Study of PSD Characteristics in Different Modulation Schemes for VLC Systems

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Abstract— Wireless communication technology is emerging very fast with reliable communication lead to emergence of very numerous technologies. There are various modulation schemes suitable in optical wireless communication like OOK, PPM, DPIM and DH-PIM. As modulation techniques is categorized into bandwidth & power efficient but for error performance there are few assumptions where there is no bandwidth limitation. In this paper we analyze the Power Spectral Density (PSD) for every modulation technique in AWGN channel & also the combined result shows that DPIM, DH-PIM are applicable for future applications.

Keywords—Visible light communication(VLC), Light- Fidelity(Li-Fi) , Free space optical communication(FSO), Wireless Fidelity (Wi-Fi) , Intensity Modulation (IM) , Direct Detection(DD) Pulse Position Modulation(PPM), Differential Pulse Interval Modulation(DPIM),Dual Header-Pulse Interval Modulation(DH-PIM),Power Spectral Density(PSD), Fast Fourier Transform(FFT).

I. INTRODUCTION

Optical wireless communication is a general term which refers to all types of optical communication where cables (optical fibers) are not used. VLC, FSO, Li-Fi & infrared remote controls are all examples of optical wireless communication.

Li-Fi technology is a new technology that transmits signal as light instead of radio waves. In urban areas where Wi-Fi network become congested & there is a lot of noise in the signal, this technology is something that can be of immense use to an individual. Both Li-Fi & Wi-Fi transmit data over the Electromagnetic spectrum but whereas Wi-Fi utilizes radio waves. Li-Fi is a new paradigm for optical wireless technology to provide unprecedented connectivity within localized data centric environment. The increasing demand for higher bandwidth, faster & more secure data transmission as well as environmental & undoubtedly human friendly technology heralds the start of a major shift in wireless technology a shift from RF to optical technologies.

The issues solved by Visible Light Communication are:

- The elimination of interference.

- A massively improved reuse of available frequency resources.
- Utilization of free, vast & unlicensed infrared & visible light spectrum leading to hybrid radio frequency & optical wireless systems.

In last few years, we have seen a growing research in Visible light communication & the idea of using LED for both illumination &data communication.

VLC = Illumination + Communication

The main driver for this technology include the increasing popularity of solid state lightning , longer lifetime of high brightness LEDs compared to other sources of artificial light like incandescent light bulbs , high bandwidth / data rate , data security no health hazards & low power consumption.

Since Li-Fi is light based but its major drawback is that it won't be able to penetrate solid objects such as walls. Though it could also mean privacy for personal user, it also questions its use for large scale delivery of data transmissions.

The dual functionality of VLC (i.e. lightning & data communication from same high brightness LED) has created a whole range of interesting application, including but not limited to home networking, high speed data communication via lightning infrastructure in offices, car to car communication, traffic light management. The levels of power efficiency & reliability offered by LEDs today are far superior compared to the traditional incandescent light sources used for lightning.

To achieve higher data rates particularly from phosphorescent white LED advanced modulation schemes (multilevel & multicarrier) & multiple input / multiple output technique could be readily used.

Despite all advantages offered by the WLED there are number of challenges. One such challenge in the designing of low cost devices with high luminous efficiency & outstanding colour quality. The single most important factor in VLC is the switching property of visible LEDs. They have ability to be switched on & off very rapidly thereby making it possible to impress data on their radiated optical power / intensity. Visible light Communication oscillates on LED bulb and of course on the receiving end there is a photo detector instead of an antenna.

The LED is preferred over LASER if the application is dual propose of illumination & communication as is the case of VLC.

II. VLC CONCEPT

A. *General system model of VLC :*

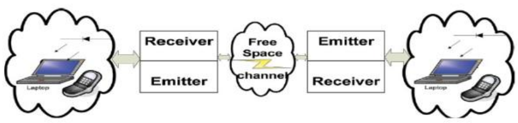

Fig: 1.1 Model of VLC

This system consists of a light source which emits light and data simultaneously. Data is sent between two or more terminals; in each terminal there is a receiver and an emitter. The emitter transmits data into free space, to be received by a receiver from a different terminal. At first, we modulate information into the luminance and then transmit the information by blinking LED. For optical wireless links, the most viable modulation is intensity modulation (IM), in which the desired waveform is modulated onto the instantaneous power of the carrier. [1]

B. Block diagram of VLC

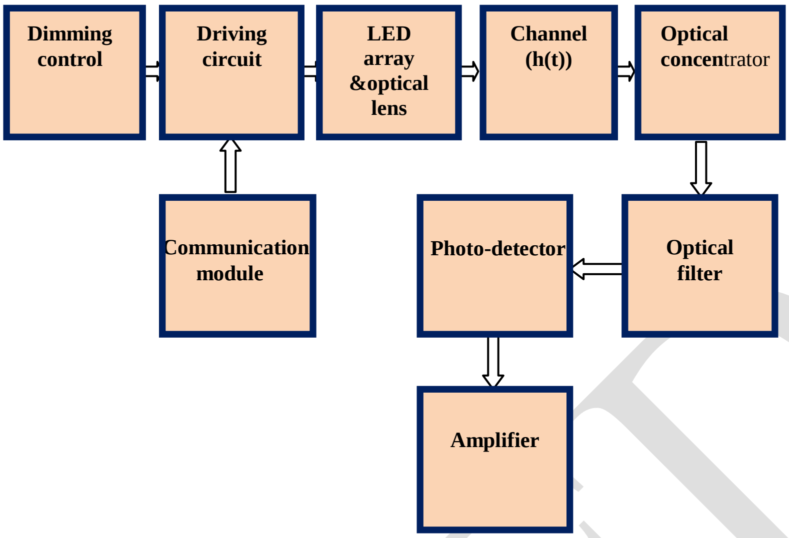

Fig: 1.2 Block Diagram of VLC

III. MODULATION TECHNIQUE

Modulation is the key processes in any communication system as it allows enhanced performance. As the performance of VLC is highly influenced by the path loss & shot noise induced by natural & artificial lights also from the speed of optoelectronic devices like LED & photodiodes. Most practical OWC systems being currently employ the IM/DD scheme for outdoor as well as indoor applications. For indoor application the eye safety limit on transmit optical power being transmitted. Unlike RF systems where the amplitude, frequency & phase of the carrier signal are modulated in optical system it is the intensity of the optical carrier i.e. modulated in most systems operating below 2.5.Gbps data rates.

The criteria on which the various modulation technique are to be assessed .For the optical wireless channel, these criteria are listed below:

1. **Power efficiency:** Furthermore, in portable battery powered equipment it is desirable to keep the electrical power consumption to minimum.
2. **Bandwidth efficiency:** Practically the bandwidth should be available to avoid interference & distortion.
3. It is highly desirable that the chosen modulation technique should be simple to implement.
4. Another consideration to reject the interference emanating from artificial sources of ambient light.
5. If chosen modulation technique is required to operate at medium to high data rates over non directed LOS or diffuse links multipath dispersion becomes an issue.
6. **Power Spectral Density:** PSD shows the strong variation as function of frequency also it shows where the frequencies are strong & weak. The unit of PSD is energy per frequency & we can get the energy by integrating PSD within that frequency

range. Computing of PSD can also be done by FFT or by autocorrelation function & transforming it.

Several modulation schemes with their inherent advantages and disadvantages are considered for use in OW systems. SC pulsed modulation schemes such as on-off keying (OOK) and pulse position modulation (PPM) are widely used modulation formats in IR wireless communications [2]. In the presence of a LOS component, OOK can be used to achieve high-speed transmission beyond 100Mbits/s [3].

I. On-Off Keying: It is the most simplest & reported modulation technique for IM/DD in optical communication in which intensity of optical source is directly modulated by information sequence.

In this technique the presence of a carrier for specific duration represents a binary one while its absence for same duration shows binary zero.

Both RZ & NRZ are applied to this technique. In NRZ , a pulse with duration equal to bit duration is transmitted to represent 1 while in RZ the pulse occupies only partial duration of a bit.

<u>Power Spectral Density for OOK:</u>

The electrical power density for OOK-NRZ is given as:

$$S_{ook} = (P_t R)^2 T_b \left(\frac{\sin \pi f T_b}{\pi f T_b}\right)^2 \left[1 + \frac{1}{T_b}\,\delta(f)\right]$$

------------ (1.)

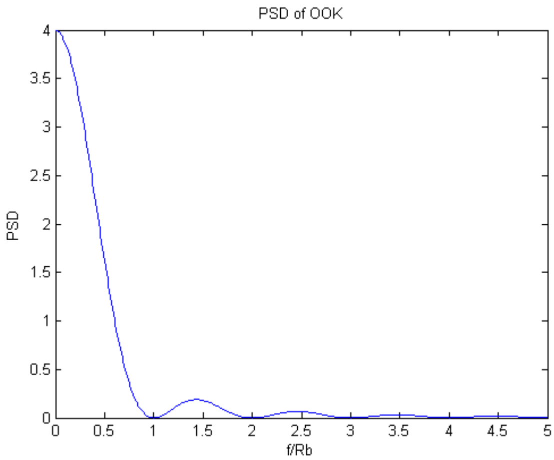

Fig: 1.3 Simulation Result of PSD for OOK

II. Pulse position Modulation: It is an orthogonal modulation technique with its significantly better power efficiency with wide range of applications .It improves the power efficiency of OOK but at the expense of bandwidth & complexity.

<u>Power Spectral Density</u>: The power spectral density for PPM can be given as:

$$S_{PPM} = |P(f)|^2 \left[S_{c_{PPM}}(f) + S_{d_{PPM}}(f)\right]$$

-----------(2.)

Where ,

P(f) is the Fourier transform of pulse shape

$S_{c_{PPM}}(f)$ & $S_{d_{PPM}}(f)$ is the continuous & discrete components.
It can be given as:

$$S_{C\_PPM} = \frac{1}{T_{sym}}\left[\left(1-\frac{1}{L}\right)+\frac{2}{L}\sum_{k=1}^{L-1}\left(\frac{k}{L}-1\right)\cos\left(\frac{k2\pi f T_{sym}}{L}\right)\right]$$
------------(3.)

$$S_{d\_PPM} = \frac{2\pi}{{T_{sym}}^{2}}\sum_{k=-\infty}^{\infty}\delta\left(f-\frac{kL}{T_{sym}}\right)$$
------------(4.)

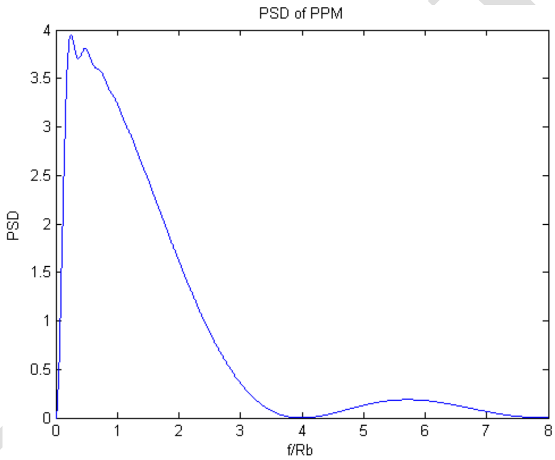

Fig: 1.4 Simulation Result of PSD for PPM

III. Pulse Interval Modulation: A number of modulation schemes based on PIM either improve throughput or reduce power requirement by adopting complex symbol pattern. One such simplest method of PIM is Differential Pulse Interval Modulation (DPIM) which offers improved performance as compared to PPM by removing redundant space in PPM.

<u>Power Spectral Density</u>: The power spectral density of DPIM is given as:

$$S_{DPIM} = |P(f)|^2\left[S_{c\_DPIM}(f)+S_{d\_DPIM}(f)\right]$$
---------- (5.)

$$S_{c-DPIM} = \sum_{k=-5L}^{5L}\left(R_k-\frac{1}{\bar{L}^2}\right)e^{-j2\pi kf\,T_{s\_DPIM}}$$
----------(6.)

$$S_{d_{DPIM}} = \frac{2\pi}{T_{s\_DPIM}\bar{L}^2}\sum_{k=-\infty}^{\infty}\delta\left(f-\frac{2\pi k}{T_{S\_DPIM}}\right)$$
---------(7.)

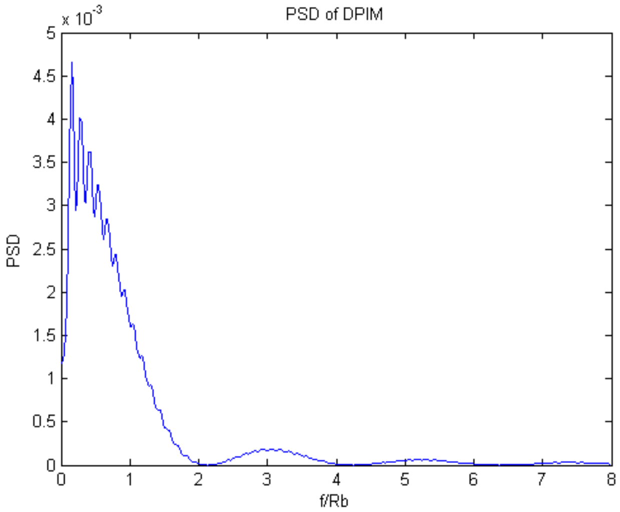

Fig: 1.5 Simulation of PSD for DPIM

IV. Dual Header PIM:

This scheme not only removes redundant time slots but also reduce average symbol length compared to PIM as to increase data throughput as well.

Power Spectral Density: The power spectral density for DH-PIM can be given as:

$$P(\omega) = \frac{4V^2 \sin^2\left(\frac{\alpha\omega T_s}{4}\right)\left\{\begin{matrix}\left[5 - 4\sin^2\left(\frac{\alpha\omega T_s}{4}\right)\right] \\ + \\ \left[9 - 8\sin^2\left(\frac{\alpha\omega T_s}{4}\right)\right]\mathrm{Re}\left(\frac{\psi}{1-\psi}\right)\end{matrix}\right\}}{\omega^2 T_s\left(2^{M-1} + 2\alpha + 1\right)}$$

-------------(8.)

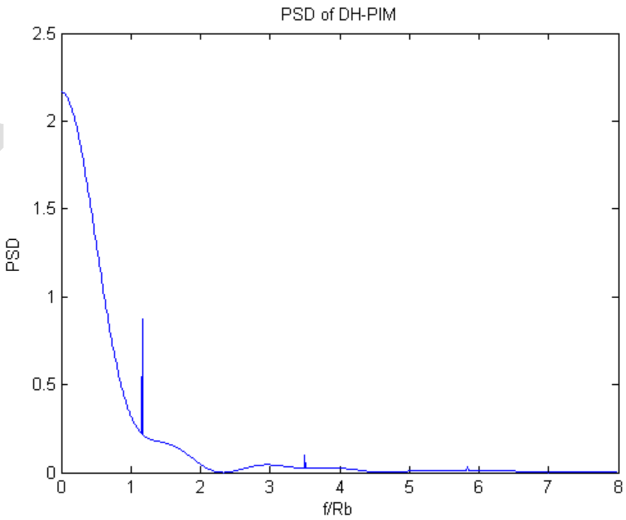

Fig: 1.6 Simulation of PSD for DH-PIM

IV. RESULT & DISCUSSION

Applying the all mathematical relations for different modulation schemes the combined result is shown in fig:1.3

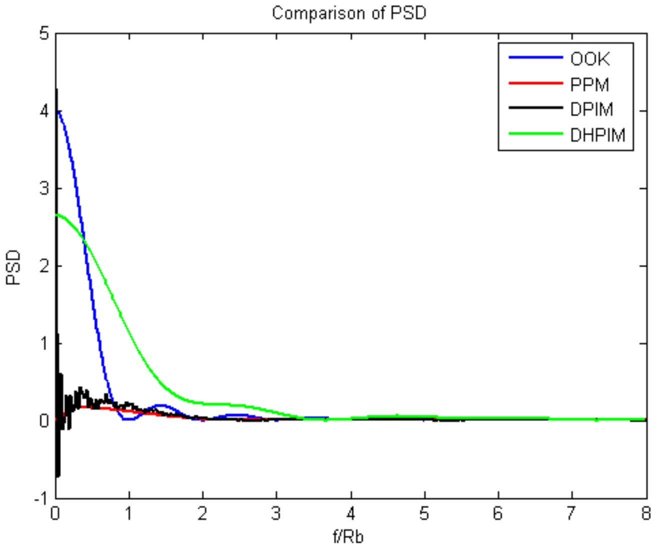

Fig:1.7 Combined simulation result of PSD

After analyzing the result, following Table: 1 summarizes the result as:

Table: 1 Comparison & Findings

Parameters	OOK	PPM	DPIM	DH-PIM
Bit rate, R_b	$1x10^6$	$1x10^6$	$200x10^6$	$1x10^6$
No. of bits or bit resolution(M)	10^3	M=3	M=4	M=4 (Alpha=1)
Samples per symbols	10	250	10^3	10^3
Bit duration, T_b	10^{-6}	10^{-6}	$50x10^6$	10^{-6}
Sampling time, T_s	10^{-7}	$0.375x10^{-6}$	$2.35x10^{-9}$	$7.27x10^{-7}$
PSD	4	0.2	4.29	2.64

V. CONCLUSION

In this paper we analyzed the PSD for the modulation techniques OOK, PPM, DPIM and DH-PIM in AWGN channel and find out the individual and combined result. From the Fig1.7 & Table: 1 we see that the PSD for DPIM is higher as compare to other techniques. OOK has also high PSD but less than DPIM. For all values of L PSD of PPM falls to zero, which allow using high cut-off frequencies to combat artificial light interference. Thus, DPIM is suitable for the optical wireless communication.

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