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Investigation of implementation of QAM optical transmission

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This study investigates the possibility of implementation of quadrature amplitude modulation (QAM) format for optical communication system. In this study, we show different ways of QAM analysis through the constellation diagram and the 16-level eye signal using OptSim^{TM}. The implementation of QAM is also verified using OptiSys^{TM} with the 64-level eye signal. The obtained results analysis shows that, both configuration yield the same QAM results and ensure successful implementation of QAM.

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1. Introduction

The coherent quadrature amplitude modulation (QAM) is an alternative way of increasing the spectral efficiency of WDM (wavelength-division multiplexing) systems to increase the total capacity of optical transmission systems [1][2]. The QAM is a combination of amplitude modulation with the phase shift keying scheme. Technically, the QAM is a modulation scheme in which data is transmitted by modulating the amplitude of two separate carrier waves, which are out of phase by 90 degrees. Due to this phase difference, they are known as quadrature carries. The QAM can assign a 2^N state by using in-phase carriers (I) and quadrature-phase carriers (Q), which is called 2^N QAM, where N bits can be transmitted by 1 symbol data as reported in [3][4].

As there are multiple points of transfer in QAM modulation, it is possible to transfer more bits per position. For QAM modulation, a signal is obtained by summing up the amplitude and phase modulation of a carrier signal, is used for data transfer. Since the number of transfer points remains high, it is possible to transmit more bits per every position change. The possible states for a particular configuration can be denoted using a constellation diagram. In the constellation diagram, the points are arranged in a square grid with equal horizontal and vertical spacing. As data is binary in digital communication, the number of points in the grid is usually being a function of power of 2 as stated above. The quantity 2^N corresponds to the QAM level, for example, 16-QAM carries 4 bits per symbol and 256-QAM carries 8 bits per symbol. However, the most common used QAM levels are 16-QAM, 64-QAM, 128-QAM, and 256-QAM [1]-[8]. Although, it is expected to transfer more bits per symbol with higher order of constellations; however, an inherent technical problem may exist. In order to maintain the mean energy of a higher order constellation at the same level, it is very important that the constellation points remain close to each other. Such configuration will cause additional chances of noise and additional corruption. Thus, higher order of QAM may deliver more data, but it is less reliable with higher bit-error-rate compared to lower order of QAM.

The QAM is a proven technique for the transmission of digital information over a wide range of channels. It has been successfully employed for the transmission of digital information applications ranging from voice-band modems to microwave links [9]. The 64-QAM and 256-QAM are commonly used in cable modem and digital cable television applications. In this paper, we have investigated the possibility of implementation of QAM for the optical transmission. This paper aims to produce simulation analysis using both the optical system simulator software, namely, OptSim^{TM} and OptiSys^{TM} to verify the proposed solution. The remaining part of this paper is organised as follows. In Section 2, the setup of QAM is included. In Section 3, we will present the simulation results and analysis to ensure successful implementation of QAM. Finally, Section 4 provides the concluding remarks.

2. Methodology

We have shown the implementation of QAM modulation format using OptSim^{TM} software as depicted in Fig. 1. The data rate used is 800 Mbps and the symbol rate is 4 bits per symbol. The QAM modulator plays an important role in this implementation as it generates signals, which are digitally modulated in the M-QAM format. In other words, the QAM modulator divides the symbols into different voltage levels before it is sent to the amplitude modulator to couple with the laser source. Different symbols will have different voltage levels and thus, the laser intensity produced by the amplitude modulator will follow the input from the QAM. For instance, 0000 will correspond to certain magnitude in the voltage level and thus produce certain laser power intensity to be coupled into the optical fiber. This will yield same theory for symbol of 1111. Since we are using 4 bits per symbol, this will yield a 16-level QAM signal. The laser source that coupled into the fiber will be detected by the PIN photo-detector. This photo-detector will convert the detected light intensity into its corresponding voltage level. The voltage levels will be further analysed and demodulated by the QAM demodulator in order to produce the equivalent results at the output. Table 1 shows some basic components (symbol, name, and description) used in the simulation for the schematic setup of QAM.

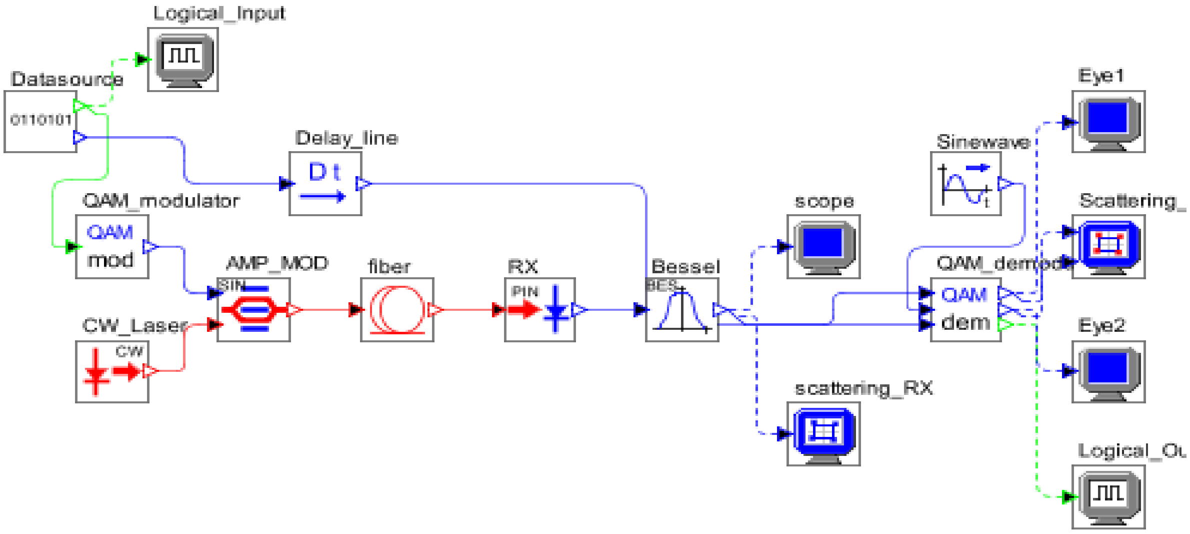


Fig. 1. Schematic diagram of QAM setup.

Due to the limitation of OptSim™ measurement components, such as bit-error-rate (BER) estimator and Q estimator, those are not possible to work in multi-level signaling, such as QAM modulation format. Thus, the analysis of BER versus transmission distance cannot be done due to such limitation. Therefore, we show another way of QAM analysis through the constellation diagram as well as the 16-level eye signal using OptSim™.

Table 1. The components used for QAM setup.

Component Symbol	Component Name	Description
0110101	Data Source	Simulates a pseudo-random bit sequence or a deterministic logical signal generator of arbitrary level (number of bits per symbol).
QAM mod	QAM Modulator	Generates digitally modulated signal in the QAM format (Gray code). The number of levels of the modulation is determined by the dimension of the input logical signal. Only logical signal having an even number of bits is permitted. In particular: - 4-bit logical signals produce 16-QAM - 6-bit logical signals produce 64-QAM - 8-bit logical signals produce 256-QAM
CW	Continuous-Wave Lorentzian Laser (CW laser)	This model implements a simplified continuous wave laser. Laser phase noise is taken into account by generating a Lorentzian emission line shape whose FWHM is specified by the parameters.
SIN	Linear Amplitude Modulator	This model implements an amplitude modulator with linear electro-optic characteristics (in terms of output power vs. applied voltage) and signal chirping. The optical signal is multiplied by an amplitude factor depending on the input voltage and on the excess loss introduced by the modulator.
	Optical Fiber Link	This component models the propagation of the optical signal along an optical fiber span.
	PIN photodiode	This component simulates a PIN photodiode.
	Electrical Bessel Filter	This component simulates an electrical filter. This component implements low-pass, high-pass, and band-pass Bessel filters. This is a standard family of filters that are also sometimes called “Maximally Flat Delay” filters.
QAM dem	QAM Demodulator	Takes a QAM modulated analytic signal, gets the two quadrature baseband signals and the detected string of bits in an output logical signal. No matched filter is used.
	Electrical Scope	Simulates an oscilloscope for electrical signals. It collects data for diagrams, such as amplitude, eye diagram, histogram at the optimum sampling instant, and power spectrum of the electrical signal.
	Scattering Diagram	It generates the scattering diagram of amplitude and/or phase modulated digital signal.
Δt	Delay	This component simulates a delay line for logical signal. The output signal is a replica of the input one delayed of T_delay picoseconds.

3. Results and analysis

A. Eye diagram analysis of QAM

Fig. 2 below shows the eye diagram to present the results of QAM modulation format using OptSim^{TM} simulation software. As stated in the above section, the symbol rate used is 4 bits per symbol. Thus, it yields a 16-level eye signal as shown in Fig. 2. This eye diagram analysis does not provide other useful information, such as the eye opening to judge the performance of this QAM modulation format. The only information appears at Fig. 2 is the number of levels of the eye signal at the electrical probe. In order to further analysis the QAM performance, more advanced simulating software might be required for the simulation process.

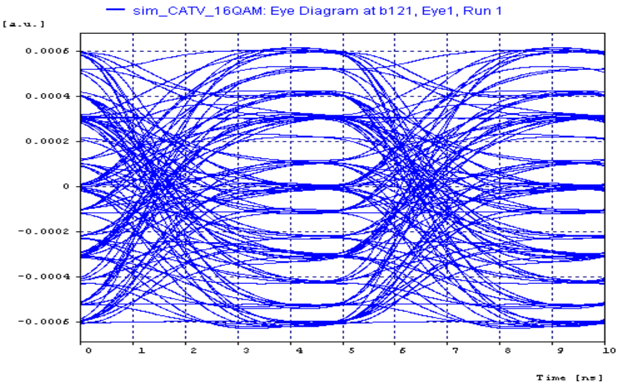
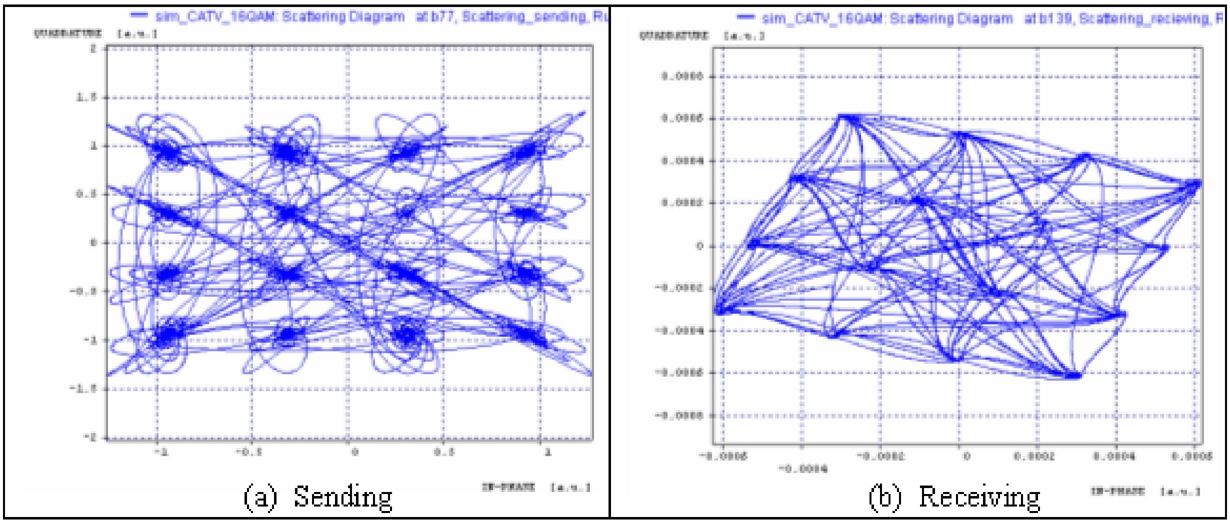


Fig. 2. Eye diagram of QAM.



(a) Sending

(b) Receiving

Fig. 3. Scattering diagram of QAM (a) sending signal; (b) receiving signal.

B. Scattering diagram of QAM

Fig. 3 shows the scattering diagram of QAM. It can be noticed that there are 16 points of signal at each sending and receiving side. This also corresponds to 4 bits per symbol, which equivalent to 16-level signaling.

It is noted that, at the sending scattering diagram in Fig. 3(a), the 16 points are located evenly on the diagram, where the horizontal signal and the vertical signal are arranged neatly to each other. On the other hand, at the receiving scattering diagram in Fig. 3(b), the location of the points differs from the sending side; however, the 16-level signals are still clearly seen and distinguished. Thus, we can conclude that the receiving scattering diagram still capable to detect the signal accordingly; thus show successful implementation of the QAM modulation format using OptSim^{TM}.

C. Implementation of QAM using OptiSys^{TM}

We have also verified the results of QAM analysis using other simulation software, known as OptiSys^{TM}. This OptiSys^{TM} software is also well known in optical simulation and is commercially available. The obtained simulation results are presented as follows.

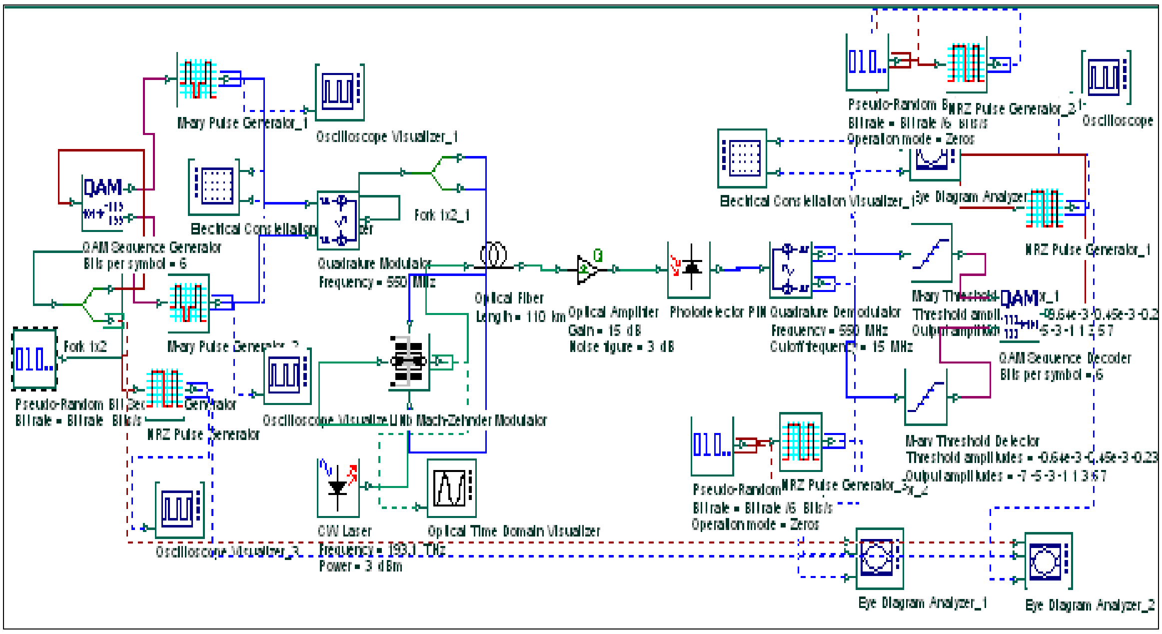


Fig. 4. Schematic diagram of QAM setup using OptiSys^{TM}.

Fig. 4 above shows the schematic setup of QAM using OptiSys^{TM}. Although the implementation of QAM using OptiSys^{TM} seems more complicated than OptSim^{TM}; however, both configuration yield the same QAM results. In OptiSys^{TM}, we have implemented a symbol rate of 6 bits per symbol; therefore, this will yield 64-level of signals either in scattering diagram or in eye diagram. Figs. 5 and 6 show the eye diagram and the scattering diagram, respectively. Fig. 5 shows the eye diagram of the 64-QAM modulation format. Each of the eyes has 8-level signals while the total eyes have another 8-level signal. Thus, this has made up to 8 × 8 signal with a total of 64-level signals.

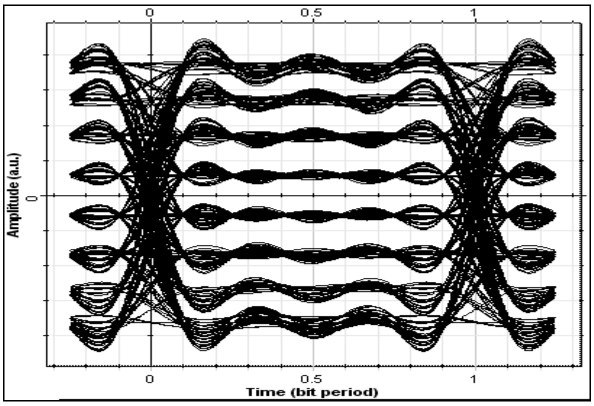
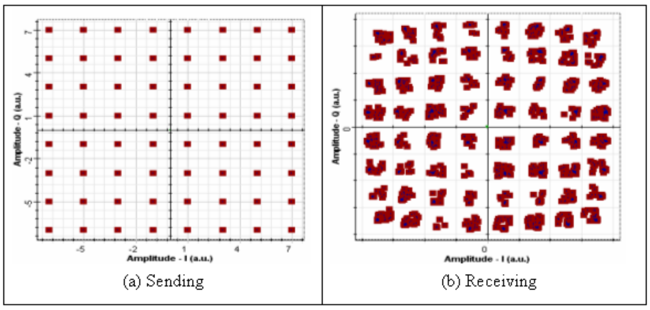


Fig. 5. Eye diagram of QAM using OptiSys^{TM}.

Fig. 6 shows the scattering diagram of 64-QAM modulation format. It is noticed that the 64-level signals are located accordingly at the sending side in Fig. 6(a). Each column consists of 16-level of signals and thus, 4 columns represent up to 64-level of signals. At the receiving side in Fig. 6(b), it is noticeable that the signal of the scattering diagram experiences some distortions. However, it is easy to see that, the signal levels are still clearly depicted at the appropriate location of the scattering diagram; thus also demonstrate successful implementation of the QAM modulation format using OptiSys^{TM}.



(a) Sending

(b) Receiving

Fig. 6. Scattering diagram of QAM using OptiSys^{TM} (a) sending signal; (b) receiving signal.

3. Conclusions

This study has verified successful implementation of the QAM modulation format by using both OptSim^{TM} and OptiSys^{TM}. We show different ways of QAM analysis through the constellation diagram, the 16-level eye signal using OptSim^{TM} (due to the limitation of OptSim^{TM} measurement components, such as BER estimator and Q estimator as explained before), and the 64-level eye signal using OptiSys^{TM}. The obtained results analysis confirms successful implementation of QAM for the optical transmission. The techniques presented of QAM modulation format can be improved further in the future research work.

However, the simulation software company might need to upgrade the performance of the existing measurement components to more efficiently detect and analysis the transmitted signals. Thus, it is beyond our capability to perform further analysis the obtained eye signals. This study will help the researcher to look into the performance of QAM that might be implemented for future optical communication networks.

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