DIGITAL MODULATION TECHNIQUES AND ITS APPLICATIONS OF LIGHT FIDELITY (LI-FI) IN FIXED BROADBAND WIRELESS COMMUNICATIONS

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Abstract

Light Fidelity (Li-Fi) technology provides the transmission of data by using illumination of LED light. There are many wireless technologies available for transmission of data. Depending the number of devices connected to the wireless network (Ex: Wi-Fi), the speed of data transmission becomes slow due to the bandwidth is shared among all the connected devices. The radio spectrum may not be available by 2020 for data transmission because the number of devices is increasing day by day. An alternative technique Light Fidelity was used to overcome these problems which were proposed by German Physicist Prof. Harald Haas.

Li-Fi is a new technology in which visible light communication is used instead of radio waves. Li-Fi refers to 5G visible light communication systems and light emitting diodes(LED) are used as a high speed communication medium. Like in Wi-Fi radio waves, the light carriers cannot pass the signals through the walls. The Li-Fi works with simple principle, if LED is "ON" it transmit the signal as "1" otherwise it transmit the signal as "0".

There are several modulation schemes used by Li-Fi when we are transmitting the data via LED light beam. The data transmission rates may vary upto 10 Gbps depending on the type of LED. It is very critical to select the appropriate modulation technique for our data which may depend on the intensity of the light. This paper will present the different modulation techniques and its applications for transmitting the data through LED bulb and depending on the type of data and category of LED, analyze which modulation technique was suitable for respective data transmission.

Keywords: LED, Digital Modulation, Multi-Carrier

1. INTRODUCTION

Wi-Fi can be used greatly used for general wireless communication with in the building where as Li-Fi is unique for high density wireless data coverage in confined area and overcoming the problems like health issues from radio frequencies. Li-Fi provides better bandwidth, efficiency and security than the Wi-Fi network by using low cost LED lights and lighting units which are using in homes, hotels, airports, street lights and car head lights. All these LED's are used to establish the connection and to transmit the data among the devices. By LED, we can achieve the speeds more than 10Gbps.

Wireless technology has widely spread lately and we can get connected almost anywhere like at home, in libraries, at work, schools, airports, hotels and restaurants. The Wi-Fi covers the IEEE 802.11 technologies. Every gaming devices, operating systems and printers are compatible with Wi-Fi. Based on the amount of the data on the network, the Wi-Fi may provide the connectivity by emitting frequencies between 2.4 GHz to 5 GHz. The areas which are enabled with Wi-Fi connectivity are known as Hotspots. After all the required settings are installed then the wireless router is plugged into the internet connection to start.

The Wi-FI network uses radio waves to transfer the data across the network like mobile phones. The computer should include a wireless adapter that will translate data sent to a radio signal. The same signal may be transmitted via antenna to a decoder known as router. The decoded data will be sent to the internet through a wired Ethernet connection.

The 802.11 networking standards will somewhat vary depending mostly on the user's needs. 802.11a will transmit data at a frequency level of 5GHz. The orthogonal Frequency Division Multiplexing used to enhance reception by dividing the radio signals into smaller signals before reaching the router. We can transmit a maximum of 54 megabits of data per second. The 802.11b will transmit data at a frequency level of 2.4GHz which is relatively slow speed. We can transmit maximum of 11 megabits of data per second. The 802.11g will transmit data at 2.4 GHz but can transmit maximum of 54 megabits of data per second as it also uses an OFDM coding. The more advanced 802.11n can transmit maximum of 140 megabits of data per second and used a frequency level of 5GHz.

It is easy to create separate uplink and downlink channels with the natural beam formers of LED, by which we can browse secure internet. The LI-FI allows us to network via a desktop photosensitive unit that works with unmodified light fixture. It delivers a capacity of 5 Mbps in the uplink and downlink channels and it will cover up to 3 meters. Depending on the color of LED it can reach up to 10Mbps.

LI-FI uses visible light communication instead of radio waves, by which we can transfer the data faster than human eye. The LED lights can also be used as access points in case of internet of things (IoT). If we are in the optical window then we have unlimited bandwidth and unlicensed spectrum. The visible light communication is a communication medium which uses visible light between 400 to 800 THz and Visible light communication is a subset of OWC. The technology uses fluorescent lamps to transmit the signals at 10kbits/s or LED's up to 500Mbps. The device called photodiode is used to receive the signals from the LED which contain an image sensor.

The Visible light communication uses the visible light for transmission of data, in which we use illumination sources for not only producing the illumination but also send the information using the same light. For example, if we switch the torch ON and OFF very quickly using a computer system. Due to the rapidity between ON and OFF states, the torch appears in ON state constantly and we cannot see the data being transmitted.

The LED bulbs are used by LI-FI technology at the downlink transmitter. In order to set up the LED system, we need some LED's and a controller which can code the data into LEDs. By varying the current very fast, the optical output can be made to vary at high speeds. By varying the rate at which the LED, we can encode the required data and thus transmit the data easily. Investigations are going on for transmitting the data at a rate of 10Gbps.

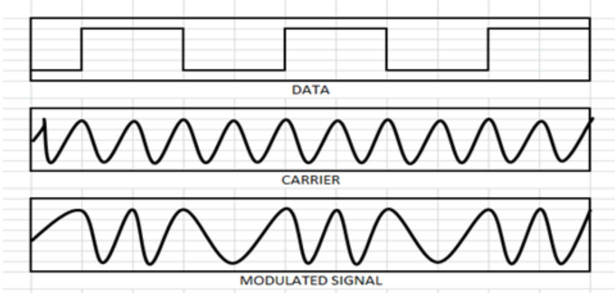
2. DIGITAL MODULATION TECHNIQUES

When we are sending the data through LED, it is mandatory to modulate the data into carrier signal format. This signal contains pulses of light sent out in short intervals. These are basically depends on the modulation technique we chosen for transmission. In digital modulation techniques, an analog carrier signal is modulated by the binary code. The device called digital modulator acts as an interface between transmitter and the communication channel. Based on their detection or bandwidth characteristics, the digital modulation techniques are categorized. The basic criteria for the best modulation technique is Signal to Noise Ratio(SNR), Power efficiency, Bit Error Rate(BER), Available bandwidth, Quality of service, effective cost. By estimating its probability of error with an assumption, the performance of each modulation schemes are measured.

In the telecommunication system several basic modulation schemes are used like Frequency Shift Keying(FSK), Amplitude Shift Keying(ASK) and Phase Shift Keying(PSK). The basic technique for digital modulation scheme can be formed by using FSK,ASK and PSK with pulse shaping, but other digital modulation techniques are also possible by combining two or more basic modulation techniques with or without introducing pulse shaping.

2.1. Binary Frequency Shift Keying (BFSK)

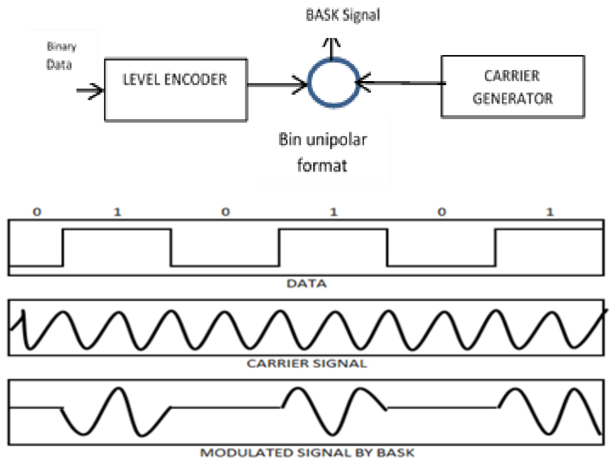
In this technique, the two different symbols are represented by two different frequencies mark and space. BFSK can be categorized as wideband or a narrowband digital modulation technique depending upon the separation between two frequencies. PSK or QAM has better error performance than FSK and thus is used for high performance digital modulation systems.



2.2. Binary Amplitude Shift Keying (BASK)

It is possible to change the amplitude of the carrier wave to obtain the binary amplitude shift keying. Due to coherent modulation in BASK , the concept of the co-relation between the signals, number of basis functions and the symbol shaping are not applicable here. In BASK modulator; the output of multiplier is modulated by binary code. The input binary sequence is converted into suitable format by the level encoder for product modulator.

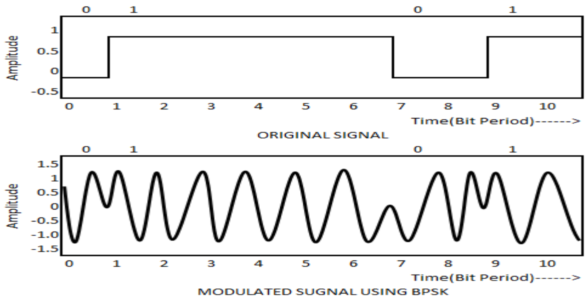
The bandwidth efficiency is very poor in BASK. The implementation of the BASK is simple but it is highly vulnerable to noise and the performance is good only in the linear region which does not make it suitable for mobile or wireless applications. The FPGA based modulator is presented for BASK modulation technique.



2.3. Binary Phase Shift Keying (BPSK)

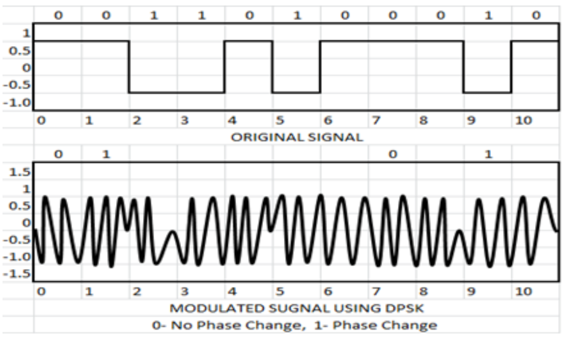
The BPSK digital modulation scheme is the simplest form of phase modulation and in this scheme, the carrier phase represent only two phase states. To produce BPSK signal, the fixed magnitude levels of +(Eb)1/2 and –(Eb)1/2 are used to represent the binary sequence in polar form with symbol 1 and 0. The resulting binary wave in polar form and a sinusoidal carrier ϕ1(t), whose frequency is given by fc = (n c/T b) for some fixed integer nc are applied to the product modulator. The required PSK wave form can be obtained at the output of modulator.

The noisy PSK signal x(t) is applied to a correlator to demodulate the original binary sequence of 1s and 0s, which is supplied with a locally produced coherent reference signal ϕ1(t). The threshold of zero volts and correlator output is compared. If the correlator output > 0, the output of the receiver will be symbol 1 and If the correlator output < 0, the output of the receiver will be the symbol 0. Otherwise the output of the receiver is in favor of 0 or 1.



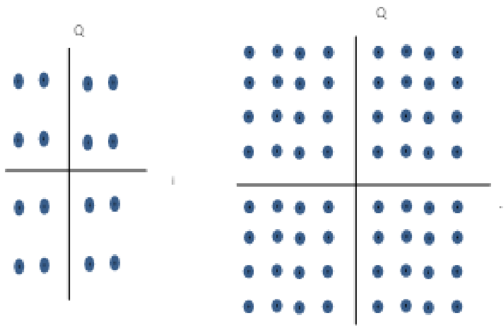
2.4. Differential Phase Shift Keying (DPSK)

We combine phase shift keying and differential encoding at the transmitter station to get DPSK. In this technique, the phase is unchanged for the transmission of symbol “1” and the phase of the signal advanced by 180^0 for the transmission of symbol “0”. The complete process is based on the assumption that the alteration of the phase is very slow to an extent that it can be considered to be almost constant over two bit intervals.



2.5.. Quadrature Amplitude Modulation (QAM)

The QAM is a modulation scheme where its amplitude is allowed to vary with phase and it can be viewed as a combination of ASK as well as PSK. Most of the digital data communication applications are using the technique QAM. When we compare with the other techniques, the QAM modulation is more efficient and useful. This modulation is applicable to almost for all the progressive modems.



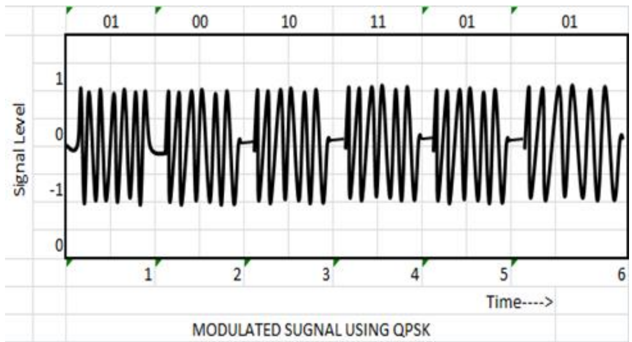
In the 16 – QAM four different magnitude levels are used and 4 * 4 = 16 states are available in the combined stream. In this scheme, each symbol represents four bits.

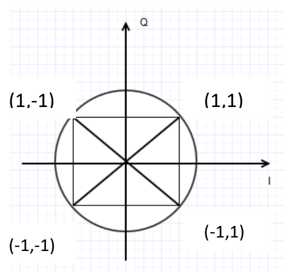
The second figure is same as 16-QAM except that it has 64 states where each symbol represents six bits. 16-QAM is a complex modulation technique but with a greater efficiency. When the link condition is high the mobile Wi-Max technology uses this higher modulation technique.

2.6. Quadrature Phase Shift Keying(QPSK) :

The Quadrature Phase Shift Keying becomes highly bandwidth efficient digital modulation technique and it have 4 message points. The major advantage over BPSK by having the information capacity double to it, the division of phase carrier signal designed by allotting four equally spaced values for the phase angle as Π/4, 3Π/4, 5Π/4 and 7Π/4. The data bits to be transmitted are combined into symbol containing two bits, each symbol can take on one of four possible values from the set 00, 01, 10 or 11.

Different phases are used to transfer more data and single carrier due to the fewer requirements of bandwidth and power. This technique can be used to maintain the data rate of BPSK but half the bandwidth requirement and also used to double the data rate compared to BPSK. It is possible to measure the performance of QPSK by its Bit Error Rate(BER) or by Symbol Error Rate(SER).



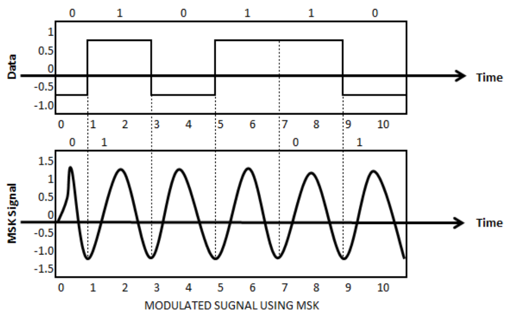


QPSK SYSTEM

2.7. Minimum Shift Keying(MSK):

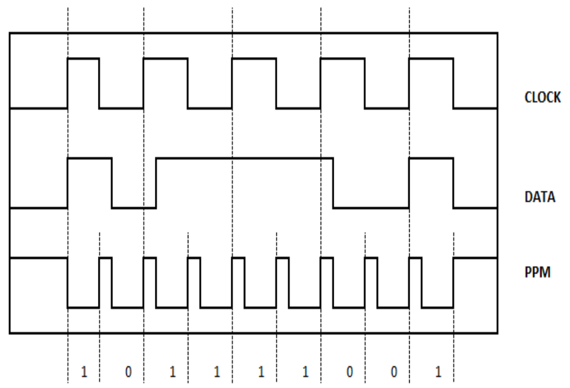
The characteristics like performing well in Gaussian channels and Fading channels can be achieved by using Minimum Shift Keying modulation technique. We can also call this technique as improved version of FSK. The minimum spacing between the two carrier frequencies should be equal to half of the bit rate for keeping the two frequency states orthogonal. Due to the ½ cosine pulse shaping, the information capacity of MSK signal is equal to that of QPSK signal with lesser bandwidth requirement of QPSK. An MSK signal can be obtained from either an

OQPSK signal by substituting a square pulse by ½ cosine pulse or from an FSK signal alternatively. The MSK technique is spectrally more effiecient than QPSK because it has lower out of band power.

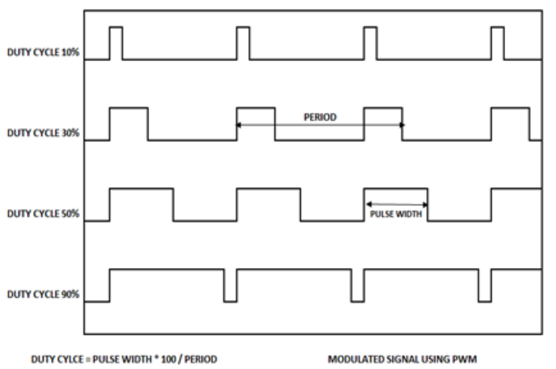


2.8. Pulse Position Modulation (PPM):

PPM is a form of signal modulation in which message bits are encoded by transmitting a signal pulse in one of possible required time shifts. This is repeated for every fixed number of seconds, such that the transmitted bit rate is bits per second. When there is a little or no multipath interference, it is primarily useful for optical communication systems.



In the sub carrier inverse PPM method, whose structure is divided into two parts subcarrier part and DC part. For lighting and indicating, the DC part is used. When there is no need of lighting and indicating SCPPM is used for VLC to save energy



***2*.9. Pulse Width Modulation (PWM):**

To encode the message into a pulsing signal Pulse-width modulation (PWM) technique is used. This modulation technique can be used to encode the information when it is transmitted, its main use is to allow the control of the power supplied to electrical devices, especially to inertial loads such as motors. In this technique, the data is transmitted by encoding with in the duration of the pulses. With in a pulse, it can be conveyed more than one bit of data.

***2*.10. Pulse Interval Modulation (PIM):**

The optical transmitter consists of an array of 6 LEDs, emitting a total radiant power of 200 mW at a wavelength of 875 nm. All the LEDs are pointing vertically upwards towards the ceiling. The receiver consists of a 1 cm2 silicon pin photodiode, followed by a 14 k□□trans impedance preamplifier. A matched filter is employed to maximize the carrier-to-noise ratio prior to the decision making process. The threshold detector samples the incoming signal every slot, and compares it with the threshold level. A logic '1' is assigned to a particular slot if the sampled signal exceeds the threshold level, otherwise a logic '0' is assumed. The clock recovery circuit uses a PLL to extract the slot clock from the incoming DPIM pulse train, which is used to generate the sampling points for the threshold detector, and count the number of slots between adjacent pulses in the demodulator circuit.

The two main advantages of DPIM over DPPM, making it an attractive modulation technique for optical communications, are the increase in capacity and the fact that symbol synchronization is not required, resulting in a simplified receiver structure. The increased capacity can be used to improve either the bandwidth efficiency or average power efficiency of the system. Expressions have been presented to characterize DPIM and its error probability performance based on a receiver employing a matched filter. Practical results are given in the form of eye diagrams for a prototype optical wireless system, thus highlighting the potential of this new scheme for optical transmission systems. Finally, problems which may arise when using DPIM in network environments, due to its non-uniform symbol structure.

2.11. ON-0FF Keying(OOK):

The simplest form of amplitude-shift keying (ASK) modulation that represents digital data as the presence or absence of a carrier wave denoted by On-off keying (OOK). In its simplest form, a binary code is represented by the presence of a carrier for a specific duration, while its absence for the same duration represents a binary zero. To carry additional information, some more sophisticated schemes vary these durations. It is very easy to generate and decode but is not very optimal in terms of illumination control and data throughput.

2.12. Intesity Modulation (IM):

A new modulation technique was introduced for optical wireless communication using incoherent LED's. the information is varied depending on the intensity of the light. As a result the signal that modulates the LED strictly positive and real valued. The major challenge in optical wireless communication is how to convert these complex valued and bi-polar values into uni-polar and real valued signals without offsetting the bit error performance. This can be achieved by using orthogonal frequency division multiplexing.

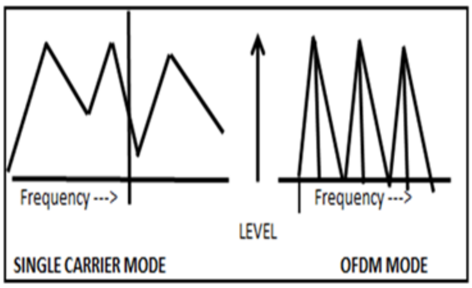
2.13. Hadamard Coded Modulation (HCM):

In order to provide required illumination, the VLC and LI-FI system use the indoor lighting systems which require high average optical powers which can cause high amplitude signals common in higher order modulation schemes to couple by the peak power constraint of the LED and lead to high signal distortion. The HCM is to achieve low error probabilities in LED based VLC system which needs high average optical powers by using Fast Walsh-Hadamard Transform (FWHT) to modulate the data as an alternative modulation technique to OFDM. HCM achieves a better performance for high illumination levels because of its small peak to average power ratio. The power efficiency of HCM can be improved by reducing the DC part of the transmitted signals without losing any information. The resulting method is called DC reduced HCM.

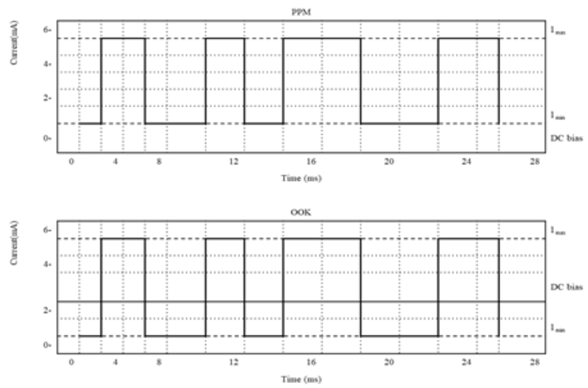
DCR-HCM is well suited to environments required dimmer lighting as it transmits signals with lower peak amplitudes compared to HCM. Interleaving can be applied to HCM to make the resulting signals more resistant against inter symbol interference in dispersive VLC links.

2.14. Single Carrier Modulation:

There is a fixed relation between average electrical power and the average optical power of the single-carrier and multi-carrier signals which varies with the change in the biasing setup i.e A combination of direct current (DC) bias and signal variance. Single Carrier modulation techniques are suitable for data transmission in OWC. The information can be encoded in the duration of the pulse with the techniques such as pulse width modulation (PWM) or pulse interval modulation (PIM). In addition, the information can be encoded in the position of the pulse, such as M-PPM. Alternatively, the information can be encoded in the amplitude of the pulse, such as M-PAM.



To avoid the any complex values, the OFDM baseband signal is used to modulate the LED intensity. The signal generated by OFDM is bipolar and optical intensity cannot be negative. So before applying the OFDM modulating signal, the LED should be biased. Therefore, to reduce magnitude distortion, and to control signal clipping by using single carrier binary optical transmission the bias current must be carefully set to get the maximum allowable forward current of the LED.



Modulation using PPM and OOK

3. WORKING PRINCIPLE

In M-PPM, log2(M)input bits form a time domain symbol. It is a sequence of M chips represented as a vector c, where one chip has a current level of √MPs(elec) . and other M-1 chips are set to 0. Here Ps(elec) is the average electrical power of the M-PPM symbol and it is related to average electrical bit power. Pb(ele) as

Ps(ele) = Pb(ele) Log2(M)

The respective energy per symbol Es(elec) and energy per bit Eb(elec) are obtained from the symbol rate Rs as

Es(elec) = Ps(elec) / Rs and Eb(elec) = Pb(elec) / Rs

Here the M chips with duration of Ts /M fit within a time period of Ts. The M-PPM symbol with a bandwidth of B= M / Ts has the duration of Ts for a symbol rate of Rs = B / M and it is grouped in the train of L symbols SL . Where L= 0,1,2, …….. n-1. The spectral efficiency of a modulation scheme is determined by the number of bits that can be transmitted per symbol duration and per symbol bandwidth,

SE = Rb / B where
Rb = log2(M)Rs is the bit rate.

The train of symbols, SL, is pre-distorted by the inverse of the nonlinear transfer function of the LED transmitter, and it is scaled by a factor, α, in order to fit within the front-end optical power constraints. Next, the signal is passed through a digital-to-analog converter (DAC) to transform the train of digital chips into a train of continuous-time pulses. A pulse shaping filter with a real-valued impulse response of v(t) is applied to obtain a band-limited signal.

In M-PPM, because of the fact that the information-carrying pulse has an optical power level greater than Pmin,norm, zero bias is required. As a result, the transmitted signal vector, F(XL), has a length of Zx = LM, and it can be expressed as follows:

F(XL) = α.SL

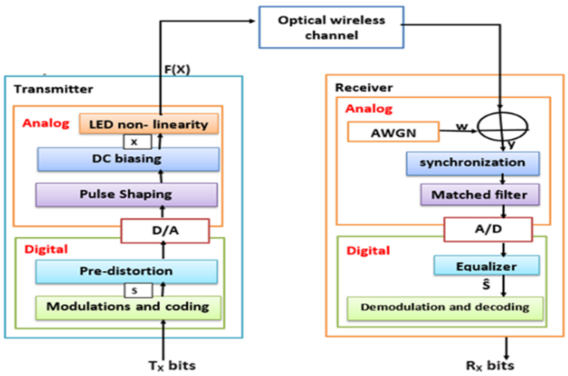
Where α = min(Pmax,norm, MPavg,norm) /√MPs(elec)

The transmitter front-end constrains

Pmin,norm and Pmax,norm,

Whereas Pavg,norm is independently imposed by the eye safety regulations and/or the design requirements. In M-PPM, when MPavg,norm < Pmax,norm, the resulting pulse level, MPavg,norm, should be set greater than Pmin,norm in order to turn on the transmitter. The average optical power of the signal is denoted as E [F(xl)] where E [·] denotes the expectation operator. In general, constraining the average optical power level to E [F(xl)] ≤ Pavg,norm results in suboptimum BER performance of the OWC systems. The best BER performance is obtained when this constraint is relaxed, i.e. when E [F(xl)] is allowed to assume any level in the dynamic range between Pmin,norm and Pmax,norm.

In order to relate the average optical symbol power, Ps(opt), to the electrical symbol power, Ps(elec), the signal is subjected to O/E conversion defined as follows:



4. APPLICATONS / LIMITATIONS OF MODULATION TECHNIQUES IN WIRELESS COMMUNCATIONS:

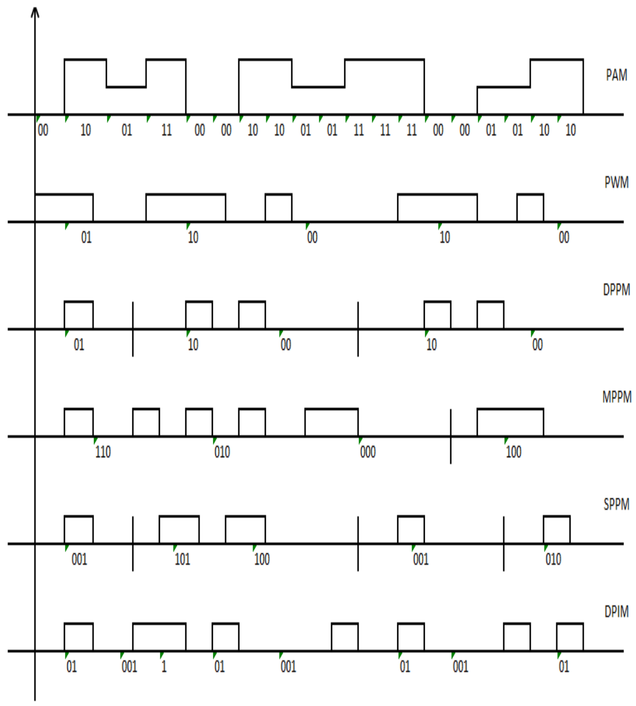
MODULATION SCHEME	APPLICATIONS / LIMITATIONS
BFSK and FSK	Paging, Public safety
BASK	Performance is good only in the linear region.
BPSK	Cable modems, Deep space telemetry
DPSK	Satellite, Aircraft, telemetry monitoring broadband video systems
16-QAM	Modems, Microwave digital radio
32-QAM	Terrestrial Microwave
64-QAM	Broadband setup boxes, Modems
256-QAM	Modems, Digital Video
QPSK	More data can be transmitted using different phases and single carrier due to the fewer requirements of bandwidth and power.
MSK and GMSK	Global system for mobile
PPM	When there is need of less lighting and to save energy
PWM	To control the power supplied to electrical devices like internal loads
PIM	Attractive modulation Technique for OWC, Problems may arise due to non-uniform symbol structure
IM	Transmission of information varied depending on the intensity of light signals.
HCM	The indoor lighting systems required high average optical power.
SCM	Hybrid modulation to control signal clipping the bias current must be set to maximum allowable capacity

$$Ps(elec) = \frac{E[F(XL)2]}{E[FXL)]2} P^2 s(opt)$$

Where E $[F(xl)]^2$ = min(Pmax,norm/M, Pavg,norm$)^2$

After passing through the optical wireless channel, the signal is distorted by AWGN, WL, at the receiver to obtain the received signal, YL. After synchronization, the signal is passed through a filter with an impulse response of v(τ − t), matched to the impulse response of the pulse shaping filter at the transmitter in order to maximize the received SNR.

At the analog-to-digital converter (ADC), the signal is sampled at a frequency of M/Ts. After equalization of the channel effect by means of linear FFE or nonlinear DFE with ZF or MMSE criteria, the distorted replica of the transmitted symbol, tilta(SL), is obtained. A hard-decision or soft-decision decoder can be employed to obtain the received bits.



Digital Signal represented using different Modulation techniques

5. CONCLUSION AND FUTURE WORK

A literature survey on the digital modulation techniques presented in this paper reveals that the selection of digital modulation technique is exclusively dependent on the type of specific application, as one application may need higher precision in reception of data, whereas the other application requirement may be available bandwidth or power. The quality of service provided by wireless communication system can be greatly enhanced with the help of correct selection of modulation scheme. Thus, increased radio coverage and reduced power consumption can be obtained by the proper selection of digital modulation technique. The some of the technique involve lesser complexities in the modulation and demodulation system design and prove cost-effective like the BASK, BFSK, BPSK and DPSK modulation schemes and can be visualized for the systems which actually does not need high amount of precisions or when financial budget is the foremost aspect and the BER performances can be tolerated. The QAM techniques are exclusively used for Microwave Digital radio, Digital video, broadband set top boxes and in Modems. In the area of mobile communication, GMSK has proved its performance over the QPSK and MSK because of the better spectral efficiency. But the search for a better modulation scheme doesn't end here as the criterion for higher data rate communication is taking the lead role in almost every field of communication and thus the Inter Symbol Interference and Bit Error Rate calculation become very crucial and important aspect for any ultramodern digital modulation scheme.

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