ANALYSIS OF POSSIBLE UTILIZATION OF THE 16-QAM MODULATIONS FOR OPTICAL TRANSMISSION SYSTEMS

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1. Introduction

In recent years, optical modulation techniques with a high spectral efficiency are investigating with a great interest. An improvement of the spectral efficiency is very important for increasing a transmission capacity of optical transmission systems utilizing the wavelength-division multiplexing technology. For these systems, multilevel optical modulation formats are suitable candidates. In this case, an interesting modulation technique is the QAM modulation. Recently, a qaud–parallel MZM modulator has been proposed to generate the 16-QAM optical signal. In this modulator, four binary data streams are mapped over a carrier light where two QPSK signals are superposed by a optical coupler.

Each optical fiber represents a transmission system, which is frequency dependent. A pulse propagation inside this transmission system can be described by the nonlinear Schrödinger equation (NLSE), which is derivate from Maxwell equations. From the NLSE equation we can expresses effects in optical fibers that can be classified as:

a) linear effects, which are wavelength depended,
b) nonlinear effects, which are intensity (power) depended.

More detailed analysis of linear effects are published in [3], [4], [5].

1. Principles of the 16-QAM Modulation

The Quadrature Amplitude Modulation QAM is a modulation technique that combines two modulation schemes (amplitude shift keying and phase shift keying). The QAM is a multilevel modulation thatis able to transmit *n* bits by *m* symbols. A main advantage of this modulation is saving the transmission bandwidth and/or increasing transmission bit rates. In this paper, wecan focus on the 16-QAM modulation because higher level QAM modulations have high performance requirements.

Figure 1 shows principles of the 16-QAM modulator using the QPMZM. This modulator consists of two QPSK modulators (QPSK1, QPSK2). Each QPSK modulator consists of the dual parallel Mach–Zehnder modulator that is driven by two binary data sequences. The QPSK2 is attenuated by 3dB to achieve a rectangular 16-QAM constellation. The QPSK2 signal must be attenuated before coupling. The QPSK1 sets a quadrant where the QPSK2 symbols (with smaller amplitude) are mapped [8].

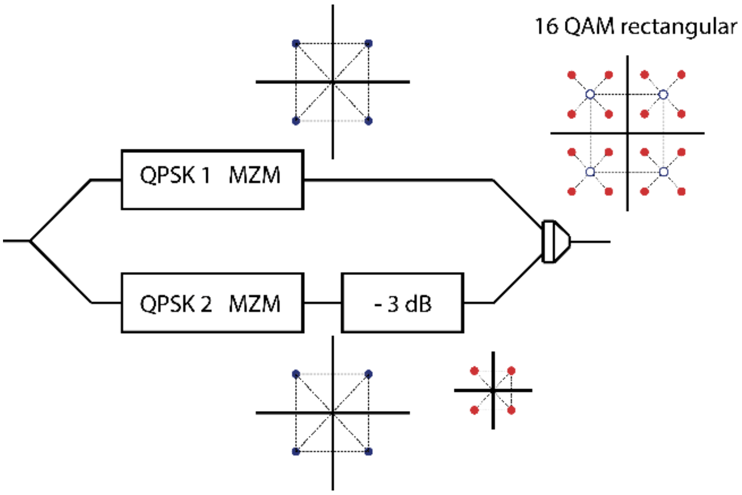

Fig.1: *Principles of the 16-QAM modulation.*

2. Principles of the 16-QAM Demodulation

The 16-QAM demodulation is divided in two steps. First step is a determination of the quadrant wherein bits are detected. First two bits from the 4-bit codewords are assigned by a phase of the received signal,second two bits are assigned by their position on imaginary and real axis. On Fig. 2, we can see decoding rules and decision levels for the 16-QAM demodulation process [8].

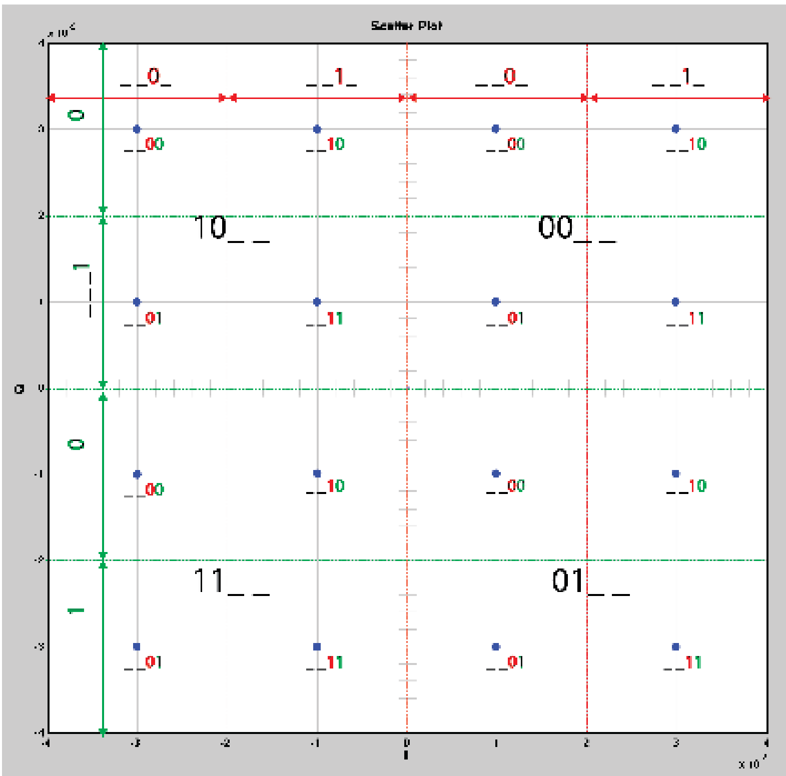

Fig.2:*Decision levels for the 16-QAM demodulation.*

3. The simulation environment for the 16 QAM modulation

Simulation experiments are realized in the program Matlab R2014a Simulink. Figure 3 showsa complete transmission path with the 16-QAM modulation technique. The block CW includes a block of the creating constructive and high frequency wave that is used as a carrier wave. It is assumed that the fiber length is 80 [km], the total attenuation is a_{total} = 16,8 [dB] (i.e. $\alpha_{specific}$ = 0,21 [dB/km]), values of the PMD 10 [ps/(nm.√km)] and the CD 10 [ps/km]. More detailed description of the created block representing the environment of optical fibers are published in [1], [2], [3],[6],[7].

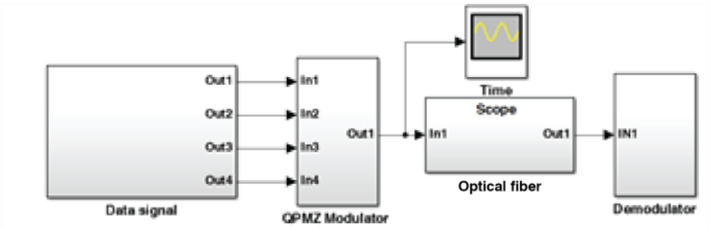

Fig.3:*The optical transmission path utilizing the 16-QAM modulation.*

In Fig. 4, we can seethe block Data signal for creating a pilot binary data stream that controls the QPMZM modulators. Four Bernoulli generators are used because of the simulation acceleration. Four data streams are coupled in a buffer and then are sending to the MZM modulator. Figure 5 shows a complete scheme of the quad parallel Mach-Zender modulator.

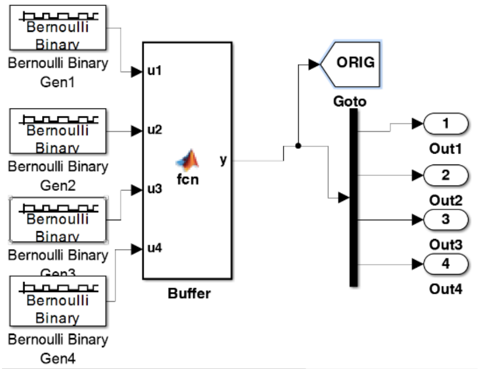

Fig.4:*The Data signal block scheme* .

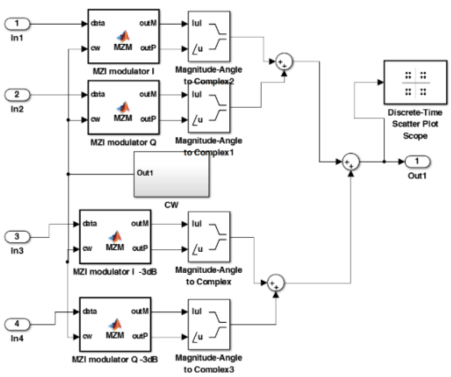

Fig.5:*The block scheme of the quad parallel MZ modulator.*

4. Simulation results

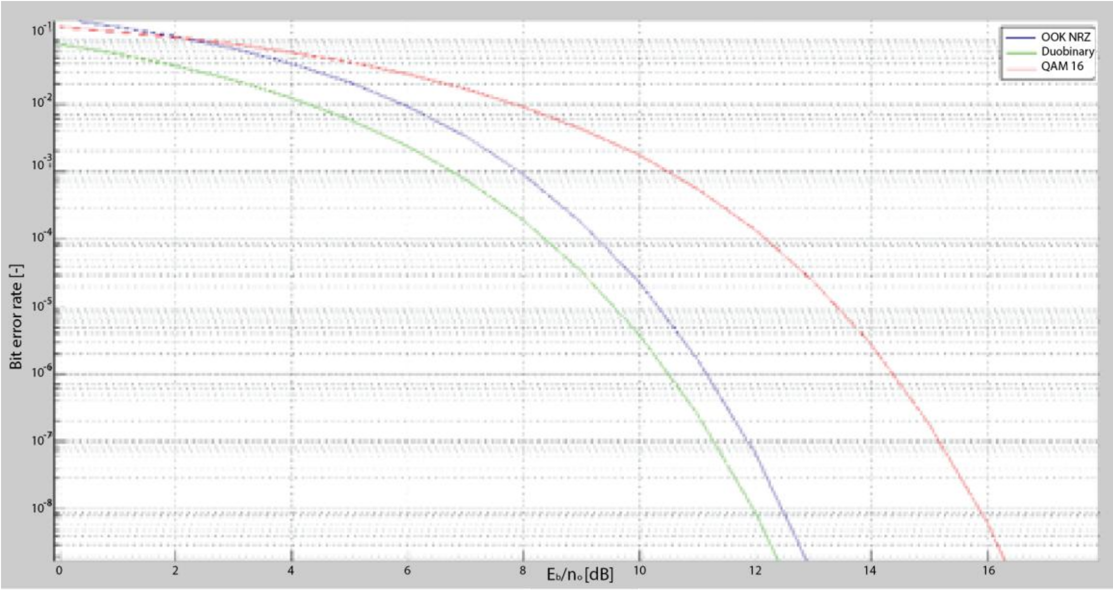

Fig.6:*The BER vs. E_b/N_0 forOOK NRZ, Duobinary and16-QAM modulations.*

On Fig.6, waterfall curves for the OOK NRZ (blue), Duobinary (green) and 16-QAM (red)modulations are shown. The 16-QAM has the worst BER from comparing these three modulations. However, because it represents a multilevel modulation format, it can lead to saving 4x more bandwidth than the OOK NRZ modulation. More detailed comparison of the Duobinary and OOK modulations is published in [9].

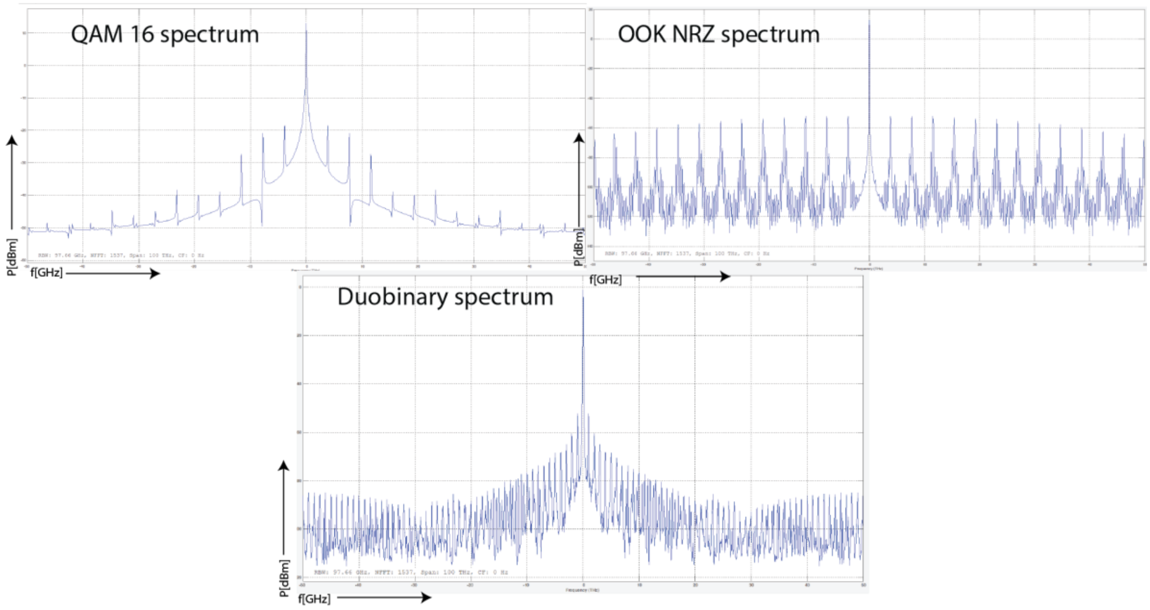

Fig.7:*The spectrum comparison forOOK NRZ, Duobinary and16-QAM modulations.*

Figure 7 shows the spectrum utilized by each modulation. The OOK NRZ modulation has the widest spectrum W_b= 97,66 GHz. The Duobinary has a twice narrower spectrum than the OOK NRZ W_b= 48,83 GHz. The narrowest spectrum with W_b= 24,41 GHz is representing the 16-QAM modulation.

5. Conclusion

We demonstrated the analysis of the 16-QAM modulation using a created Simulink optical transmission path. The general block scheme of the optical transmission system consists of the Mach-Zendermodulator,the Mach-Zender demodulator, the environment of optical transmission medium and scopes.The model introduces a functional scheme for the 16-QAM optical transmission system. From simulation results we can see that the 16-QAM modulation is not applicable in long distance optical systems because it has a bad resistance to distorting effects. Because this modulation format has the narrowest spectrum, it will be practically applicable in optical systems utilizing the wavelength division multiplexing technology.

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