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Low Rate Arbitrary Waveform Generator for Visible Light Communication (VLC)

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ABSTRACT

Over the decades, more and more predictable lighting systems tend to be replaced by LED lighting systems because of their advantages such as high energy efficiency, long life and less heat radiations. Because of the LEDs' ability of switching to different light intensities at fast rate, these lighting solutions could be used for both lighting and transferring data. This characteristic of the LEDs has led to the development of a new technology, known as Visible Light Communication (VLC). In this type of communication, the receiver is usually a photo detector. Designing of Low Rate Arbitrary Waveform Generator for VLC gives solution to remove part of flicker which occurs in range of (~3-200) HZ with reference to standard IEEE 802.15.7. Afterwards, performance of low rate AWG will be analyzed by implementing it in indoor VLC system model .This AWG is design for data rate of 10kbps. It can also be designed for high data rates. ON-OFF Keying (OOK) modulation technique is implemented for designing AWG. Furthermore with simple LOS (line of sight) channel model it is possible to understand, how the VLC channel propagates through the room. For OOK modulation the BER (Bit Error Ratio) curves is also derived.

KEYWORDS: Visible light communication (VLC), Light emitting diode (LED), Arbitrary waveform generator (AWG),Flicker,LOS,BER.

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1. INTRODUCTION

Visible light communication (VLC) is a innovative technology in which the visible range is used to send data. Due to the transmitting distance of the light emitting diodes (LEDs), VLC is limited to short-range technology. In the electromagnetic spectrum, the range of visible spectrum lies between 350 nm and 800 nm of wavelength and the frequencies ranges between 4.3 x 1014 Hz and 7.5 x 1014 Hz. VLC technology are commonly used because their current intensity are easily modulated, with respect to their transmitter and receiver i.e. incandescent, photodiode and fluorescent light bulbs. LEDs are dependent of doping procedure, as a result their output and their robustness are improved, and they have longer life span in comparison to the incandescent and fluorescent light bulbs.[1]

In any illumination application (general lighting, displays, transport vehicles lights to mention only a few), it is predicted that LEDs are going to surpass the common light bulbs. They are going to provide dual applications, that is lighting and communication. As in the case of any communication technology, transmission in VLC technology is normally classified by a transmission matrix, which is a numerical presentation of the channel impulse response. The size of this matrix changes with the number of groups of LEDs and with the number of LEDs per group. High data rate transmission can be performed by increasing number of LEDs.

VLC technology confronts a lot of challenges: a few are associated to the communication system design and others are associated to the practical implementation. To appropriately apply a VLC communication system, some constraints have to be met: the lighting hurdle associated to the average optical power and the communication aim associated to the throughput. During transmission, LED flicker should be mitigating under dimming conditions, the data rate has to be reduced significantly. [2-3]

Research on VLC technology has been started from decades. The history started in 1880, when Alexander GrahamBell invented the photo phone. This device was used to transmit audio information by modulating with sunlight. In the 1960s, optical communications were taken in to account. Light amplification by stimulated emission of radiation (LASER) and light emitting diodes (LEDs) were invented [4]. Afterwards, in 2003, recent research work starts on VLC technology. Natagawa Laboratory, in Keio University, Japan, used LEDs to transmit data. In 2006, the centre for information communication technology research (CICTR), Pen State, USA, proposed the first combination of power line communications (PLC) and white LED to give broadband access for indoor applications. Since then, there have been enormous research works on VLC. Among them, light fidelity (Li-Fi), founded by Harald Haas from the University of Edinburgh in the United Kingdom [5], is one of the most interesting success of VLC for the several years.

2. LITERATURE REVIEW

The indoor VLC lighting is going through a revolution. The incandescent bulb that has been extensively used to light our surroundings, since its development over a century ago is slowly being phased out due to its exceptionally low energy efficiency. Even in the most modern incandescent bulbs, no more than 10% of the

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electrical power is converted to useful emitted light. The condensed fluorescent bulbs introduced in 1990s have achieved increasing popularity in the last decade as they provide a improved energy efficiency (more lumens per watt).

However, current developments in solid-state lighting devices through Light Emitting Diodes (LEDs) have enabled extraordinary energy efficiency and luminaries' lifetime. Normal luminous efficiency (quantity of electricity is used to give the proposed illumination)of greatest in-class LEDs is as above as 113 lumens/watt in 2015 [6] , and is proposed to be about 200 lumens/watt by the year 2020. This is a great improvement as compared to existing incandescent and fluorescent bulbs which supply an average luminous efficiency of 15 and 60 lumens/watt [7] correspondingly.

Likewise, the lifespan of LEDs starts from 25000 to 50000 hours significantly greater than solid fluorescent(10000 hours).Apart from the energy savings and lifespan advantages, the LEDs also have other benefits like compact form factor, decrease consumption of dangerous equipment in design and reduced heat creation even after long time of permanent usage. Due to these significances, LED is taking up on a constant rise and it is predicted that almost 75% of all illumination will be given by LEDs by the year 2030[8]. The rapid boost in the usage of LEDs has provided a unique opportunity .Different from the older illumination technologies, the LEDs have ability of performing at different light intensity levels at a very fast rate. The switching rate is sufficient to be imperceptible by a human eye. This property can be used for communication where the information is encoded in the emitting light in different ways. A photo detector (also referred as a light sensor or a) or an image sensor (matrix of) can receive the modulated signals and decode the data. This predicts that the LEDs can perform dual purpose of providing illumination as well as communication. In last decades, VLC research has shown that it has ability of achieving very high data rates (nearly 100 Mbps in IEEE 802.15.7 standard and up to Gbps in research).

3. RESEARCH METHODOLOGY

3.1LOS(Line of Sight)Channel Model

To simulate VLC systems one of the most important features is the channel block. The channel represents how the transmitter light ray moves through space to arrive at the receiver. There are two main classifications to analyze VLC channel, are the line of sight transmission (LOS) and the non line of sight transmission (NLOS). In the NLOS transmission generally it is given by rays which are reflected by obstacles and, after some bounces, it reaches to the detector. Moreover, in this paper only LOS will be discus in detail.

Typical VLC use LEDs to communicate with photodiodes, the modulating signal is the current signal $m(t)$ that passes through the LED that generates the optical power output $x(t)$. In simple words the modulation is based on the light power generated from LED.

The receiver is a photo detector that produces a photocurrent $y(t)$. The photocurrent (square law detector) is directly proportional to the optical power that impinges the photo detection surface.

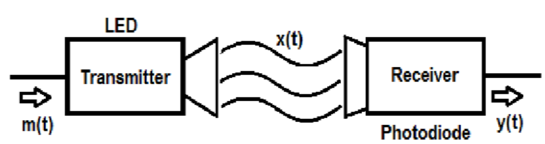

Fig.1 Block diagram of an optical intensity,

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direct detection communication channel.
Where m(t) is the LED's current, x(t) is the optical power, y(t) is the photocurrent generated from photodiode[9].

An indoor VLC channel in general should work with two components: the LOS channel and the diffusive channel. The first is composed by all the line of sight rays that hit the photodiode without bouncing on other objects; the second is the sum of all light rays that bounce on the objects in the room (walls are consider as objects) and, in general, it's called non line of sight (NLOS) and is very important for very fast VLC systems.

$$P_r = (K_{los} + K_{nlos}(0))\,P_t = \left(K_{los}(0) + \sum_{refl} H_{refl}(0)\right) P_t \quad (1)$$

Power and channel for a VLC IM-DD LOS and NLOS channel

When one designs a VLC system it must be take in account this fact and the consequences: in radio frequency system the SNR is proportional to average received power, in VLC system the SNR instead is proportional to the square of the average received optical power.

$$SNR_{VLC} = \frac{R^2 H^2(0) P_r^2}{N_o}$$

$$H(0) = \int_{-\infty}^{\infty} h(t)\,dt \quad (2)$$

Equation 2 SNR for a VLC and OWC system.
Rb is the bit rate, N_o is the noise spectral density, Pr is the received power of the photodiode, H (0) is the channel DC gain and R is the photodiode responsivity.

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Figure derives the first and simplest case that one should consider is LOS (line of sight) channel, without the reflecting contributes, with a point Lambertian light source and constant received irradiance. This can be achieved by imposing the condition that the transmitter receiver square distance (d) is larger than receiver surface (R_r): $d2 \gg R_r$.

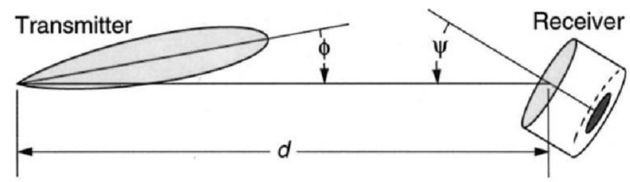

Fig.2: Transmitter to receiver LOS path from [10]

The approximation used before brings to constancy of the luminous flux on Ar

$$d^2 \gg R_r \rightarrow \int_{A_r} P_r * A_r \quad (3)$$

Equation 3: constancy of the luminous flux implies simplification of the area integral
The angular distribution of the optical radiation could be defined by Lambertian radiant intensity

$$Z_\circ(\omega) = \begin{cases} \frac{(m_l+1)}{2\pi} cos^{m_l}(\varphi) \ for \ \varphi \epsilon \left[-\frac{\pi}{2}, \frac{\pi}{2}\right] \\ 0 \quad for \quad \varphi \geq \frac{\pi}{2} \end{cases}$$

Equation 4 where m_l is the Lambert's mode number a way to describe the directionality and φ is the angle between the led normal and d (vector that connect transmitter and receiver).

The Lambertian mode is related to LED semi angle; this parameter can be found on the LED datasheet

$$m_l = \frac{-ln2}{ln\left(cos(\varphi)_{\frac{1}{2}}\right)} \quad (5)$$

Equation 5: calculation of Lambertian order

The effective area of receiver photodiode is based on the receiver surface inclination. One should project the surface on the axis d that connects transmitter and receiver

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$$A_{eff}(\omega) = \begin{cases} A_r cos(\varphi) & 0 \le \varphi \le \frac{\pi}{2} \\ 0 & \varphi > \frac{\pi}{2} \end{cases}$$

Equation 6: receiver surface projection A is the area of the receiver photodiode, φ is the angle between the photodiode normal and d.

To evaluate the LOS channel one should multiply all the factors found until now to obtain:

$$H_{LOS}(0) = A_r \frac{(m_l + 1)}{2\pi d^2} cos^{m_l}(\varphi) F_s(\sigma) cos(\sigma)$$

Equation 7: H_{LOS} DC LOS gain. Where m_l the Lambert's mode number is φ is the angle between the photodiode normal and d, σ is the angle between the led normal and d.

This is the channel gain, now one can simply multiply the LOS channel gain by the input optical power to obtain the power on the receiver:

$$P_r = H_{LOS}(0) P_t \quad (8)$$

Equation 8: P_r is the received power, K_{LOS} is the DC LOS gain, P_t is the transmitted power

To express the impulsive optical gain it is necessary multiply DC LOS gain with a Dirac's delta:

$$H_{LOS}(i) = A_r \frac{(m_l + 1)}{2\pi d^2} cos^{m_l}(\varphi) F_s(\sigma) cos(\sigma) \partial\left(\tau - \frac{d}{c}\right) \quad (9)$$

3.2 Flicker

The two main constrains in visible light communication are, flicker mitigation and dimming support. Flicker belongs to the fluctuation of the brightness of light. Any possible flicker resulting from modulating the light sources for communication must be mitigated because flicker can cause noticeable, negative/harmful physiological changes in human eye. To reduce flicker, the changes in brightness must fall within the maximum flickering time period (MFTP). The MFTP is defined as the maximum time period over which the light intensity can change without the human eye perceiving it. While there is no widely accepted optimal flicker frequency number, a frequency greater than 200 Hz (MFTP < 5 ms) is generally considered safe for transmission of data. Therefore, the modulation process in VLC must not introduce any noticeable flicker either during the data frame or between data frames [10].

Dimming support is another important consideration for VLC for power savings and energy efficiency. It is desirable to maintain communication while a user arbitrarily dims the light source. The human eye responds to low light levels by enlarging the pupil, which allows more light to enter the eye. This response results in a difference between perceived and measured levels of light. The relation between perceived and measured light is given by.

$$Perceived\ light(\%) = 100 \times \sqrt{\frac{Measured\ light(\%)}{100}}$$

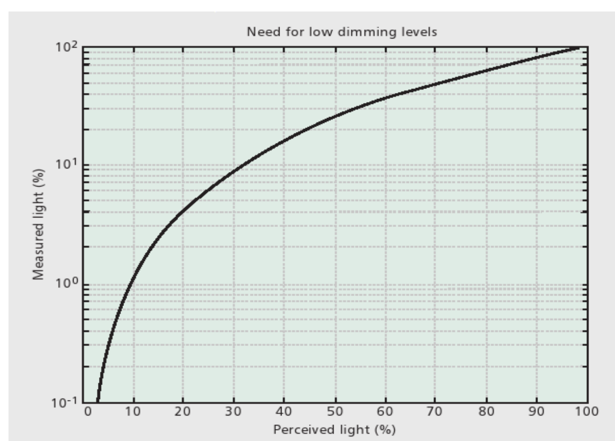

Fig.3 Human eye shows nonlinear sensitivity to dimming [11], motivating the need for high-resolution dimming support.

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3.3Method to Reduce Flicker by Conventional Way

There are several predefined standards to reduce flicker such as RLL code in IEEE 802.15.7,but in our case we reduce flicker in a unique and simple way.

By following conventional method, first step is to generate OOK signal having data rate of 10 kb/sec. Reason of selecting pulse train of OOK is that ,in VLC system only accepts ‘’0 ‘’and ‘’1’’ and Signal should have positive amplitude because in OOK there is no negative signal.

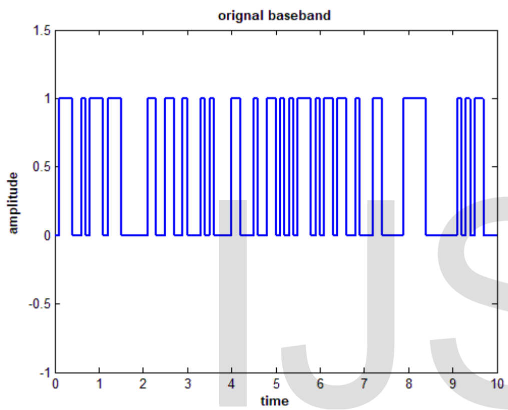

Fig.4 OOK signal.

3.4 Flicker Elimination

In time domain we can’t see frequency components and noise in the time domain signal. In order to watch complete frequency spectrum of above signal then we must have to take Fourier transform of signal. In Fourier transform we can see the complete spectrum of signal in frequency domain. As the above signal is continuous in time domain because it satisfies the property of continuous signal. So it is necessary to take Fourier transform of signal not by only using built-in FFT command in MATLAB, because it will not gives desired results .In order to achieve desire results it is necessary to take Fourier transform of above signal which also includes negative range because when this signal is recovered in time domain again then the full spectrum of the signal is possible to be attained which fulfil requirements of the project.

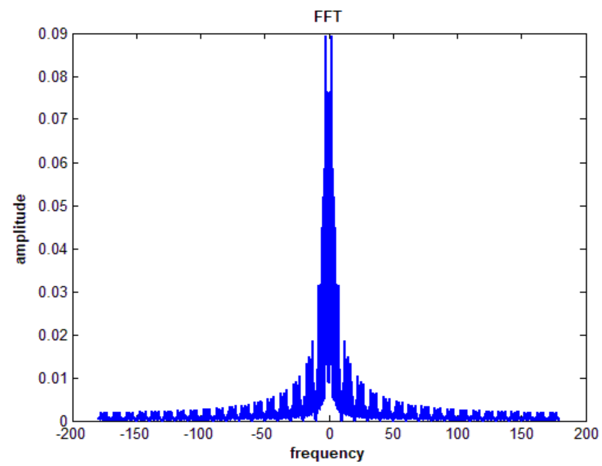

Fig.5 FFT of above signal.

3.5 Removing Part Of Frequency From FFT Spectrum

As discuss earlier that flicker occurs generally in low frequency range. According to IEEE 802.15.7 this range starts from ~3-200 HZ. In order to remove flicker one should have to select appropriate range to remove flicker. In my case i have selected from (50-150) HZ. Due to symmetry of signal i removed these frequencies from both sides of spectrum, because when signal is continuous and FFT of signal should be taken from both sides in order to recover signal. While removing frequency no filtering or any predefined coding is used in this project, which makes research unique. In this case only frequency from (50-150) HZ is removed in coding by using command z (abs (fvec2)>50 & abs (fvec2) <=150) =0) in MATLAB and then multiply with (z denotes (FFT)) signal).

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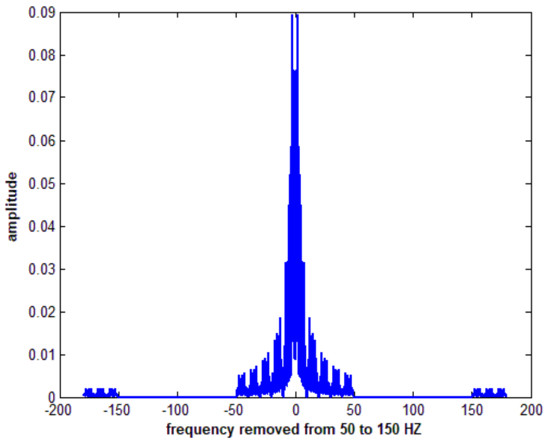

Fig.6 Frequency from (50-150) HZ is removed from above signal.

3.6 Signal in Time Domain

Now in order to check, whether our signal is capable for transmission or not. We must have to watch signal in time domain. By analysing signal in time domain we can judge that whether our signal is close to our original signal or not, but in my case signal looks closer to our original signal

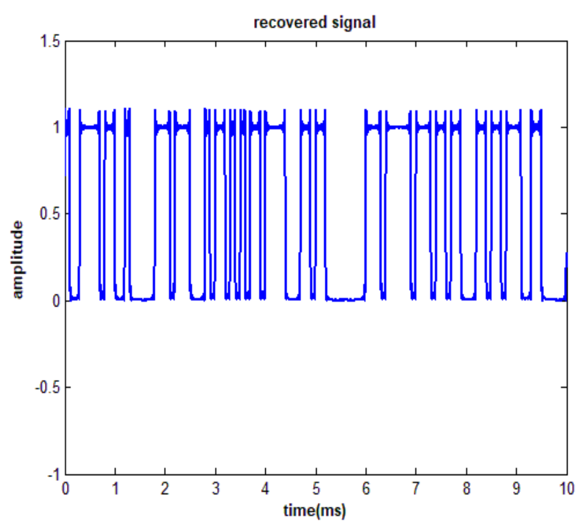

Fig.7 IFFT of above signal after removing frequency.

3.7 Analyses of Signal after Removing flicker

This thing is clearly obvious that after removing some frequency components flicker has been reduced. After taking IFFT of signal, it seems to look like the original signal which is a basic requirement of the project, which assured that flicker has removed successfully. By comparing the above signal with the original signal almost all bits are right which reflects that signal is capable to transmit in VLC. Moreover, to check behaviour and signal to noise ratio of the signal, it should be implemented in the VLC model where it will be clearly observed that how many bits are corrupted and how much are right. For best communication BER(bit error ratio) should be under 10^{-3} .This means that out of one thousand bits only one bit is corrupted, which reflects reliable communication.

4. SIMULATIONS RESULTS AND DISCUSSION

In order to visualize the performance of VLC systems, for which all work has been elaborately explained, now some simulations will be performed with the help of system model. For our simulations we decided to use the MATLAB computer software because it is a very popular software with a toolbox pack (like BER function) suited to communication systems. Furthermore many VLC research entities use MATLAB algorithms. In the following we present three simulations.

LOS CHANNEL SIMULATION

The MATLAB algorithm that calculates the LOS channels gain.

The algorithm considers:

1. Empty room with x, y, z dimension.
2. LED located on the ceiling at fixed position (lx,ly,lz), with fixed direction of emission perpendicular to the floor and fixed half-power angle (half power).
3. Photo-receiver parallel to floor at rz distance from ceiling with responsivity “resp” and with

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receiving surface “ar”.

Parameters	Value
Transmitted optical power	1 Watt
Room dimension	3.5*3.5*2.7(m^3)
LED half power angle	30(deg)
Detector responsivity	1(A/W)
Receiver area	1 cm^2
Gain of optical filter	1
Reflective index	1
Electronic charge	1.60 e^{-19} c
Absolute temperature	295[K]

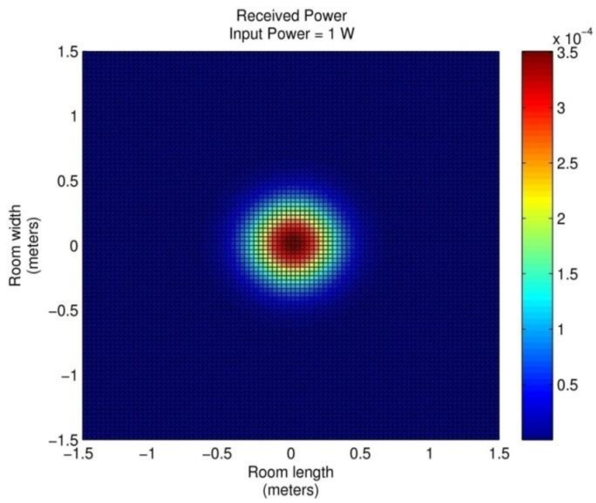

Fig.8 Distribution of received optical power at half-power angle =10 deg

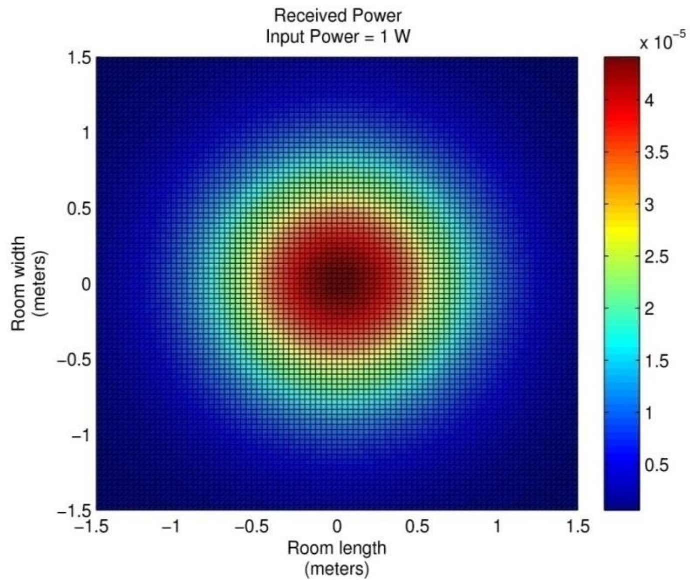

Fig.9 Distribution of received optical power at half-power angle =30 deg.

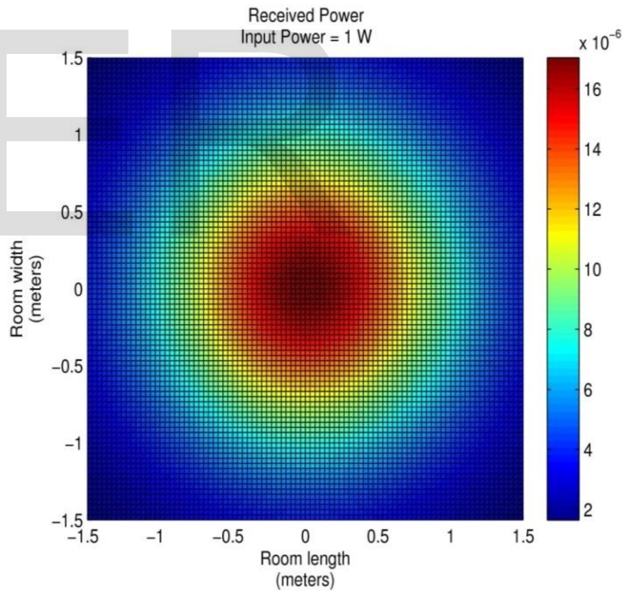

Fig.10 Distribution of received optical power at half-power angle =50 deg.

From top to bottom: 10, 30, 50 degrees half-power angle. The colour indicates the received power. In the centre the full red colour is the biggest power received, on sides the dark blue indicates the lowest power received.

4.1 OOK SNR(BER) Simulation

We want to calculate the BER (Bit Error Ratio)

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curve as a function of the SNR for the OOK in a VLC system. The BER can be calculated by comparing the original transmitting signal with the received signal after the receiver.

OOK is one of the most commonly used modulation scheme in OWC and VLC. This Modulation shows the bit 1 as ON signal and the bit 0 as OFF signal .The modulation block consist in taking the bit value and multiply that by the led luminous power. Reception block generates a photo current proportional to the transmitted luminous power plus white Gaussian noise n(t), both proportional to R the responsivity of detector.

Pavg, Ipeak and Epeak for OOK consideration:

The electrical power, peak and bit energy for one period o wave is calculated in equation 10.

$$P_{peak} = I_{peak}^2 R_b = 2E_b \qquad (10)$$

Equation 10 Peak power and energy peak and bit for one period.

The electric peak current is proportional to the luminous power received and the luminous power received is proportional to the square root of the electric wave power :

$$A_{peak} = 2RP_{avg(ook)} = 2R\sqrt{\frac{R_b E_b}{2R^2}} \qquad (11)$$

Equation 11 peak current generated from photo receiver

$$P_{(avg(ook))} = \sqrt{\frac{N_\circ R_b SNR}{2R^2}} = \sqrt{\frac{R_b E_b}{2R^2}} \qquad (12)$$

Equation 12 Received luminous power .

4.2 Theoretical OOK error probability

To evaluate the simulated BER curve one can compare the simulated BER curve with a theoretical BER curve.

$$P_{err} = p(0)\int_{S_{th}}^{+\infty} p\left({}^{S}/_{0}\right)\mathrm{ds} + p(1)\int_{0}^{S_{th}} p\left({}^{S}/_{1}\right)\mathrm{ds}$$

Equation 13 OOK bit error probability.

The $p(0)$ and $p(1)$ represent the probability of obtaining respectively 0 or 1, $p\left({}^{S}/_{0}\right)$ and $p\left({}^{S}/_{1}\right)$ are the tail density probability of obtaining 0 instead 1 and vice versa, sth represent the threshold level. The integral gives the distribution function. If one consider white Gaussian noise the tail density probability for Gaussian noise are equation 14

$$p\left({}^{S}/_{0}\right) = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left(\frac{-s^2}{2\sigma^2}\right) \qquad p\left({}^{S}/_{0}\right) = \frac{1}{\sqrt{2\pi\sigma^2}} exp\left(\frac{-(s-I_p)2}{2\sigma^2}\right) \qquad (14)$$

If symbols are equiprobable the probability of detecting one or zero are the same $p(0) = p(1)$ =1/2 and the optimum threshold point is 0.5 (peak current).By and substituting variables final formula will be:

$$P_{err} = Qfunc\left(\frac{S_{th}}{\sigma}\right)$$

$$Qfunc(x) = \frac{1}{\sqrt{2\pi}}\int_{x}^{+\infty} e^{\frac{-\alpha^2}{2}} d\alpha \quad (15)$$

Equation 15 Error probability Qfunc is Marcum's Q-function on right.

Equation 15 is calculated before matched filter,after matched filter and with substation above equation we can calculate theoretical OOK error probability.

$$P_{err} = Qfunc\left(\frac{S_{th}}{\sigma}\right) = Qfunc\left(\frac{E_{peak}}{2\sqrt{\frac{E_{peak}N_\circ}{2}}}\right) = Qfunc\left(\sqrt{\frac{E_{peak}}{2N_\circ}}\right) = Qfunc\left(\frac{E_b}{\sqrt{2E_b N_\circ}}\right)$$

$$P_{err(ook)} = Qfunc\left(\sqrt{\frac{E_b}{N_\circ}}\right)$$

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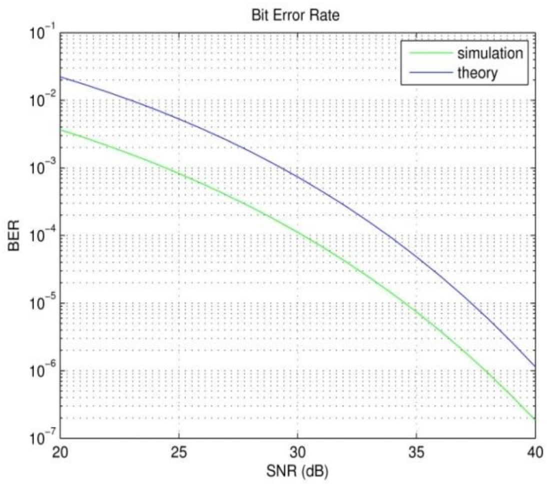

Fig.11 Simulated BER close to 10^{-3}

5 CONCLUSION

In our work, we proposed an innovative approach to reduce flicker which causes big problems in visible light communication. We reduce it by removing some of the frequency components in which a flicker occurs. After removing flicker we have seen the signal in time domain looks like an original signal which means that our approach is acceptable. After that, we analyze signals by calculating bit error rate at the receiving end. For this purpose, we design the system model, where we assign some parameters, so that we can check received signal power. It is observed that as the half-power angle increases, more power is received. Hence, concluded that our bits are good enough for transmitting data in VLC, because our result is close to 10^{-3} which is considered good for communication.

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