

12.5 Gbps QAM-OFDM Optical Wireless Communication-System in Coastal-Water-Environment Applying 520-nm Green-LD

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Abstract

Over few decades, underwater-optical-wireless-communication (UOWC) system is used extensively to fulfil the demand of high-bandwidth and high data-rate transmission. Here we have demonstrated the architecture of UOWC system using green laser-diode (LD) applying quadrature-amplitude-modulation and Orthogonal-frequency-division-multiplexing (QAM-OFDM) data-transmission. 12.5 Gbps data are transmitted successfully over 27.5 m, 26 m and 24.5 m distances for 64, 128 and 256 QAM respectively and BER values are 5.23×10^{-9} for 64-QAM-OFDM, 4.17×10^{-9} for 128-QAM-OFDM and 1.72×10^{-9} for 256-QAM-OFDM in coastal-water environment. We have obtained clear constellation diagrams, low BER values and good Q-values by employing the proposed architecture. So, the proposed architecture is useful for high data-rate transmission using this QAM-OFDM modulation format in coastal water.

Keywords: Underwater communication; Orthogonal-frequency-division-multiplexing Quadrature-amplitude-modulation; Bit rate error.

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1. Introduction

In recent year of underwater-activities, there are expanding demands of large transmission-speed, long-distance and high-bandwidth data-transmission¹. UOWC-system has accomplished the necessity of bandwidth-requirement and long-distance, high-speed, larger data-rate transmission². The attenuation of water affects the light-propagation in UOWC-system. Scattering and absorption are two-major factors of attenuation³. Combination of QAM and OFDM are promising modulation-techniques, as it can eliminate inter-carrier-interference (ICI) along with inter-symbol-interference (ISI) with addition of cyclic-prefix (CP) and effective-channel-equalization technique⁴. In previous work, 4.8 Gbps data over 5.4 m distance was transmitted applying 450 nm laser-light in 2015⁵. 9.6 Gbps data, 8 m propagation-distance UOWC-system demonstrated experimentally employing 405-nm two stage injection-locked blue LD⁶. A 1.5 Gbps link was established applying 450 nm laser-diode over 20 m length⁷. Using blue-LD, 225.90 Mb/s and 231.95 Mb/s links were made by applying 32-

QAM and 64-QAM OFDM respectively⁸. Employing 520-nm LD and OFDM technique, a 26 m 5.5 Gbps air-water link was performed in 2017⁹. A 500 Mbps link was made over 100m distance using OOK-NRZ modulation and 520-nm LD in 2019¹⁰. A 6.23 Gb/s data-rate with limited-resolution-DAC and applying QAM-OFDM technique was reported¹¹. In this paper, 12.5 Gbps data-rate UOWC-system has been demonstrated employing 520-nm green-LD in coastal-water environment using QAM Intensity-modulation/Direct-detection (IM/DD) OFDM-technique. Constellation diagrams, bit-error-rate (BER) and Q-values are determined for system-performance. The bit-rate errors of transmitted-data are observed as 5.23×10^{-9} for 64-QAM-OFDM signal, 4.17×10^{-9} for 128-QAM-OFDM and 1.72×10^{-9} for 256-QAM-OFDM, respectively. Very good Q-values and constellation-diagrams are obtained applying our architecture. Optisystem software is used for the proposed simulation-work. LP-Cosine roll-off-filters are used to reduce channel-interference, effect of jitter and inter-symbol-interference¹². These filters enhance system performance and boost data-rate transmission¹³. It is constructed by Nyquist-filter that one has property of vestigial-symmetry¹⁴. Its spectrum has odd-symmetry about $1/2T'$ here, T' is symbol duration. Its transfer-function in frequency-domain is¹⁵,

$$G(f) = \begin{cases} T' & |f| \leq \frac{1-\alpha}{2T'} \\ T' \left\{ \cos^2 \left[\frac{\pi T'}{2\alpha} \left(|f| - \frac{1-\alpha}{2T'} \right) \right] \right\} & \frac{1-\alpha}{2T'} \leq |f| \leq \frac{1+\alpha}{2T'} \\ 0 & |f| > \frac{1+\alpha}{2T'} \end{cases} \quad (1)$$

2. Simulation setup

Figure 1. indicates the block-diagram of the proposed-architecture of 12.5 Gbps data-

transmission. At first data-streams of $2^{32} - 1$ word-length are generated by pseudo-random-bit-sequence (PRBS) generator. Here 520-nm green laser-diode (LD) is applied as carrier in our system. The data-streams are transformed to I and Q symbols in QAM-sequence-generator in accordance with bits per symbol. The OFDM-modulator modulates the QAM-symbols into different orthogonal-subcarriers. The number of subcarriers is 512 and cyclic prefix is 50. Then OFDM modulating-symbols are passed through Raised Cosine filters to remove distortions and it shapes OFDM-pulses and minimizes the Inter-symbol-interference (ISI). Quadrature-modulator is applied to raise the OFDM signal-frequency. Then electrical-signal combined with carrier-signal and electrical-gain is modulated into optical-signal at Mach-Zehnder modulator (MZM) having dc bias-voltage of 6.5V. Then optical-amplifier having gain of 15 dB amplifies the optical-signal and it is sent through a converging-lens to minimize divergence of this-signal. Then the optical-signal is transmitted through a modelled underwater-channel filled with coastal-water having attenuation-coefficient 0.57 dB/m of green laser-source. Then the optical-signal is transmitted through a convex-lens and amplified using an optical-amplifier with gain of 15 dB. After passing through photo-detector (PD) it is converted into electrical-signal and the signal is sent through low-pass filter. The quadrature-demodulator demodulates electrical-signal and converts to low-frequency-signal and it extracts I-Q signal. After that, I-Q demodulated-signal is filtered by Raised Cosine filters. At OFDM-demodulator the signals are multiplexed to retrieve the data. Finally, the signal is decoded by QAM-sequence-decoder. Lastly, it is passed through BER-analyzer to get BER-value.

3. Results and Discussions

Figure 2.(a), (b) and (c) show the constellation-diagrams for 64-QAM, 128-QAM and 256-QAM signals transmission over 27.5

m, 26 m, and 24.5 m distances, respectively. From-figure, it is obvious that clear constellation-maps have been obtained by using this architecture.

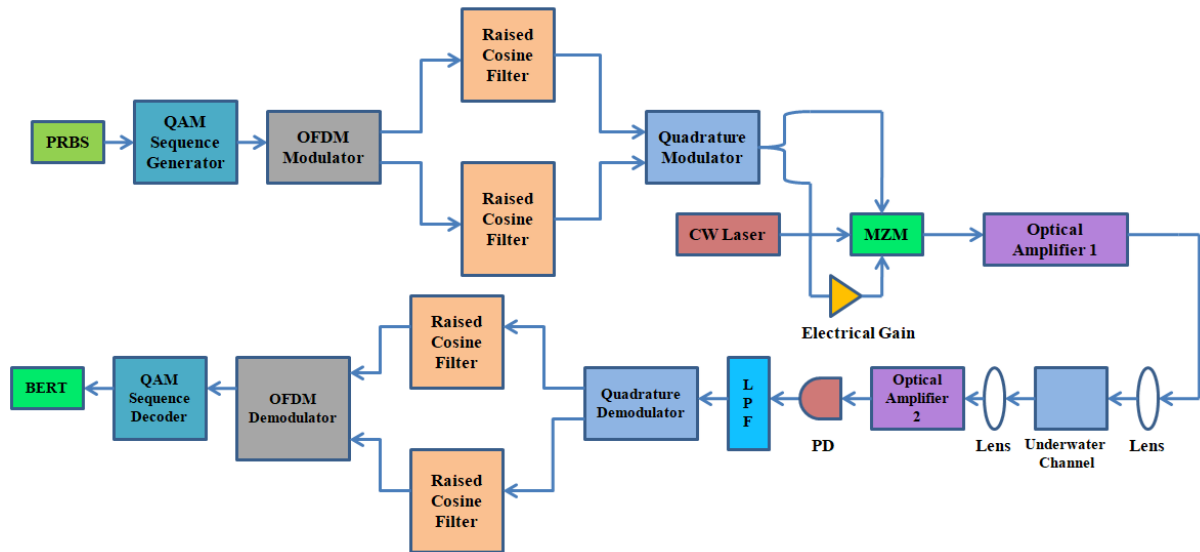


Figure 1. Simulation setup for QAM-OFDM data-transmission

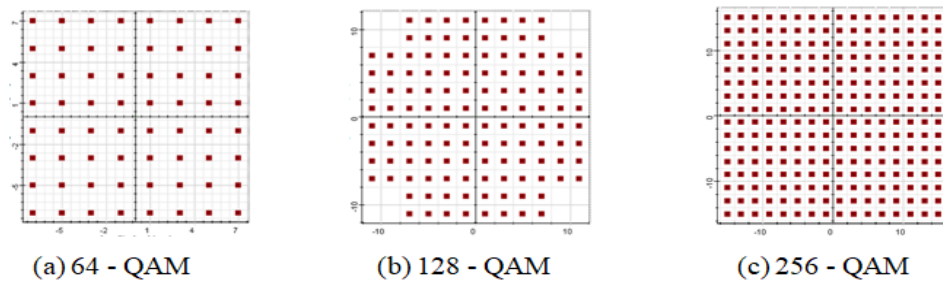


Figure 2. Constellation-diagrams for (a) 64-QAM, (b) 128-QAM and (c) 256-QAM

Figure 3. shows Log (BER) versus received-optical-power graph for 64-QAM, 128-QAM and 256-QAM-OFDM transmission over 27.5 m, 26 m, and 24.5 m distances, respectively. For communication-system expression of BER can be written employing the relation¹⁶,

$$BER \approx \exp\left[-\left(\frac{2P_r}{I \times E}\right)\right] \quad (2)$$

Where P_r is received-optical-power, I is the bit-rate and E is energy of laser-light. From this-graph we can say that, at the data-rate 12.5 Gbps, the minimum received-optical-power

required to achieve bit-rate-error $\sim 10^{-9}$ is greater for 256-QAM than 128 or 64 QAM, respectively.

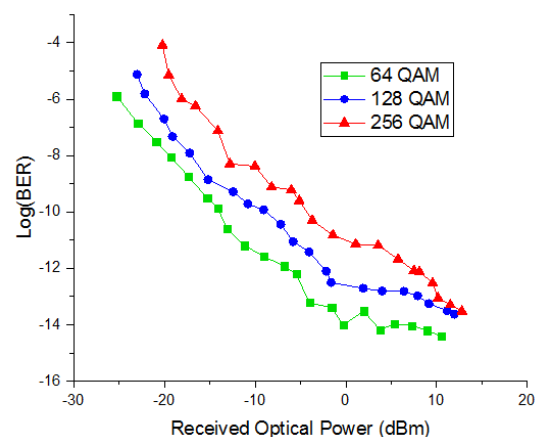


Figure 3. Log(BER) versus Received-Optical-Power (dBm) graph

Now, the variations of BER with Q-factor-value for 256, 128 and 64 QAM-OFDM transmission are manifested in **Figure 4.**, which obeys the equation¹⁷,

$$\text{BER} = \frac{1}{2} \text{erfc} \left(\frac{Q_f}{\sqrt{2}} \right) \quad (3)$$

Here $\text{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^{\infty} e^{-u^2} du$, is the complementary-error-function and Q_f is the Q-factor value. Q-factor measures the quality of signal relative to its noise. A higher Q-factor indicates clearer signal which means the signal-to-noise ratio (SNR) is high, that leads to higher data rates and smaller BER-values [17]. In our system, we have obtained very good Q factor-values (greater than 5) at BER-value $\sim 10^{-9}$ which is indicated in fig.4.

The larger Q-factor value shows smaller BER-value and from **Figure 4.** It is obvious that 64-QAM gives better Q-factor value at BER-value $\sim 10^{-9}$ compared to 128 or 256 QAM. So, in this-work we have employed QAM IM/DD OFDM data-transmission in coastal-water-environment using green-LD. Using various bits-per-symbol values (6, 7 and 8) and the Q-values and BER-values are compared at a particular bit-rate for 64, 128 and 256 QAM-OFDM-transmission. Best BER-performance and Q-factor value have obtained for 64-QAM-OFDM transmission which indicates that at 12.5 Gbps data-rate-transmission, 64-QAM shows better BER-performance, Q-factor-value than 128 or 256-QAM but it requires larger received-optical-power for 256 QAM than 64 or 128 QAM.

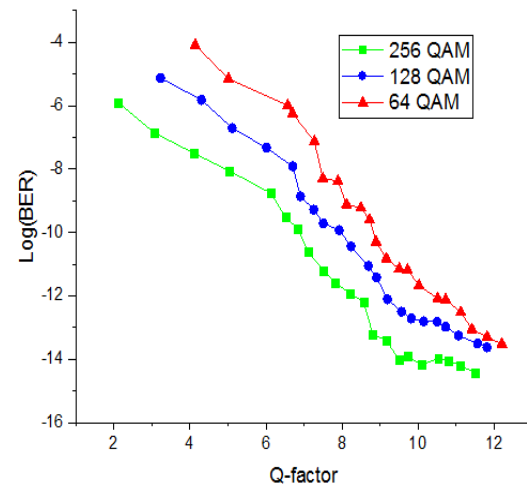


Figure 4. Log(BER) versus Q-factor graph

4. Conclusion

In this paper, an UOWC-system utilizing Quadrature-amplitude-modulation and orthogonal-frequency-division-multiplexing technique has been demonstrated using 520-nm green-LD. At 12.5 Gbps data-rate, the observed corresponding bit-rate-errors are 5.23×10^{-9} , 4.17×10^{-9} and 1.72×10^{-9} for 64, 128 and 256 QAM, respectively. In our architecture we have introduced pulse-shaping filters to achieve better Q-factor values, smaller BER values and larger propagation-distances. Employing these filters 12.5 Gbps higher data-rate has sent over 24.5 m, 26 m and 27.5 m distances for 256-QAM, 128-QAM and 64-QAM respectively which show better results for visible-light-communication system. Also very good Q-factor (>5) is obtained in our architecture. Clear constellation-diagrams and good Q-values are obtained in the proposed-architecture, and it indicates that our proposed system is suitable for 12.5 Gbps signal transmission over 27.5 m, 26 m, and 24.5 m distances, underwater-transmission.

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