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Feasibility Analysis of FDM Technique for Visible Light Communication (VLC) System

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ABSTRACT: High speed communication is now a day's very vital issue in every aspect of life. People checking their email whether at the same time they have attend any conference through video conferencing with flexibility and efficiently. But due to limited version of Radio Frequency (RF) spectrums and high interference at restricted area, visible light communication (VLC) is a good solution in case of wireless communication. VLC can provide Terabit per second (Tbps) data rate without interfere with other electromagnetic waves. To reduce the number of multiple devices and cost optimization, multiplexing can be implemented in case of VLC system. Hence the main objective of this paper is to check the feasibility of Frequency Division Multiplexing (FDM) in case of On-Off Keying (OOK) modulated signal of the system.

KEYWORDS: RF, VLC, OOK, FDM, THz, Tbps, SNR, AWGN, AM, BER

I. INTRODUCTION

High data rate communication system is a burning issue in present civilization. In present days the available current applications of internet and the usage of high speed communication is increasing day by day. Hence Terahertz (THz) communication is an upcoming issue for future wireless communication systems. Moreover the main challenge of present wireless communication device is to use the devices in restricted area such as airport, inside the aircraft or hospital due to higher interference rate of RF spectrums. In addition RF spectrums are limited and electromagnetic waves are more injurious to health, visible light is a good solution to provide THz bandwidth as well as Terabit per second data rate for wireless devices [1]. However suitable multiplexing techniques required to optimize the cost of multiple devices. That's why FDM is a good solution to multiplex different users data through a single channel in case of indoor and outdoor visible light communication. The main goal of this paper is to verify the FDM technique in case of the signal provided by VLC system. VLC system uses OOK modulation due to simplicity and high data rate capability. In addition the usable spectrum of VLC system is 375-750 THz frequency band [1, 2]. So high number of users can be multiplex through a single channel by using FDM techniques and optimize the cost as well. To implement FDM, amplitude modulation is the main key to shift the OOK modulated spectrum perfectly. Hence in this paper the amplitude modulation of OOK modulated signal is also analysed to check the feasibility of FDM in case of different values of SNR of AWGN channel.

II. RELATED WORK

A. Visible Light:

Visible light is a form of electromagnetic radiation which can visible to the human eye. This visible light spectrum is a very small part of the electromagnetic spectrum. The EM radiation has different wavelength and frequencies. This broad range of wavelengths is known as the electromagnetic (EM) spectrum. That radiated spectrum is typically divided into seven regions in order of decreasing wavelength and increasing frequency and energy as well. The spectrums are divided into radio waves, microwaves, visible light, ultraviolet (UV), X-rays, infrared (IR) and gamma-rays.

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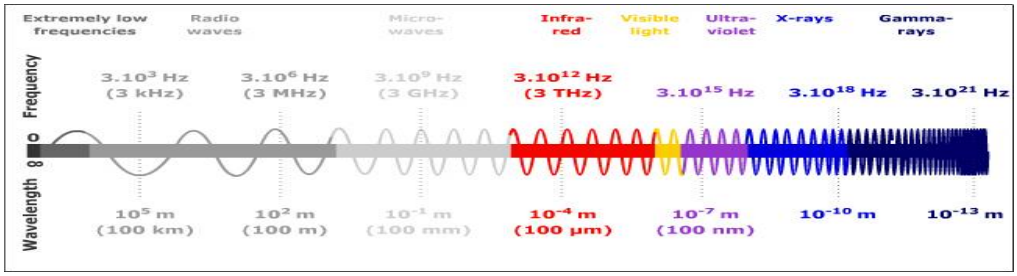

Figure 1: Visible light Spectrum [15]

The electromagnetic waves that human eye can see are confined to this small area, called the visible light region. This part of the radiated spectrum is the range of light frequencies to which the human eye is most sensitive. Visible light shares many characteristics with the other EM waves, because it is a type of electromagnetic wave. All these electromagnetic waves originate from the vibration of charged particles. But these charged particles come from a variety of sources, like the sun, other stars, and warm objects like light bulbs and animals. Any source of EM radiation that human eye can see - like the light from the sun - is considered visible light. So, other sources of visible light would be flames, red-hot metal, and the glowing screen on the cell phone. Thus visible light is kind of visually-perceivable electromagnetic waves. Figure 1 shows that the visible spectrum covers wave lengths from approximately 400 nm (4 x 10^{-7} m) to 700 nm (7 x 10^{-7} m). [5]

B. Visible light communication (VLC):

VLC is an optical wireless communication using LEDs for illumination and communication simultaneously. [3,4]. Presently, VLC systems are being developed by scientists seeking to create ultra high-speed, high security, biologically effective communications networks which allow the creation and expansion of seamless computing applications using very large bandwidth which provide high-frequency pulsed light instead of radio waves and microwaves. Such systems basically use modulated light wavelengths are emitted (and received) by a variety of suitably adapted standard sources, such as indoor and outdoor lighting, displays, and illuminated signs, televisions, computer screens, digital cameras and digital cameras on mobile phones for communication cases, primarily through the use of Light Emitting Diodes (LEDs).

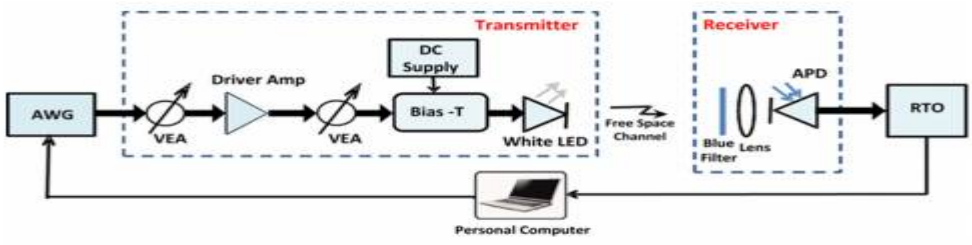

Figure2: Visible Light Communication System [2]

In figure 2, the working principle of DMT is given. A high speed sequence is divided into N binary streams. Effective modulation has been done by using IFFT. The hermitian symmetry property has been achieved by using the 2N information symbols. The effect of ISI has been reduced by using the method cyclic prefix consisting of Ncp samples. DAC has been used to convert the digital signal to analog signal. An FFT block is used in the receiver end which will provide the original samples that were generated by IFFT at the transmitter. LEDs will be the future of newly lighting system as they enjoy many advantages over conventional lighting devices such as Mean Time before Failure (MTBF), high lighting efficiency, specific spectrum and environmental friendliness. LED can be modulated at higher speeds which make it a perfect candidate for data transmission .However, data transmission in VLC is done by changing the light intensity Change in amplitude is so small for a naked human eye that it is un-noticeable [9]. So, right choice of modulation scheme, selection of line coding scheme, use of equalizer at transmitter and receiver can further improve the performance of LED [5]. A further advantage is that VLC systems can transmit data more precisely and securely

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over short distances than radiofrequency/microwave communications devices whose signals can be easily detected outside the rooms and buildings they originate in.

C. Frequency Division Multiplexing (FDM):

Frequency division multiplexing (FDM) is a method which has the capability to divide the total bandwidth into a no overlapping frequency can be used to carry a unique signal. FDM only concern with analogy signals. FDM is mostly used for radio and the television broadcasting. Recently this technique is considered as one of the best solution for the VLC (visible light communication). The different information signals that are passes over a FDM system are known as baseband signals. An electronic oscillator is used to generate carrier signal at a unique frequency that used to carry baseband signals. The modulation technique normally changes some parameter of such as its frequency, phase or amplitude with the baseband signal.

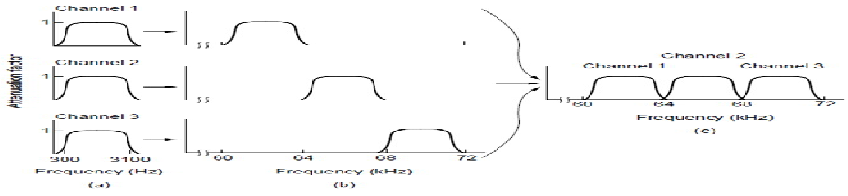

Figure 3: FDM system with three different carrier signals[16]

After modulation of carrier signal with baseband signal, a sub frequency is generated near the carrier frequency which varies from ($f_C + f_B$) to ($f_C - f_B$)[6]. The carrier frequency located on each side of the sideband contains the information from the modulated signal. It is quite clear from the figure that the three different carrier signals has been used with different frequency and combined them with some gaps which is known as guard bands between the channels. This guard is used to solve the problem of overlapping between the channels. These special properties of FDM can provide a huge number of information from the transmitter to the receiver within very narrow band of frequency. These narrow bands around the carrier frequency are also known as pass band of the channel.[5]

D. AWGN Channel:

Additive white Gaussian noise (AWGN) is a very basic noise model which is used in different information theory to observe the effect of many unwanted process that are very commonly found in the nature. AWGN channel is mostly used as a model in which white noise is linearly added with a constant spectral density and it expressed as watts per hertz of bandwidth. AWGN channel does not account for interference, fading and frequency selectivity. But it still can generate simple mathematical models which are capable enough to observe the performance for any particular system. The main properties of AWGN channel is mentioned as below [7]:

- Any kind of noise can be added with the main signal.
- Uniform power across the frequency band for the baseband signal.
- Normal distribution across the time domain with an average time domain value of zero.

The channel capacity of AWGN mainly depends on the maximum power of the channel and a zero-mean normal distribution with variance N.

The channel capacity C for the AWGN channel can be define by following equation:

$$C = \frac{1}{2}\log\left(1 + \frac{P}{N}\right) \ldots\ldots(1)$$

where, P refers the maximum power of the channel, and N means the noise of the signal.

The amplitude of the AWGN channel increased when the signal to noise ratio (SNR) decreases. When signal passes through the AWGN channel, the average number of output of a narrow band pass filter is:

$$= f_o \sqrt{\frac{SNR + 1 + \frac{B^2}{12 f_o}}{SNR + 1}} \quad \ldots\ldots.(2)$$

Where, f_o= the centre frequency of the filter, B= the filter bandwidth, SNR= signal to noise power ratio.

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This channel is going to be very much effective for visible light communication system because of the properties of the channel. In indoor VLC communication level is very low and even we can ignore the noise but when we consider for the outdoor, the level of noise is quite high and the variation of noise is also in huge range. In that case different type of noise can be added to VLC system through AWGN channel can be analyzed properly. In both VLC and AWGN got the uniform power across the frequency band for the baseband signal which will help to analysis the results more accurately [6].

E. On-Off Keying (OOK):

OOK data is conveyed by turning the LED off and on. In its simplest form a digital '1' is represented by the light 'on' state whether a digital '0' is represented by the light 'off' state. The main advantage of this method is to create and decode. The IEEE 802.15.7 standard uses Manchester Coding to ensure the period of positive pulses is the same as the negative ones but this also doubles the bandwidth required for OOK transmission. On the other hand, for higher bit rates run length limited (RLL) coding is used which is more effective. OOK can be extension by adding an dimming which adapts the aggregate output to the correct level. Figure 4 shows the overview of data modulation schemes by OOK modulation [17].

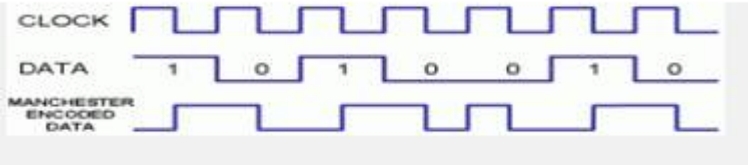

Figure 4: The OOK modulation Scheme [17]

F. Adaptive filter:

The main purpose of adaptive filter is to cancel out the noise in real time which is very much desired after demultiplexing process. Due to low SNR of AWGN channel and harmonic impact, it is very difficult to cutoff the desired signal at the receiver end without perfect filtering. Hence effective and advanced adaptive filtering is a good choice in this case. Figure 5 for noise cancellation is given below:

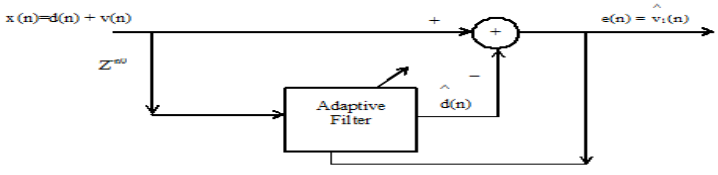

Figure 5: Adaptive noise cancellation without reference [9]

A FIR adaptive filter can estimating a desired signal d(n) from a desired signal x(n). So estimated d(n) is calculated from [9]:

$$\hat{d}(n) = \sum_{k=0}^{p} w_n(k)\, x(n-k) \quad \ldots\ldots\ldots \quad (3)$$

$$\hat{d}(n) = W_n^{\,T} X(n) \quad \ldots\ldots\ldots \quad \ldots\ldots\ldots \quad (4)$$

Where,

$$W_n^{\,T} = [w_n(0), w_n(1), w_n, .., w_n(p),]^T \ldots\ldots(5)$$

$$X(n) = [x(n), x(n-1), \ldots, x(n-p)]^T \ldots\ldots(6)$$

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The adaptive filter coefficients equations for LMS algorithm are [9]:

$$W_{n+1} = W_n + \Delta W_n .....(7)$$

$$W_{n+1} = W_n + \mu \nabla \varepsilon(n) ....(8)$$

Here, ΔW_n is correction coefficient

The NLMS coefficient equation for FIR adaptive filter [9],

$$W_{n+1} = W_n + \beta \frac{X^*(n)}{\|X(n)\|^2 + \varepsilon} e(n) .....(9)$$

Thus Recursive Least Squares (RLS) filter is one kind of adaptive filter which can adaptively cancel out the noise in real time based on renowned least square method [10]. Moreover it is very advanced and effective type of filtering process. The main objective of RLS algorithm is to subtract noise from an input signal. In case of RLS filtering the reference signal is connect to the Input port and the desired signal should be placed on the desired port to automatically match the filter response in the Noise Filter block [8]. As the system converges to the desired filter response, the filtered noise should be completely reduced from the "Signal" which consists of the desired signal and noise. However the "Error Signal" should contain only the original signal. In this research work the RLS filter is placed after the AM demodulation segment, where the unwanted signals should be discard after demultiplexing process.

III. Proposed Model and System Design

Figure 6 shows the system design of VLC system, which is based on OOK modulation and demodulation schemes [10]. It transmits randomly generated bits and shows the input and output bits in scope. Moreover an AWGN channel is integrated along with the model to provide more realistic view.

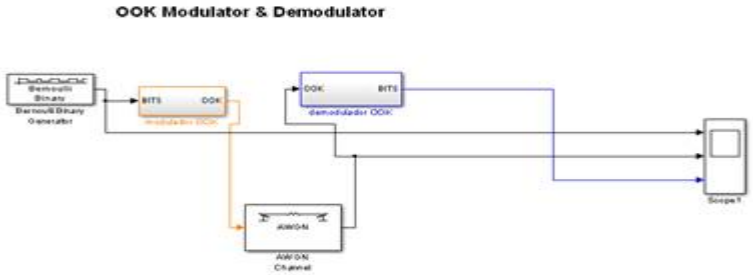

Figure 6: OOK modulation schemes with AWGN channel.

In this research the main objective is to multiplex different VLC signal and pass through a multiplexing system based on Frequency Division Multiplexing techniques for cost optimization and reduce complexity. To implement FDM successfully the theory of amplitude modulation should be successfully implemented at the multiplexing side; however amplitude demodulation should be successfully executed at the demultiplexing side of the system as well. Hence the main goal of this research work to verify whether the OOK signal can be successfully amplitude modulated and modulated signal can be recovered by using amplitude demodulation system [12]. However an AWGN channel should be placed between MUX and DEMUX to provide the system more practical view.

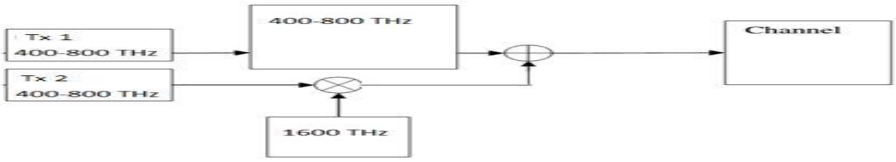

Figure 7: Proposed Multiplexing system for VLC system

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Figure 7 shows the proposed multiplexing system for VLC. As example figure 8 shows that multiple transmitters send data simultaneously and both are multiplexed in one channel by using FDM technique. Firstly the data of Tx1 is directly transmitted where as the data of Tx2 is amplitude modulated and added with Tx1 data to perform FDM lucratively. The multiplexed spectrum is showed in figure 2.3 [13].

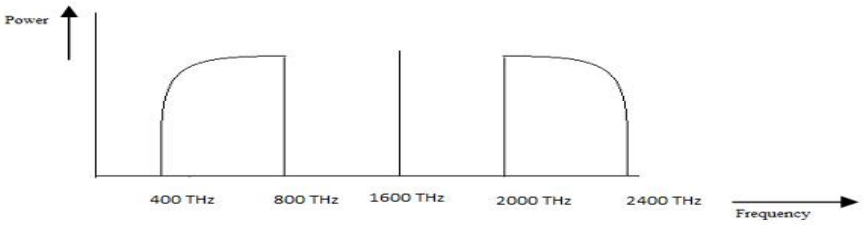

Figure 8: Multiplexed spectrums of VLC system

However figure 9 shows the proposed demultiplexing system for VLC system. A splitter should be used to split the received spectrum afterwards for first receiver the spectrum should be filter out and for second receiver a band pass filter is used to cut off the expected spectrum and multiply with same carrier as transmitter end to extract the received signal for RX 2 [13].

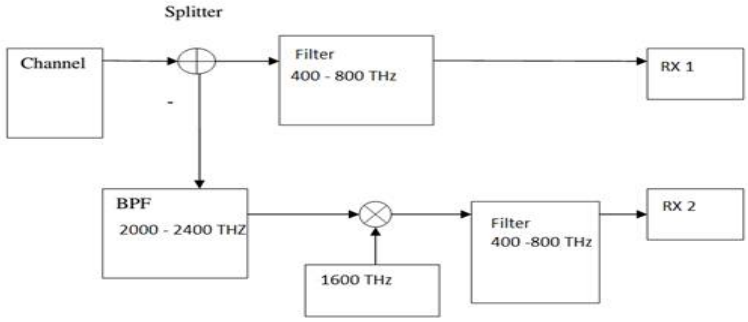

Figure 9: Proposed Demultiplexing system for VLC system

Moreover for RX2 a filter should be placed after the amplitude demodulation process to discard unexpected signals. The main objective of this research is to show the feasibility of FDM system for VLC systems. So in case of simulation only the AM system is integrated with VLC OOK system to verify that the signal can be amplitude modulated and demodulated properly along with AWGN channel and to analyse the bit error rate in this scenario. The demultiplexed spectrum is showed in figure 10 which can be received by the respective receivers [13].

Figure 10: Proposed Demultiplexing system for VLC system

Figure 11 shows that the simulation model of VLC along with FDM system. There some random bits are generated and OOK modulated in case of transmitter end, moreover the OOK signal is amplitude modulated with carrier wave and send through AWGN channel [11,12]. In this case only one multiplier is used for AM and another multiplier is placed for amplitude demodulation purpose to check the feasibility of the system.

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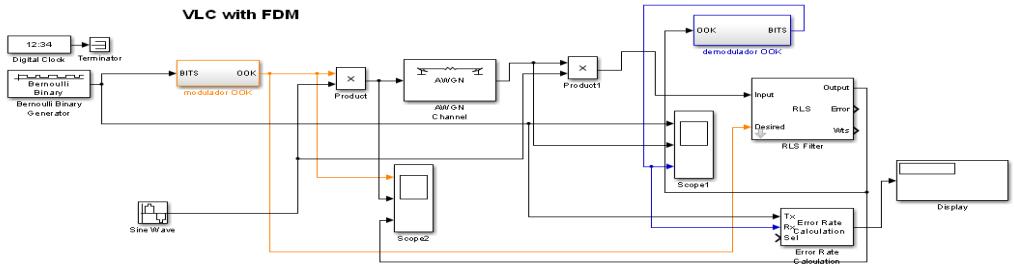

Figure 11: VLC system with FDM and AWGN channel

Finally the signal is multiply with same carrier and the extract signal is recovered by RLS filter to perform the FDM effectively [14]. In addition some scopes and display system is integrated with the system to analyse the results and bit error rate.

IV. SIMULATION RESULTS

The main concern of the research is to analyse the performance of Frequency Division Multiplexing system. The signal to noise ratio is varying due to distance between MUX and DEMUX. Due to short distance the SNR is very high; however the SNR is decrease when the distance increases.[18] Hence the simulation system has been analysed based on different SNR values of AWGN channel. Figure 12 shows the transmitted bit (BITS IN showed in figure 12) stream along with OOK modulated signal of VLC system without Multiplexing whereas the received bit (BITS OUT showed in figure 12) streams are showed at lower part of the figure after OOK demodulation as well.

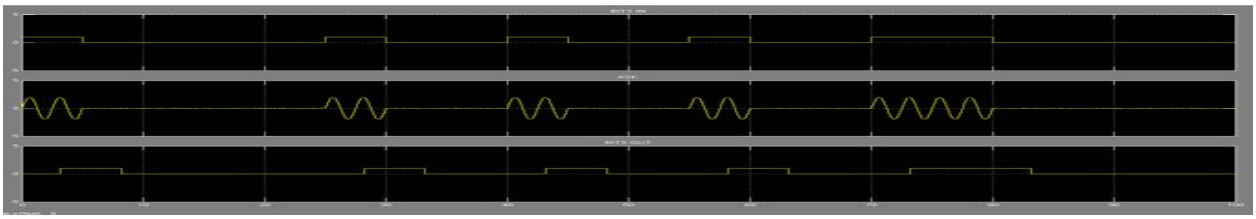

Figure 12: Transmitted and received bit along with OOK modulated signal

The multiplexing and demultiplexing system is placed at transmitter and receiver part respectively. Initially 1m distance has been considered along with 60 dB SNR. So figure 13 shows that the Amplitude modulation is perfectly performed in case of OOK modulated signal and not distorted as well after passing through the AWGN channel. Moreover figure 13 shows the transmitted and received bit (BITS IN & BITS OUT in figure 13) streams are identical and no bit error occurs in this scenario.

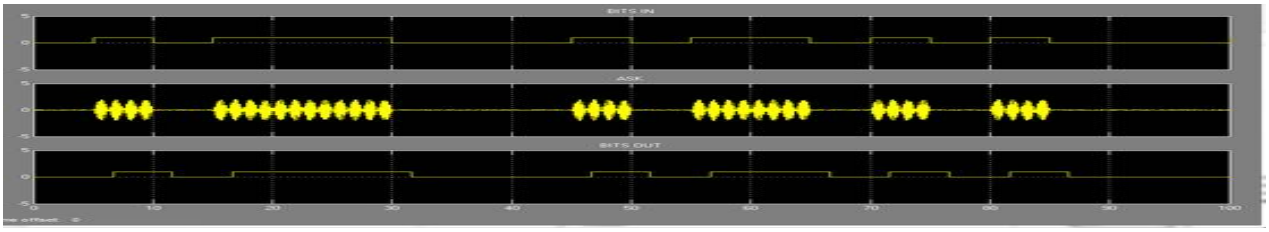

Figure 13: AM performance in case of 1m distance (SNR=60dB)

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Whenever the distance increases the SNR is decrease substantially. Hence for 5m distance 30 dB SNR is considered. So according to 5m distance between transmitter and receiver, figure 14 showed that modulated signal is distorted a little when the distance increases. However the bit error rate is zero as well and the VLC system is working perfectly with FDM system by comparing bits in and bits out in figure 14.

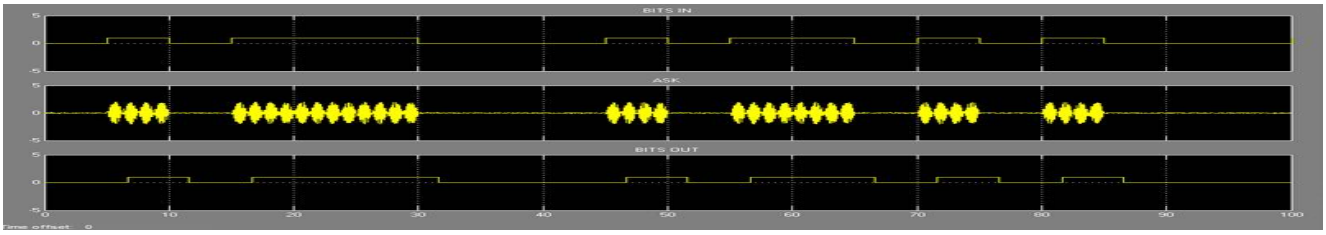

Figure 14: AM performance in case of 5m distance (SNR=30dB)

Afterwards the distance increases to 10m and the SNR dropped to 20 dB in case of figure 15. Hence bit noise intensity has been introduce with transmitted OOK signal when pass through the AWGN channel. However the transmitted and received bit streams are same in case of 10m distance which showed in following figure (BITS IN & BITS OUT in figure 15).

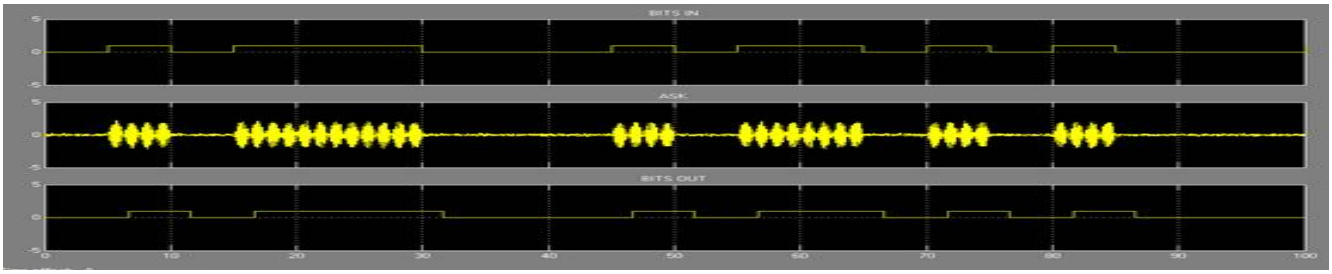

Figure 15: AM performance in case of 10m distance (SNR=20dB)

Furthermore figure 16 shows that the distance increases to 18m and the SNR slumped to 10 dB. Thus more noise has been integrated with transmitted OOK signal in case of AWGN channel. However figure 16 shows that the transmitted and received bit streams are identical and no bit error occur in this case as well.

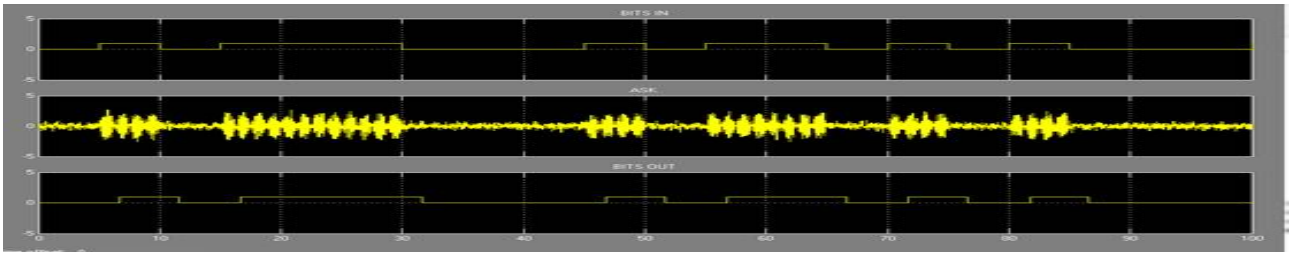

Figure 16 : AM performance in case of 18m distance (SNR=10dB)

In case of worst case scenario the distance increased to its maximum range (30m) hence the SNR dropped to 0 dB which showed in figure 17. So this scenario high noise intensity of the transmitted OOK modulated signal of the VLC system due to least number of SNR. As a result following figure shows that the AM signal is exceedingly distorted in this case and the received bit stream has a little bit distortion due to extremely low SNR of AWGN channel. This can be clearly visualized by comparing the BITS IN and BITS OUT of figure 17.

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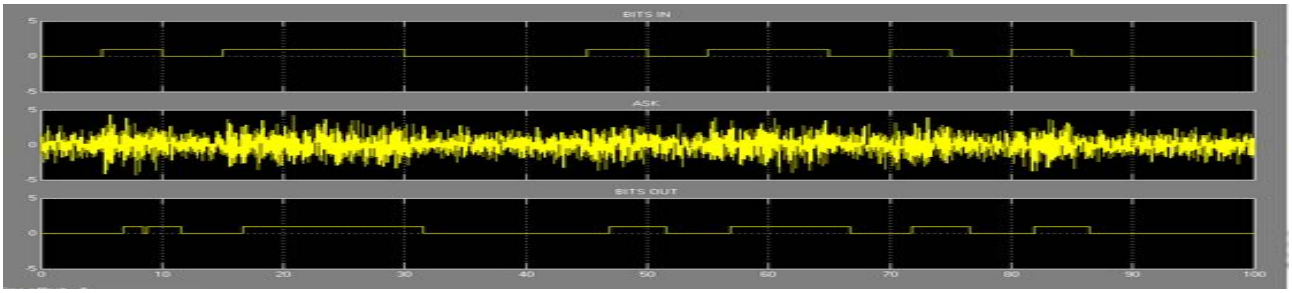

Figure 17: AM performance in case of 30m distance (SNR=0dB)

Finally it can be decided that by using AM technique Frequency Division Multiplexing (FDM) can be performed in case of VLC system. Because the OOK modulated signal can be amplitude modulated properly to shift the frequency spectrum according to carrier signal. Moreover the main OOK modulated signal can be recovered after AM demodulation process along with AWGN channel. However by using present VLC system the MUX and DEMUX system can be worked for less than 30m distance whereas the SNR should be greater than 0 dB according to the analysis of simulation results. Furthermore the bit error rate was zero for each observation which was showed by BER display.

V. CONCLUSION

The main objective of the paper is to check the feasibility testing of OOK signal for FDM multiplexing techniques in case of different SNR level. Moreover the amplitude modulation is a vital issue to implement FDM successfully in case of VLC systems. So by analysing the results it is evidently visible that the On-Off Shift Keying modulation can be perfectly modulated by amplitude modulation techniques and recovered perfectly by amplitude demodulation techniques and adaptive RLS filtering process. The simulation showed that the multiplexing system is working perfectly in any case of SNR and provided bit error rate is zero in each case of Signal to noise ratio. Finally it can be stated certainly that the frequency division multiplexing technique can be implemented with visible light communication system to provide simplicity and cost optimization. Moreover this system can provide high flexibility in case of indoor and outdoor high data rate wireless communication devices.

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