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Underwater optical wireless communication analysis using blue laser diode

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ABSTRACT

In the proposed system, a 450nm blue laser diode is directly modulated by 16 Quadrature Amplitude Modulation (QAM) data which are orthogonal. The simulation is done by assuming underwater with ambient noise present in the underwater covering a distance of 20 meters. Due to the presence of noise and attenuation of the wireless medium, the optical power is decreased to a great extent. The photo detector converts the weak optical signal to electrical signal. The phase and amplitude of the signal is change caused by noise present in it. A Butterworth filter is implemented to obtain the original signal at the receiver side. It is shown that the output binary data has change due phase due to the corruption of the noise.

Keywords: Lasers, LED, QAM, Photodetector, Optical wireless channel, Blue lasers, Demodulation, PIN diode.

1. INTRODUCTION

Laser delivers a very bright beam of light for underwater applications as measurement, surveying, distant ranging, reference pointing, communication and control, physical sensors. Diode LASER is particularly suited to the marine application because of their insensitivity to vibration, long life, compact size, wide input voltage. Human eyes are sensitive to light in the wavelengths between 400nm(violet) to 700nm(red) (VIBGYOR). It is interesting to know that human eyes have cones that are sensitive to a different segment of the visible color spectra: red, green, blue (RGB). Red light is absorbed 6 times faster by water than green light. Minimum absorption occurs with 480nm i.e., Blue light. Human eyes can see green light better than any other color and it travels through the water with less absorption. However green laser diode is not suitable because the wavelength changes with temperature and the cost is more expensive. In this report, using blue laser diode (GaN) operating at 450nm is employed to directly modulate a 16 Quadrature Amplitude modulation (QAM) Orthogonal Frequency Divisional Multiplexing (OFDM) data. In this research, we consider the channel to be sea water, which is interrupted by noise; it is termed as ambient noise. The laser is used to convert the electrical signal to optical signal at a very high bit rate. In the proposed channel, the modulated signal is disturbed by the unwanted noise signal. Usually, photo detectors are used to convert the optical signal back to the electrical domain. In this paper, we also designed a filter and amplifier to obtain the original bit sequence.

Optical Wireless Communication (OWC) uses unguided visible, infrared (IR), ultra violet (UV) light to carry signal in the optical domain. The OWC system operates in the visible band (390-750nm) are called Visible Light Communication. Visible Light Communication (VLC). The free space optical Free Space Optical (FSO) work at the infrared spectrum (750-1600nm) which can offer a very high data rate of 10Gbits/sec and provide a solution for the long haul network. Before the development of optical devices and photo detectors [12], wireless communication is implemented in the radio (RF). As more and more users increase, there is a limitation for frequency. The high data link network cannot be supported by the radio frequency the electromagnetic spectrum where the wireless system is deployed is limited in capacity and costly [3] due to the regulation of the frequency band usage. So, researchers come out with a new technology to solve overcome the demand for free spectrum in the upper part of the electromagnetic spectrum. One disadvantage of the optical wireless system are that when the transmitter and receiver are not at line-of-sight Line of Sight (LOS). Typically free space optic communication can produce a data rate of 100Mbits/sec. When light passes through free space or even underwater, the signal power can degrade due to attenuation causing loss of signal. The wireless optical communication consists of lasers or LED at the transmitter to convert to optical domain from electrical domain. The optical signal is very sensitive to any obstruction between transmitter and receiver. The laser or LED radiate optical power [6] over a wide solid angle providing a mobility to the receiver. The term optical wireless LAN is associated with a wireless communication that is free from the frequency

regulation requirements of a particular country. Messages are transmitted in the form of infrared light beams. The optical wireless LAN can be used to illuminate the room while serving as a medium to transfer data. The advantage of this form of communication [11] is its easily installable components. It is also an alternative for the radio wireless communication associated with frequency allocation. The set up uses a transceiver that includes the optical devices such as the LED [21] and photo diode. The quasi-diffuse links slowly diverges a beam of light from the ceiling in the form of a spot.

2. TRANSMITTER SYSTEM DESIGN

A. Proposed Transmitter model

The proposed wireless communication [2] is based on assuming a pseudo-random binary bit to be performed 16 Quadrature Amplitude Modulation (QAM) Orthogonal Frequency Division Multiplexing (OFDM). The modulated data is directly modulated by the laser [20] diode at 450nm. The laser converts the electrical signal to optical signal and the lens collimate at one focal point which is transmitted through underwater. The channel is considered to have ambient noise sources and the optical signal is also attenuated by the absorption of and water molecules and suspended particles. Blue laser at the 450nm wavelength is less absorbed in underwater that makes it suitable for research purpose.

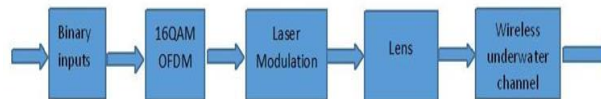


Figure 1. Transmitter proposed block diagram

B. Lens Function

The lens is used to pass the laser beam so that it will collimate at one focal point. The lens system focusing the light has a fixed focal length, but the focal length required to focus various wavelengths (colors) of light is different. Therefore, each color will focus at different points, causing 'chromatic aberration'. The laser diode light contains only a single frequency. Therefore, it can be focused by even a simple lens system to an extremely small point. There is no chromatic aberration since only one wavelength exists, also all of the energy from the light source is concentrated into a very small spot of light.

3. TRANSMITTER DESIGN ANALYSIS

Pseudo-random binary number is taken as input source that is pass to a QAM modulator to change its carrier and phase so that it can be efficiently transmitted to the assumed water channel. Notice that the conversion from electrical to optical takes place in the laser diode. As you know laser is work on the principle population inversion, the energy and information [10] content in the electrical energy is converted in the form of photons. The white light source act as the noise at the same frequency of the laser(450nm). We consider there is no loss in coupling as this is a simulation since in real world there is actually no coupling. Let the received signal be given as $y[t]$, the noise represented as $n[t]$, we can write

$$y[t] = s[t] + n[t]$$

Where,

$y[t]$ is the 16 QAM modulated output.

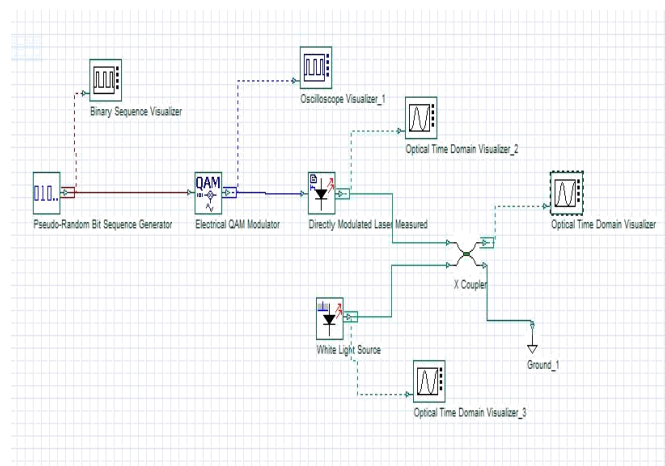


Figure 2. Transmitter system design

All lasers are based on the same principle. Light from an external source passes through the sides of a transparent material, or laser medium, to excite [14] light-emitting photons within a single photon creates 2, that creates 4, that creates 16 in a process called cascading or avalanching.

A. Simulation Results

Given in figure 3 is the source input i.e., the pseudo-random bits. This signal is set to send data at the rate of 2.5 Gbps. The voltage value is 1 volt on the vertical axis and the horizontal axis is the time period in nano second. The binary inputs is a Non-Return to Zero (NRZ) type.

The pseudo-random bits as input is sent to a 16 QAM. The modulator performs both amplitude and phase modulator to modulate with the given signal. After modulation, the amplitude value has increased to 3volts. The QAM split the input binary data into in-phase and quadrature phase at 90 degrees. So, in figure 4, we can see there is phase change at each time period.

The output of the QAM modulator is then passed to the blue laser. It is operating at 450nm wavelength. Blue light is less absorbed by the water molecules that make it very desirable for underwater wireless communication research. The lasers directly modulate

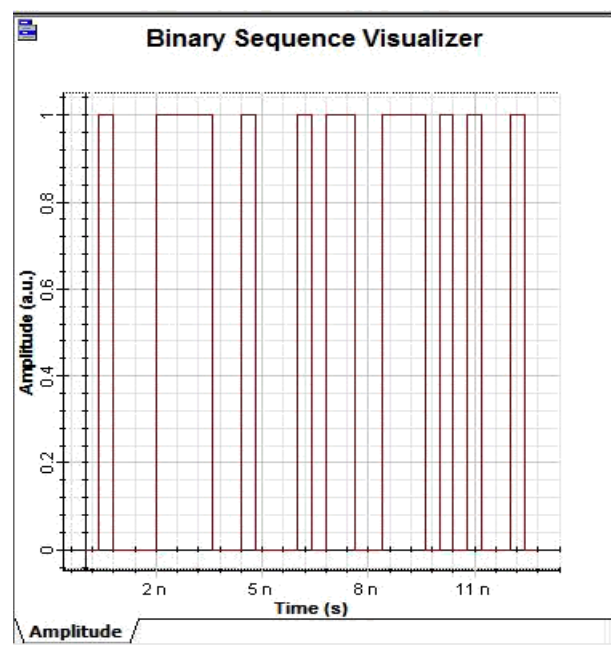


Figure 3. Pseudo Random Bit Sequence

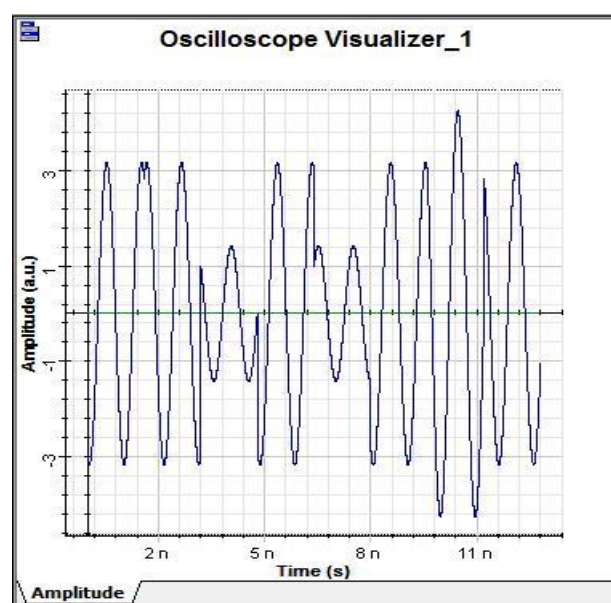


Figure 4. QAM Output at the transmitter

the 16 QAM data which are orthogonal. Thus, the electrical signal is converted into optical signal by the laser device. The laser optical power is obtained to be about 12mW as shown in figure 5.

In this modulation type, the output power of laser device depends directly on input drive current. This means the light is emitted from the device when

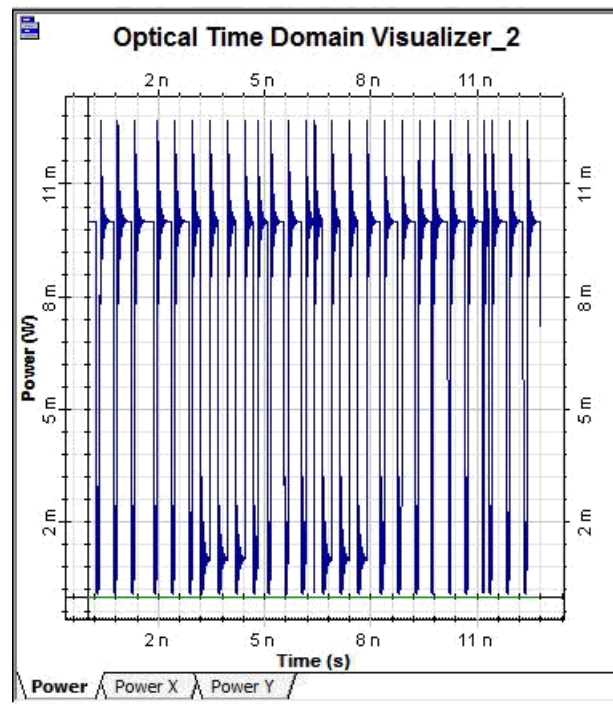


Figure 5. The output of directly modulated laser

"1 (binary one)" is being transmitted and no light is emitted when "0 (binary zero) " is being transmitted. The threshold current is 20mA, the power it generates is set to 10dbm.

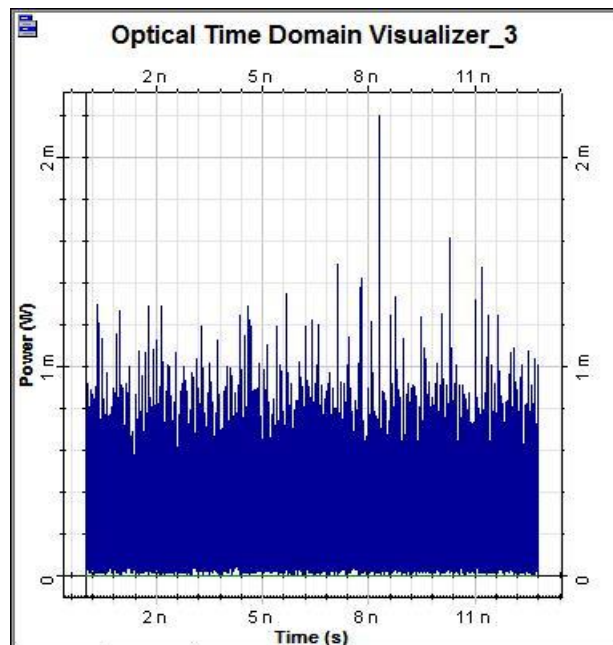


Figure 6. Noise signal power

The underwater channel has a noise with high frequency. The white light source is used as the noise in the considered water 666 THz. The mean power level of the noise is about 1mW shown in figure 6. This is taken so as to have distorted and attenuated optical signal. The average power level is about 1mW. Due to the interruption by the noise, the optical power has reduced to about 8mW shown in figure 7. The noise has distorted the original signal. The phase of the signal is also shifted to random values.

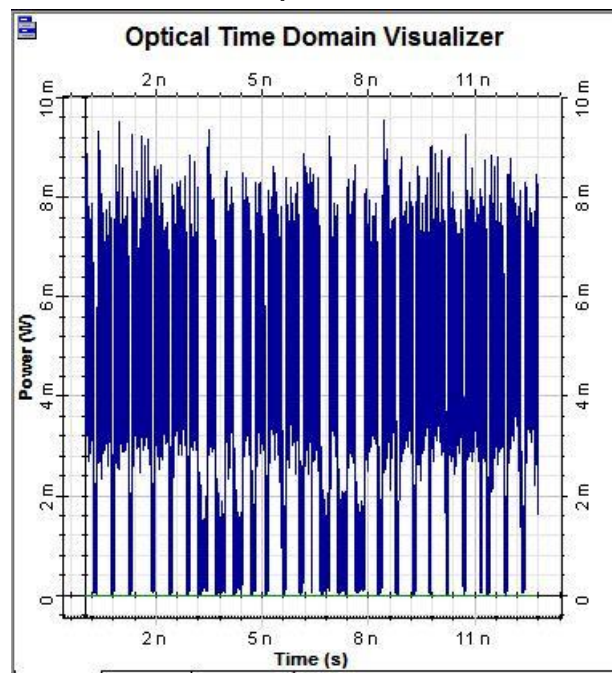


Figure 7. The output of laser after interrupted by noise

Comparing figure 5 and 7, it is seen that the noise level decreases due to the disturbance by the white noise sources. The wireless distant ranges are depending on the optical power level. This makes the distance range to be the only 20meter. As the photo detector has to detect this weak optical signal, it has to be amplified to obtain a reasonable binary data at the receiver side.

4. OPTICAL WIRELESS CHANNEL

The optical wireless channel is considered to attenuate the optical signal from the laser corrupted by the noise. The attenuation constant [13] is given as 0.04dB/km. The transmitter optical efficiency is given as 1. It means that there is no loss of power by the lens used to collimate the laser beam. The OWC is set to operate at a wavelength of 100nm. The operational length of the channel is set to be 20 meters.

The effects of attenuation [1] of laser power are dependent on the wavelength of light and the water particles present. Due to attenuation, the laser beam divergence increase. The main loss is due to scattering of light and absorption [8] by water molecules.

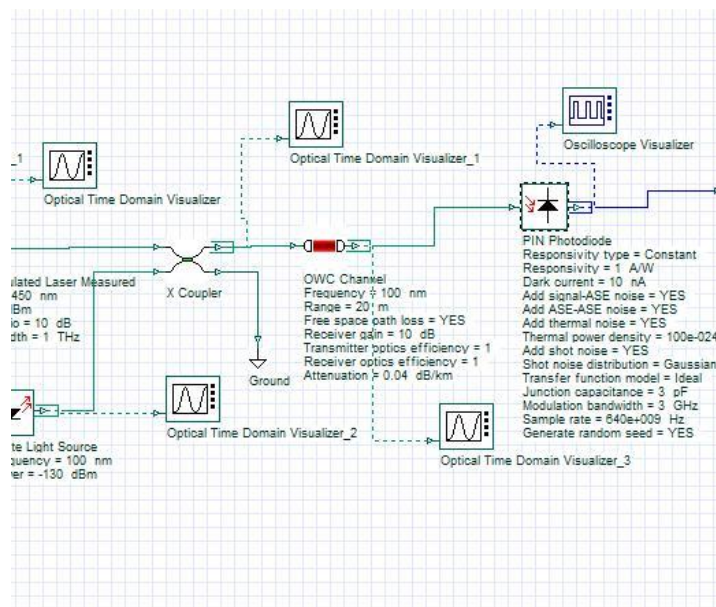


Figure 8. Wireless channel

A. Simulation Results

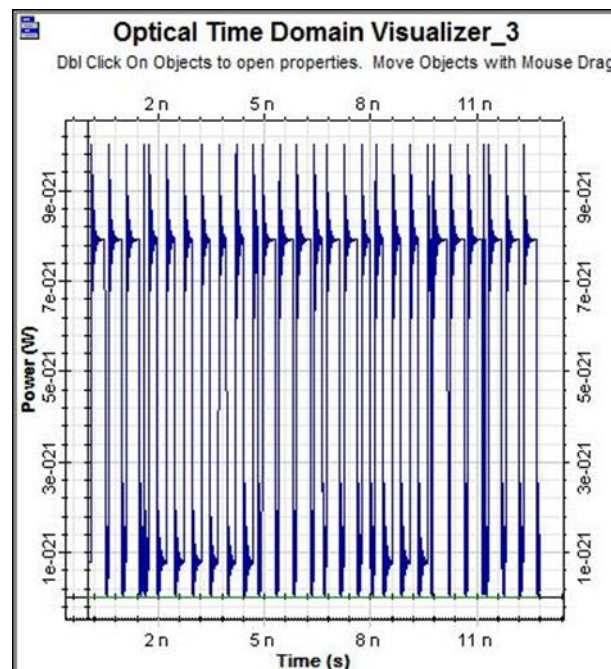


Figure 9. Output of OWC

Due to attenuation effects of underwater and the ambient noise, the optical signal has significantly fallen down to as low as 9×10^{-21} W. Consequently, this weak signal is in a free space and it is not sustainable for long distance. The range is only permissible to 20 meters.

5. RECEIVER SYSTEM DESIGN

The optical signal which is corrupted by noise and attenuation is collimated to a lens to one focal point. It is assumed that there is no loss of power when the laser beam passes through the lens. The photo detector converts the optical signal to electrical signal by the generation of an electron-hole pair. Note that there is also noise source in photo detector. The photo detector usually works in the reversed bias and it is a current controlled device. The output from the photo detector is amplified by an electrical amplifier because the electrical signal is very weak. The signal has to be demodulated to obtain the binary inputs used at the transmitter. A specific cut off frequency has to be given to discard the noise added in the primary signal. Then the signal is finally passed to a [19] low pass filter to get a good and clear signal. The filtered is chosen such that its cut off frequency is in the GHz because laser operates in very high frequency.



Figure 10. Receiver proposed block diagram.

A. Receiver Design Analysis

In the receiver block diagram, the photo detector [9] converts the optical signal to electrical signal. Due to the attenuation of the wireless channel and the interference of the noise sources the output power of the photo detector drastically drop down micro range. We assume the detector is PIN diode with junction capacitance of 3pF, modulation to be 3GHz. There is also noise source present in the diode such as thermal noise dark current noise (10nA) which also decrease the output power of the photo detector. The responsivity [16] of the diode is set to be 1A/W and always constant Responsivity measures the input to output, gain of a detector system. In the specific case of a photo detector, responsivity measures the electrical output per optical input.

B. Simulation Results

When the photodiode is used in reverse bias mode, it acts as a detector. The PIN photodiode is used as the sensor to sense the weak optical signal from the underwater channel. The PIN diode converts the low power [6] optical signal interrupted by the noise into its equivalent electrical signal. It is shown that in figure 12, the signal is mixed with the noise having phase and amplitude distortion. The amplitude value has decreased to about 20 μ volts.

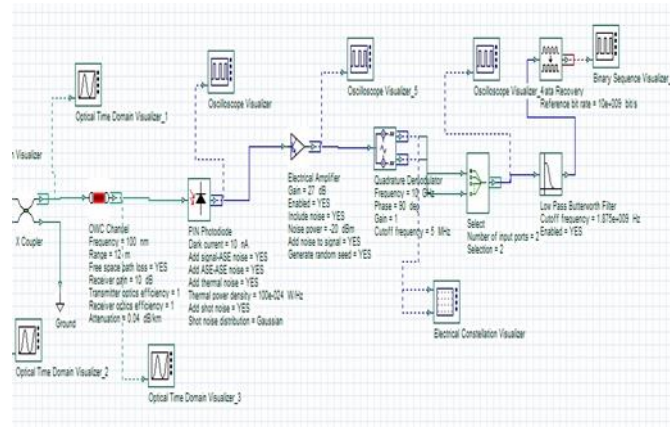


Figure 11. Receiver system design

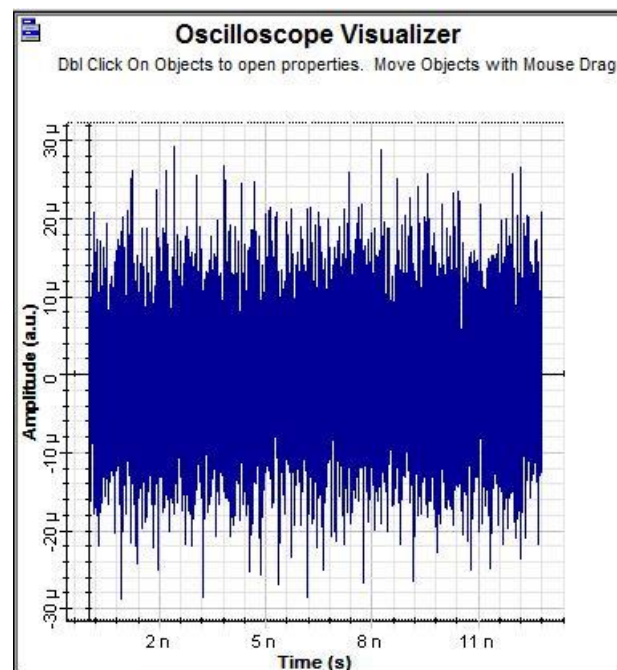


Figure 12. The output of the photo detector

As the electrical signal from the photo detector is very low, it is amplified using an electrical amplifier having a gain of 27dB. The noise in the amplifier also affect the signal and the noise power of the amplifier is set to be -20dBm. As shown in figure 13, the amplitude of the received signal has increased to a mean value of 5000 volts. The received signal has undergone through many noise environment. As a result, the signal has changed its phase and amplitude completely altered from the original input data.

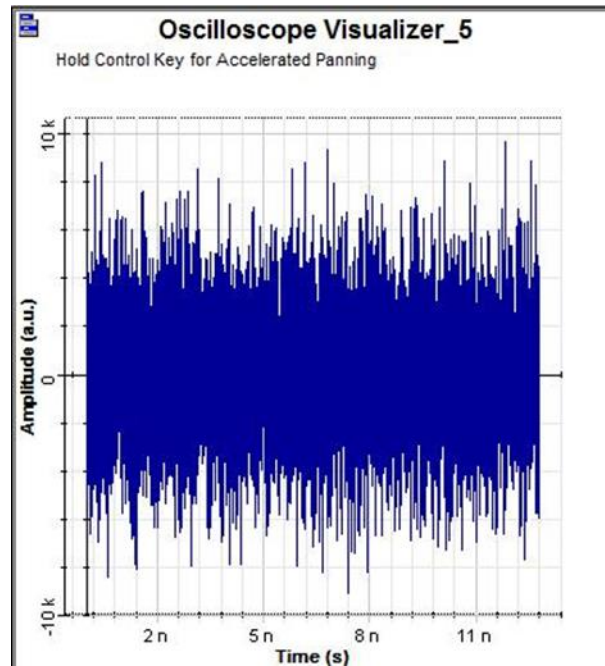


Figure 13. Output of amplifier

The amplified signal is then sent to the QAM demodulator. The demodulator separates [15] the signal into two-phase, i.e; in-phase and quadrature phase which are 90 degrees apart. Due to the distortion contributed by the noise, the demodulated output has a voltage value of 2000 volts. There is a sharp peak in the signal and the phase change is no more orthogonal as shown in figure 14. The constellation [18] plot is also taken. It is seen that due to the noise and attenuation, there is unwanted noise level in the signal. The constellation points have shifted to a various position as shown in figure 15

The output of the demodulator is then sent to the summer and the waveform shows that the phase of the modulated signal has shifted and there is noise contained in the output of the demodulator.

This signal from the demodulator is then sent to a low pass Butterworth filter to filter [4] out the unwanted signal above cut off. The cutoff frequency of the filter is given 1.87GHz. Since the data is sent at the rate of 10Gbits/sec and the amplifier has cut off frequency of 5GHz, the cutoff frequency off Butterworth filter [10,22] is given the said value so that even a

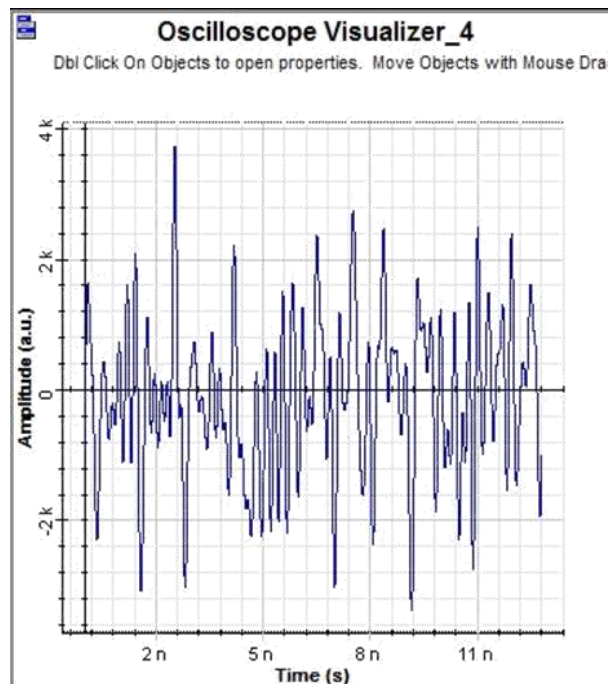


Figure 14. Output of demodulator

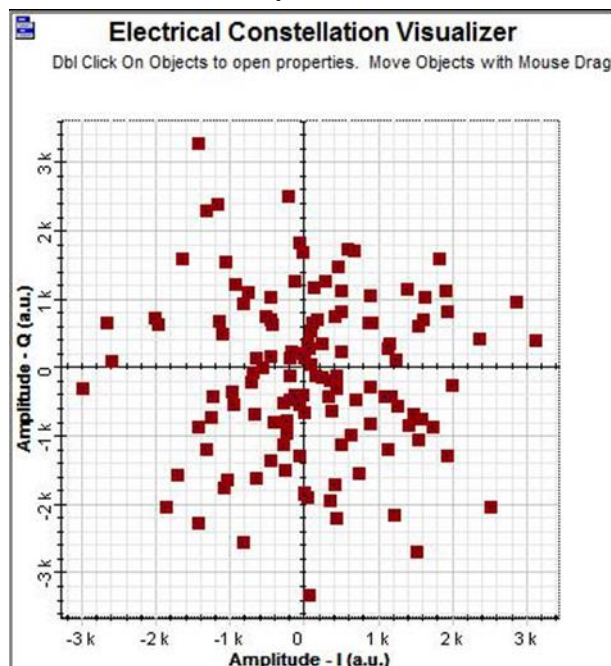


Figure 15. Constellation diagram of demodulator

the single bit will not be filtered out. However, in doing so, we cannot completely discard the noise present in the signal.

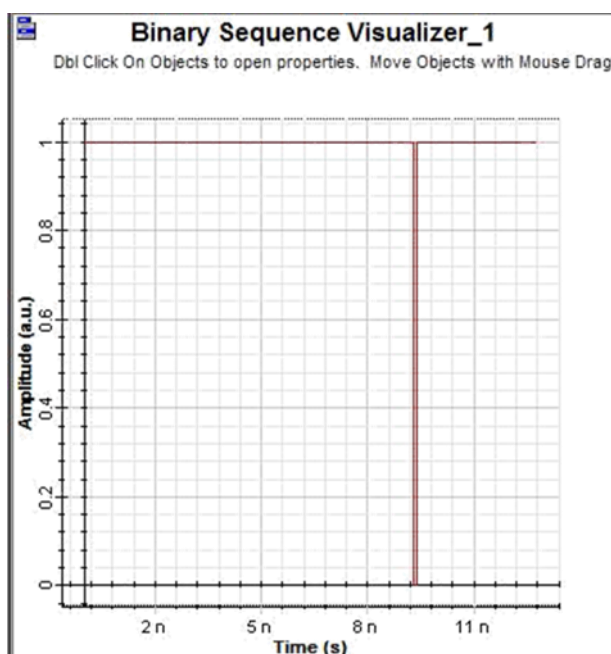


Figure 16. Recovered data

The filtered signal [5] is passed to data recovery block which shows the digital conversion of the waveform having a bit rate of 10GHz. It is given this value so that we can obtain the original uncorrupted binary values as is given at the bit rate of 10Gbits/sec. The data obtained at the receiver is with error [17] as seen from the figure 16. The phase has changed within two time period and the transition time from binary '0' to '1' is very small.

6. CONCLUSION

In this paper, a simulation design an optical wireless communication is shown. The transmitter takes a pseudo-random binary bit sequence that is modulated by 16 QAM modulation technique which is orthogonal. The output of QAM is directly modulated by a laser operating at the 450nm wavelength (blue laser). This laser converts the electrical signal to optical signal. We assumed that the wireless channel to be underwater and there is noise in the water. The white light source is acting as the noise source. The optical wire-less channel (OWC) is used to range up to 12meter. Since it is underwater wireless the power is enormously attenuated. So, after optical to electrical conversion by photodiode the signal is amplified to get an accountable electrical signal. The main disadvantage of this communication system block design is the addition of noise and power attenuation. This noise cannot be clearly eliminated even though a low pass Butterworth filter is implemented. The recovered data is affected badly with a large phase shift and very small transition time. Therefore, an

algorithm to reduce the noise has to be designed. For further improvement, any order of modulation either 16-ary or 32, 64 QAM modulation technique according to our data requirement can be implemented. There are many types of laser which can be used in place of the blue lasers.

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