Intrinsic-Negative) Photo Diodes and avalanche photodiodes (APDs) because they are able to provide speedy photodetection. These photodetectors require external power to work. This is the major drawback. By replacing the Photo Diode with a solar panel, this drawback can be avoided. The solar panel is able to convert the optical signal to an electrical signal, without an external power supply whereas the Photodiode needs a trans-impedance amplifier (TIA) to amplify its current output.

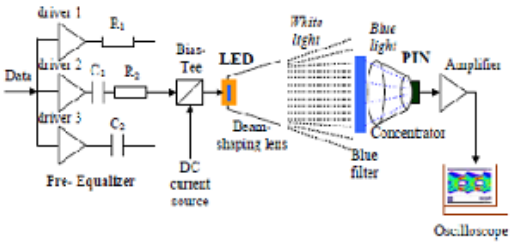

Fig 2. Photodiode based Receiver [10]

The photodiode can cover only a short communication distance. Because of artificial and natural light sources, there is interference. Received signal strength will be attenuated by a large amount. Streetlights, radiation from the sun, and other sources in the ambient environment, generate noise. These are the limitations of photodiode. These can be easily overpowered using an Image Sensor based receiver [5]. In the place of photodiode if we use a solar panel, it simplifies the receiver circuitry. Hence there is no need of a trans-impedance amplifier (TIA).

SOLAR CELL BASED RECEIVER

A Solar cell can be used as a light sensor in place of photo-diode. It has the benefits of a huge light gathering area, simpler hitting of light from light source, does not need an external power supply and no need of trans-impedance amplifier (TIA). Indirect sunrays and fluorescent lamps create noise . This is a major problem that affects the performance of the communication system [6].

Energy harvesting and data acquistion can be attained at the same time by means of a Solar-cell-based OWC receiver . A component that needs a power supply is an active element. Photo-detector is an active component. Photodetectors are of two types – PIN (Positive-Intrinsic-Negative) and APD (Avalanche Photo Diode). Photodetectors should have an appropriate bias and a trans-impedance amplifier (TIA). TIA tranforms the electric current through the PD into a voltage signal, which will be processed. Because no information is contained in it, the direct current (DC) portion of the signal is left out. Because of ambient optical radiation arising from other light sources and sun rays, The DC component emanates. Before signal processing itself, The DC component can be filtered. Hence it will not interfere with communication. It can be utilized to provide power to devices and other equipment instead of getting filtered out. Hence data acquisition and energy capturing are performed at the same time in an OWC system [7].

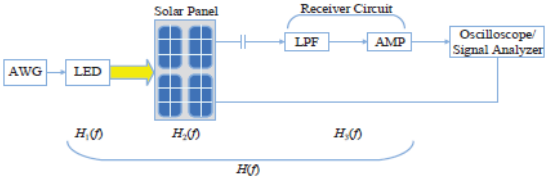

Fig 3. Solar Panel based Receiver [7]
AWG: Arbitrary Waveform Generator, AMP: Amplifier

Since a Solar cell is a passive device, it doesn't need an extra power supply for the conversion of the detected light signal into an electrical signal. Whereas the photo-detectors are active devices, i.e., they have to be provided with power, which escalates not only cost, but energy dissipation, and they are more complex. For a solar-cell-based Optical receiver, the DC component of the electrical signal detected can be used to provide power to the terminal devices [8].

CAMERA / IMAGE SENSOR BASED RECEIVER

An OWC receiver can make use of an image sensor. Image Sensor consists of a number of photodiodes. VLC using image sensor based receiver is known as image sensor based VLC. It

can be also called as OCC (Optical Camera Communication). This receiver uses only the image sensor pixels which detect LED light sources and eliminates other pixels. Image sensor based receiver is an efficient solution for outdoor applications. Three cases are shown here : Vehicle-to-infrastructure Visible Light Communication (V2I-VLC),Infrastructure-to-vehicle Visible Light Communication (I2V-VLC), and vehicle-to-vehicle Visible Light Communication (V2V-VLC) [9].

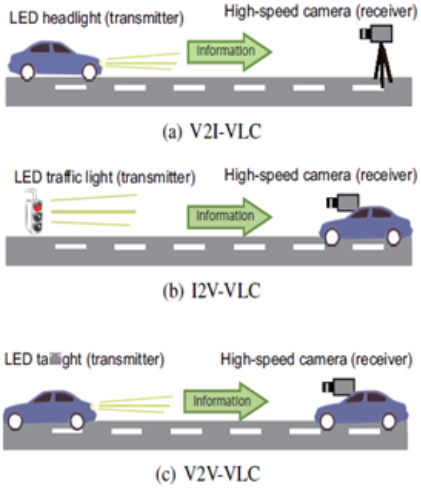

Fig 4. Image sensor / Camera-based Receiver [9]

Table 1. Comparison of Receivers for Optical Wireless Communication

Paper Referred	**Receiver Type**	**Observations**
Hoa Le Minh et al [10]	Photodiode-based	VLC receiver contains a blue filter, a concentration lens, a photodetector (PIN type) and a low noise trans-impedance amplifier (TIA).A Filter is utilized to remove unwanted spectrum components.
Yuki Goto et a l[11]	Camera / Image sensor- based	Camera based receiver performs spatial separation of a number of light sources. It can create a high value of Signal-to-noise ratio (SNR), and communication without interference .
Masayuki Kinoshita Et a l[9]	Camera / Image sensor- based	Image sensor is able to separate number of light sources. It adds an efficient feature to VLC. An image sensor can be used as a VLC receiver. VLC using image sensor based receiver is called as image sensor based VLC. It is also known as OCC (Optical Camera Communication). This receiver uses only the pixels of image sensor which detect LED sources and other pixels are eliminated , including those detecting noise . Image sensor based VLC is an efficient solution for outdoor applications of OWC.
Yang Liu et al [12]	Solar Cell- based	There is a limitation on the rise time and fall times of the detected signal because of the solar cell's high capacitance effect . Even at a very low illuminance level of 100 lux , Solar Cell is sweet enough for receiving the downlink signal .
Z. Wang et al [7]	Solar Cell- based	Solar panel is a passive component. There is no need of an extra power supply for the conversion of the incident light signal into an electrical signal. An OWC system which has a solar panel-based receiver can achieve communication and energy harvesting.at the same time
Shuyu Zhang e tal [13]	Solar Cell- based	Achieving functions of Communication and energy harvesting simultaneously have huge implications for the connectivity of smart devices, which could become self-powered entities as portion of 'Internet of Things'.
Bilal Malik et al [14]	Solar Cell- based	A Solar cell- based VLC receiver's Signal Conditioning Unit is utilized to regular the input signal deteriorated from solar panel's output. A solar cell performs as a photodetector. The aim is to recover an electric signal and to

		harvest the electric energy transmitted by the visible light. It powers the receiver circuit by conversion of the optical signal into an electronic signal.
Won-Ho Shin et al [15]	Solar Cell- based	A receiver circuit, self reverse-biased is employed to improve energy capturing performance and data communication. The reverse bias on the solar panel improves the response period and responsivity .
Rohail Sarwar e tal [16]	Solar Cell- based	A solar cell used as a photodetector with energy capturing at the same time . The solar cell is considered as a passive componet. It can convert incident light signals into electrical signals. The energy generated is utilized to power user terminals.
Hung-Yu Chen et al [17]	Solar Cell- based	Data rate of 0.4 Mbit/s at bit-error-rate (BER) of 10^{-9} within wireless transmission distance of 75 cm, and a data rate of 0.3 Mbit/s at BER of 10^{-9} within wireless transmission distance of 125 cm can be achieved. It is demonstrated using the solar cell as an optical Rx for VLC. The solar cell costs less .It is able to convert the light signal into an electrical signal without the need of an external power supply.

IV. CONCLUSION

This Survey shows OWC as a promising way of communication. Various receivers such as Photodiode based receiver, Image sensor based receiver and Solar cell-based receiver can be used for Optical Wireless Communication. Photodiode based receivers can provide high-speed photodetection. Image sensor based receivers can separate number of sources which can provide high SNR (Signal to Noise ratio). Solar cell based receivers find use in communication, and energy capturing at the same time. Solar cell based OWC systems have demonstrated good performance in case of transmission distance and data rate. But, the technology is still in the developing stage, and the future scope as well as the challenges include improvement of transmission distance and data rate.

REFERENCES

[1]. D.Karunatilaka, F.Zafar, V.Kalavally, R.Parthiban, "LED based indoor visible light communications: state of the art", *IEEE. communications surveys and tutorials .vol.17.no.3.*,pp.1649-1677, 2015.

[2]. Isiaka Alimi, Ali Shahpari, Artur Sousa, Ricardo Ferreira, Paulo Monteiro and António Teixeira, "Challenges and Opportunities of Optical Wireless Communication Technologies" , *Optical Communication Technology, Pedro Pinho, IntechOpen*, DOI: 10.5772/intechopen.69113.,2017.

[3]. Ozgur Ergul, Ergin Dinc, Ozgur B. Akan, "Communicate to illuminate: State-of-the-art and research challenges for visible light communications", *Physical Communication, Volume 17*, Pages 72-85, 2015.

[4]. Vinay Kumar Singh, Dhananjay Patel, U.D. Dalal, "A 100Mbps Visible Light Communication System Using Optical Wireless Channel for Indoor Application Based on Composite White Light Generated Using RGB LEDs", *Procedia Computer Science, Volume 93*, Pages 655-661,2016.

[5]. M. Z. Chowdhury, M. T. Hossan, A. Islam and Y. M. Jang, "A Comparative Survey of Optical Wireless Technologies: Architectures and Applications," in *IEEE Access, vol. 6*, pp. 9819-9840, 2018, doi: 10.1109/ACCESS.2018.2792419.

[6]. Sindhubala, K.; Vijayalakshmi, B., "Receiver Intend to Reduce Ambient Light Noise in Visible-Light Communication using Solar Panels", *Journal of Engineering Science & Technology Review* . *Vol. 10 Issue 1*, p84-90. 7p.,2017.

[7]. Z. Wang, D. Tsonev, S. Videv and H. Haas, "Towards self-powered solar panel receiver for optical wireless communication," 2014 *IEEE International Conference on Communications (ICC), Sydney, NSW, 2014*, pp. 3348-3353, doi: 10.1109/ICC.2014.6883838.

[8]. Z. Wang, D. Tsonev, S. Videv and H. Haas, "On the Design of a Solar-Panel Receiver for Optical Wireless Communications With Simultaneous Energy Harvesting," in *IEEE Journal on Selected Areas in Communications, vol. 33, no. 8*, pp. 1612-1623, Aug. 2015, doi: 10.1109/JSAC.2015.2391811.

[9]. M. Kinoshita et al., "Motion modeling of

mobile transmitter for image sensor based I2V-VLC, V2I-VLC, and V2V-VLC," 2014 *IEEE Globe com Workshops (GC Wkshps), Austin, TX, 2014*, pp. 450-455, doi: 10.1109/GLOCOMW.2014.7063473.

[10]. Hoa Le Minh et al., "80 Mbit/s Visible Light Communications using pre-equalized white LED," *34th European Conference on Optical Communication, Brussels, 2008*, pp. 1-2, doi: 10.1109/ECOC.2008.4729532.

[11]. Y. Goto et al., "A New Automotive VLC System Using Optical

[12]. Communication Image Sensor," in *IEEE Photonics Journal, vol. 8, no. 3*, pp. 1-17, June 2016, Art no. 6802716, doi: 10.1109/JPHOT.2016.2555582.

[13]. Y. Liu, H. Chen, K. Liang, C. Hsu, C. Chow and C. Yeh, "Visible Light Communication Using Receivers of Camera Image Sensor and Solar Cell," in *IEEE Photonics Journal, vol. 8, no. 1*, pp. 1-7, Feb. 2016, Art no. 7800107, doi: 10.1109/JPHOT.2015.2507364.

[14]. Shuyu Zhang, Dobroslav Tsonev, Stefan Videv, Sanjay Ghosh, Graham A. Turnbull, Ifor D. W. Samuel, and Harald Haas, "Organic solar cells as high-speed data detectors for visible light communication," *Optica 2*, 607-610 (2015).

[15]. B. Malik and X. Zhang, "Solar panel receiver system implementation for visible light communication," *IEEE International Conference on Electronics, Circuits, and Systems (ICECS), Cairo, 2015*, pp. 502-503.

[16]. Won-Ho Shin, Se-Hoon Yang, Do-Hoon Kwon, and Sang-Kook Han, "Self-reverse-biased solar panel optical receiver for simultaneous visible light communication and energy harvesting," *Opt. Express 24, A1300-A1305* (2016).

[17]. R. Sarwar et al., "Visible light communication using a solar-panel receiver," *16th International Conference on Optical Communications and Networks (ICOCN), Wuzhen, 2017, pp. 1-3*, doi: 10.1109/ICOCN.2017.8121577.

[18]. H. Chen, K. Liang, C. Chen, S. Chen, C. Chow and C. Yeh, "Passive optical receiver for visible light communication (VLC)," *TENCON 2015 - 2015 IEEE Region 10 Conference, Macao, 2015*, pp. 1-2, doi: 10.1109/TENCON.2015.7372787.

[19]. 18. Van Muoi T. (1989) Optical Receivers. In: *Lin C. (eds) Optoelectronic Technology and Lightwave Communications Systems. Springer, Dordrecht* , doi:10.1007/978-94-011-7035-2_16

[20]. A. Căilean and M. Dimian, "Current Challenges for Visible Light Communications Usage in Vehicle Applications: A Survey," in *IEEE Communications Surveys & Tutorials, vol. 19, no. 4*, pp. 2681-2703, Fourthquarter 2017,doi:10.1109/COMST.2017.2706940.