Modeling of the PSK Utilization at the Signal Transmission in the Optical Transmission Medium

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***Abstract*:** This paper deals with a modeling of the phase shift keying (PSK) and the possibility of implementing PSK modulations using Mach-Zehnder modulators in the Matlab simulation environment. Next, a simulation of selected multi-level PSK modulations utilizing at the signal transmission in the optical transmission medium is executed. Finally, a comparison of modulated optical signals before and after passing a model of the optical transmission path is introduced, using constellation diagrams, signal characteristics, eye diagrams and waterfall curves of individual signals.

***Keywords*:** optical transmission medium, Phase Shift Keying, QPSK, 8PSK.

1. Introduction

The optical transmission medium represents an environment, which is suitable for the long distance information transmission using optical power signals. The main advantages for utilization of optical fibers are low costs to implementation, long operating life and resistance to e.g. electromagnetic interferences. Since a need for higher transmission speeds is growing, it is necessary looking for advanced modulation techniques, which are usable in this transmission environment [1-3].

This paper deals with a modeling of the phase shift keying (PSK) modulation technique and its multi-level variations, which appears to be very resistant to nonlinear effects present in the optical transmission medium [4, 5]. Next, simulations of the signal transmission using selected multi-level PSK (QPSK and 8PSK) variations in Matlab Simulink 2014 environment are introduced. Finally, constellation diagrams, signal characteristics, eye diagrams and waterfall curves for QPSK and 8PSK modulated optical signals before and after passing a model of the optical transmission path are presented.

2. Principles of the Phase Shift Keying (PSK)

The phase-shift keying technique belongs to group of modulations with carrier wave modulation [6, 7]. The phase shift keying appears to be very resistant against nonlinear effects, because the envelope of signal is constant. For information transmission, a phase modification of carrier signal is used. The carrier signal phase is shifted depending on transmitted information. The phase shift must be also known to demodulator. The simplest PSK modulation shifts carrier signal phase by π for logical 1 and for logical 0 does not shift the carrier signal phase. In practice, we can meet more often with its equivalents [6-11]:

- Multi-level PSK – MPSK (where *M* is number of levels),
- Differential Phase Shift Keying – DPSK,
- Differential Binary Phase Shift Keying - DBPSK,
- Differential Quadrature Phase Shift Keying – DQPSK.

The fundamental difference between PSK (resp. MPSK) and DPSK (resp. DMPSK) is based in a constellation diagram layout. Differential phase shift keying does not have determined symbols in constellation diagram as it is in common PSK, but it has a table of phase shifts (in degrees or radians) where is each phase shift represented with a symbol. Very advantageous PSK formats are multi-level PSK, because one phase shift is represented with 2 or more bits (it is depended from number of modulation levels). To the most known PSK variations belong four-level QPSK and 8PSK techniques. These modulation formats are possible to design with in parallel connected Mach-Zehnder modulators (MZM). The outgoing signal from each Mach-Zehnder modulator is a BPSK signal, which is phase shifted when necessary. The number of used MZM is depended on the amount of modulation levels. For construction of QPSK, it is necessary to use 2 MZM with a phase shift π/2 between them. A schematic connection of QPSK modulator is shown on Fig.1. [6-8].

A constellation of individual symbols in outgoing signal is shown on Fig. 2, where the letters X, Y, Z and W represent symbols.

For the 8PSK design, it is possible to use two QPSK modulators (i.e. four MZM modulators), with a phase shift π/4 between them. The 8PSK scheme is shown on Fig.3.

The constellation of symbols by using quad-parallel connection of MZM for 8PSK is shown on Fig.4. The final 8PSK symbol is represented by combination of symbols from two QPSK modulators [16, 17].

Symbols with index 1 (squares) are symbols of QPSK 1, symbols with index 2 (crosses) are symbols of QPSK 2 and final 8PSK symbols (asterisks) are represented by two letters with relevant subscripts.

3. Simulations of the PSK optical signals

The simulations are performed in Matlab Simulink 2014 and consist from implementation of modulation formats to model of optical transmission path [12-15]. In simulation, it is assumed with a fiber with length of l = 80 [km] and wavelength λ = 1550 nm, that means the total attenuation is a_{total} = 16,8 [dB] (i.e. $\alpha_{specific}$ = 0,21 [dB/km]), other specific values are PMD = 10 [ps/(nm.√km)] and CD = 10 [ps/km]. Modulation techniques QPSK and 8PSK are chosen for simulating. At the 8-level PSK, three bits are transmitted through transmission medium at once, since 2^3 = 8. At the

QPSK two bits are transmitted at once, since $2^2 = 4$. Individual symbols are possible to express as complex numbers, thus, as a combination of imaginary and real parts or with combination of magnitude and phase towards to zero. Symbols are located with phase shift $\pi/4$ between them at 8PSK and with $\pi/2$ shift at QPSK. The benefit of 8PSK modulation is higher transmission rate, since one phase shift is represented by three bits entering the modulator. Disadvantage of the multi-level PSK is a smaller phase distance between symbols, which can lead to higher error rate by comparison with modulation techniques with less modulation levels. The complete model of the optical transmission path accommodated for the 8PSK utilization at the signal transmission is displayed on Fig.5.

A model consists of next fundamental parts:

- Source of data signal - red
- Source of optical signal (CW) - green
- Modulator 8PSK (MZM 8PSK) - blue
- Model of optical transmission path (SMF) - orange
- Demodulator 8PSK - violet
- Block for BER calculating - yellow

A source of data signal consists of the Bernoulli Binary Generator block, which represents a information flow, which is after next processing modulated. Further, it consists of Buffer and the Encoder block. A complete data signal block that is entering the modulator is shown on Fig.6.

A task of the Encoder block is preparing from continuous information bit flow single bits, which are divided with demultiplexor. These bits are processed with mathematical operations so they can control branches I1, Q1, I2 and Q2 in the QPSK modulators. An internal connection of the Encoder block is shown on Fig.7.

The CW block represents a source of carrier signal, which enters the modulator. It is a basic block for simulation of optical modulation techniques and its output simulates optical signals needed for information transmission. The CW block consists of several sine generators, which are set to generate many signals at the same time, since a real source of optical emissions is not monochromatic (i.e. it has not only one carrier wave (λ), but there are more waves ($\Delta\lambda$)). The CW block is shown on Fig. 8.

An output of the Data signal block is connected a modulator block. The modulator block consists of two QPSK modulators and their output signals are summed. On Fig.9, internal connections of the 8PSK modulator block are shown. Each of QPSK modulator blocks consists of two MZM modulators that are divided according to that if they control I or Q branch of the outgoing signal. The mutual connection of the MZM modulators in the QPSK 1 modulator block is on Fig.10.

After the optical transmission path, a modeling is going on by a demodulator block, in which the signal after passing through the optical path model is entering [12-15]. Its task is to isolate a phase from the incoming signal and to decide what kind of bits is received. These bits are coupled with a multiplexor block to a single signal (i.e. to symbols), which is compared in the BER calculator block with original transmitted signal. An internal connection of the 8PSK demodulator block is on Fig.11.

On next figure (Fig.12), constellation diagrams for the 8PSK are shown before passing through a model of the optical transmission path (IN) and after passing through the model (OUT). As can be seen on Fig.12, the signal after passing through the optical transmission path is attenuated and dispersed (following attenuation, dispersion and nonlinear effects on the transmission path) and phase shifted (following dispersion and nonlinear effects on the transmission path). The received phase shift is approaching the decision levels of the 8PSK demodulator (0 to π, $-\pi/2$ to $\pi/2$, $\pi/4$ to $3.\pi/4$ and $-3.\pi/4$ to $-\pi/4$), overshoot of this levels causes increase of error rate.

For comparison of multi-level PSK variations, constellation diagrams for the QPSK are included. Constellation diagrams for the QPSK before passing through a model of the optical transmission path (IN) and after passing through the model (OUT) are shown on Fig.13. In the same manner, an influence of negative effects in the optical transmission medium is observable. As can be seen on Fig.13, the QPSK modulation can be used for longer distances than the 8PSK, since the phase distance between individual symbols is greater (decision levels of the QPSK demodulator are from 0 to π for the first bit and from $-\pi/2$ to $\pi/2$ for the second bit).

On Fig.14, 8PSK optical signals are shown. The first part (DATA) shows a data flow converted from a binary format to integer one. The second and third parts represent phase shifts of the carrier signal in radians as follows: MODULATOR represents a phase shift of the outgoing signal from a modulator and DEMODULATOR represents a phase shift of the signal after passing through a model of the optical transmission path. The last part (DATA) represents a demodulated data signal (also in a integer format).

In the same manner, QPSK optical signals are shown on Fig.15.

On Fig.16, waterfall curves for the QPSK and 8PSK are shown based on the presented simulation parameters. The 8PSK curve is shown with a red dashed line and the QPSK curve with a blue continuous line. As can be seen, the QPSK needs less E_b/N_0 as the 8PSK for a successful transmission of payload with lower BER (e.g. at the $BER = 10^{-6}$, the difference between QPSK and 8PSK is approximately 3,5 dB of E_b/N_0).

On Fig.17, an eye diagram for the 8PSK after transmission through a model of the optical transmission path (on the demodulator input) is shown.

In the same manner, an eye diagram for the QPSK is shown on Fig.18.

4. Conclusions

Modeling of QPSK and 8PSK modulation techniques and their possible utilization at the signal transmission in the optical transmission medium using MATLAB Simulink 2014 environment is presented. These modulation techniques are performed using parallel connections of MZM modulators. Next, a complete presentation of simulation blocks for QPSK and 8PSK modulators and demodulators with detailed descriptions are introduced. Finally, QPSK and 8PSK modulation formats are compared with each other using constellation diagrams, signal waveforms, eye diagrams and waterfall curves from a viewpoint of negative effects present at the signal transmission in the optical transmission environment. The QPSK is more resistant to negative influences degrading the signal transmission than the 8PSK. On the other hand, the 8PSK is transmitted 3 bits with one phase shift, which means higher possible transmission rates. Thanks to the modeling and simulations, it is possible to find appropriate modulation techniques and consequently to execute advanced analysis of their utilization for deployment in the real optical transmission systems.

5. Acknowledgement

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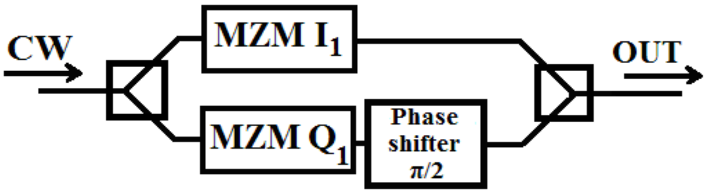

Fig.1: The QPSK modulator scheme with 2 MZM modulators

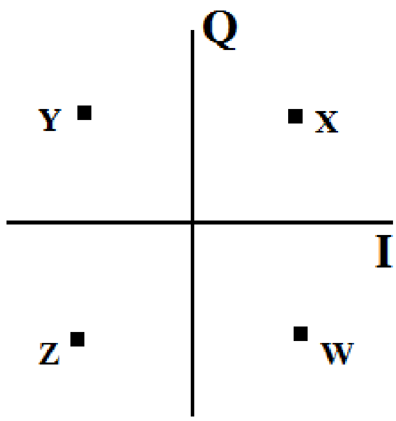

Fig.2: The QPSK constellation diagram

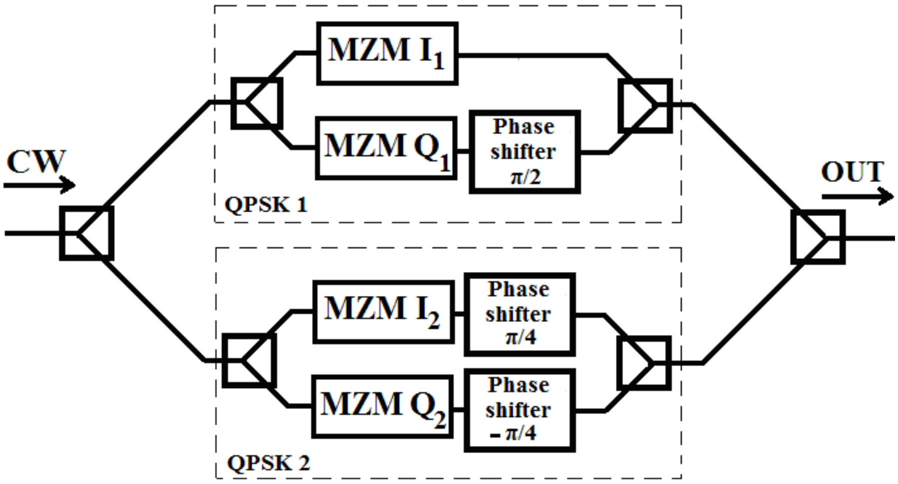

Fig.3: The 8PSK modulator scheme with 4 MZM modulators

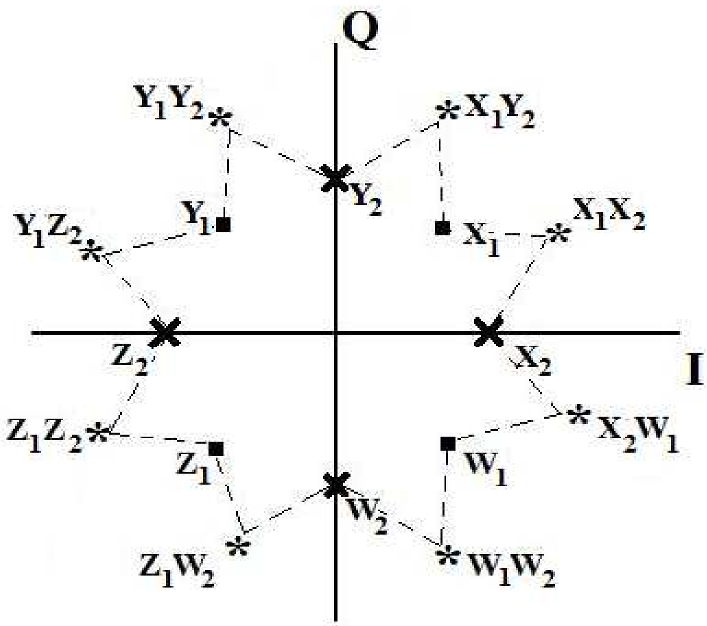

Fig.4: The 8PSK constellation diagram

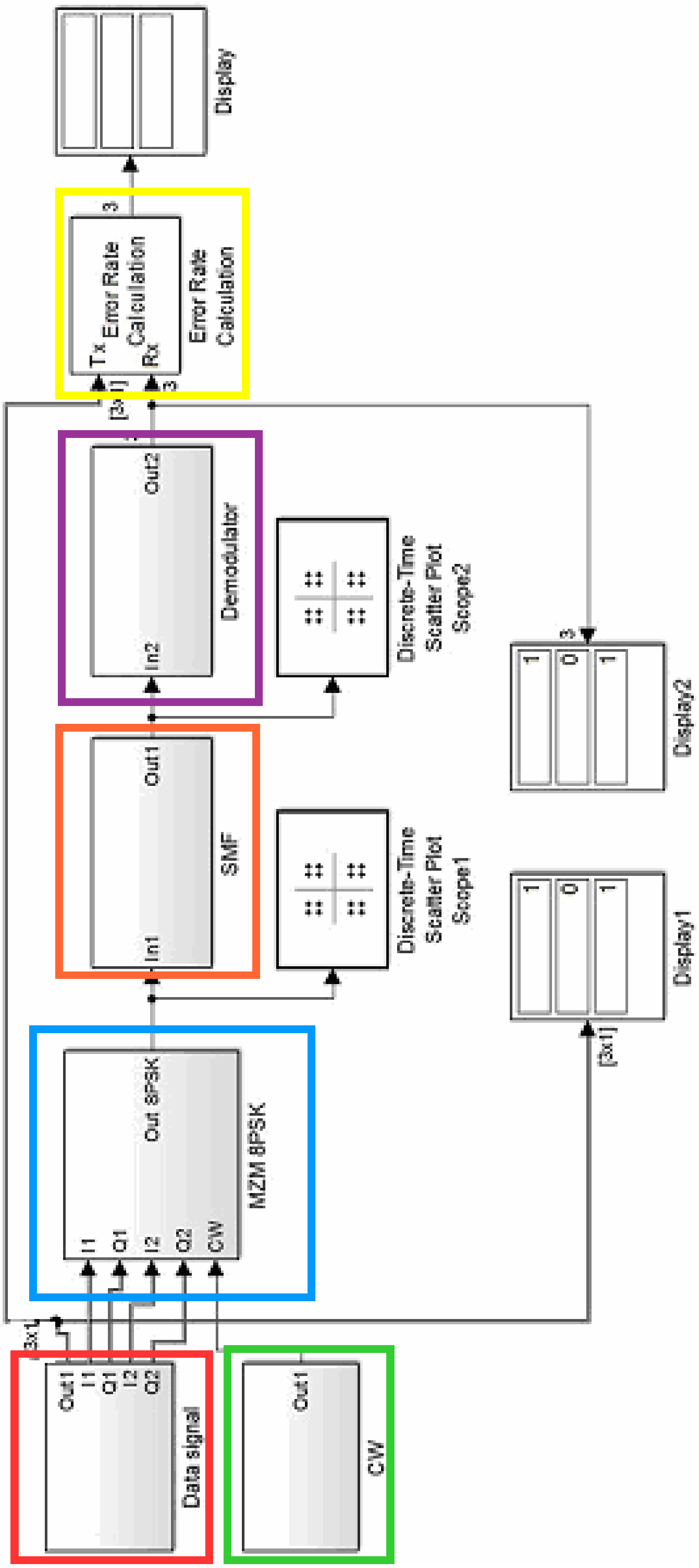

Fig.5: The optical transmission path for the 8PSK utilization

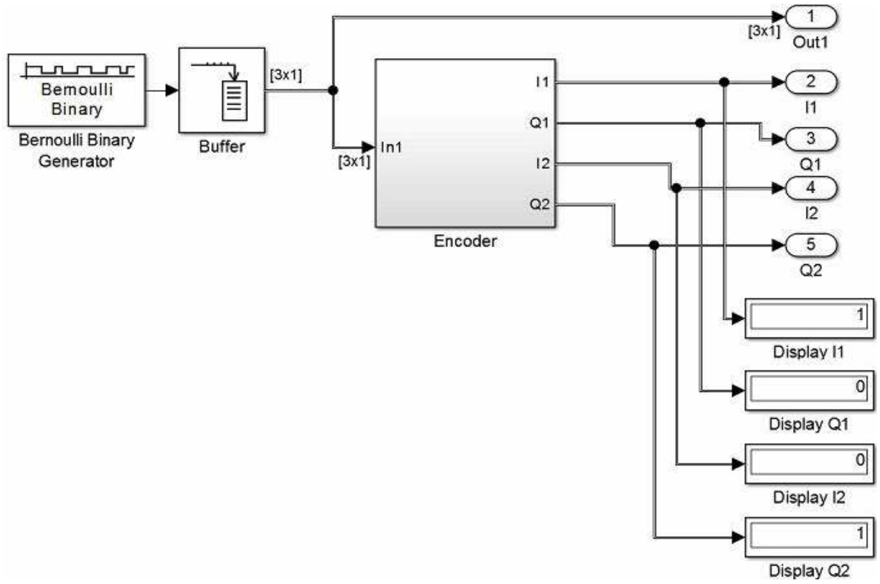

Fig.6: The Data signal block scheme

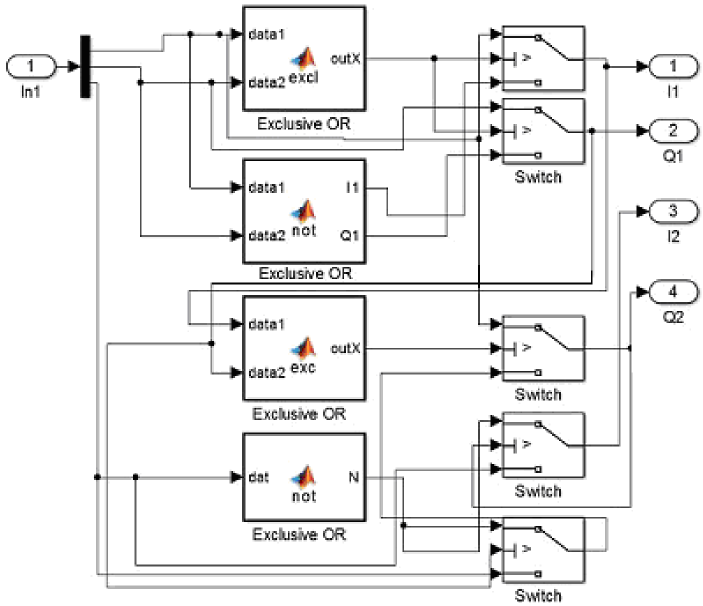

Fig.7: The Encoder block scheme

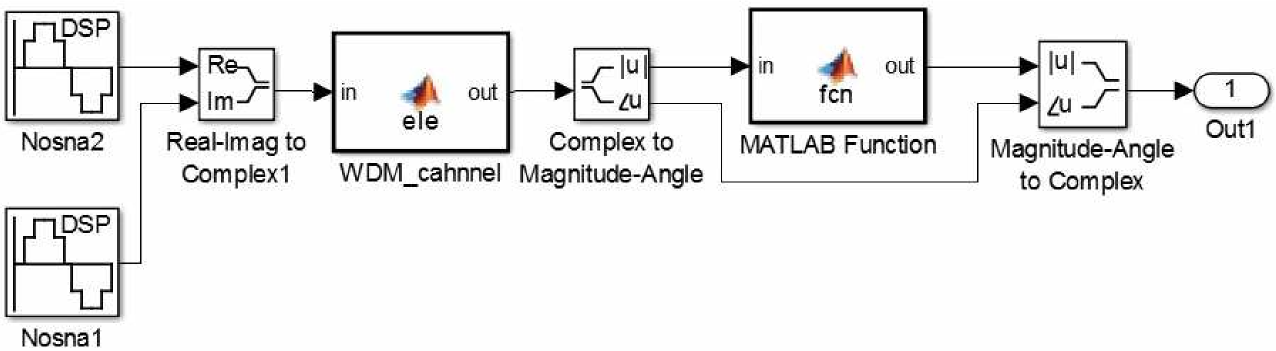

Fig.8: The CW block scheme

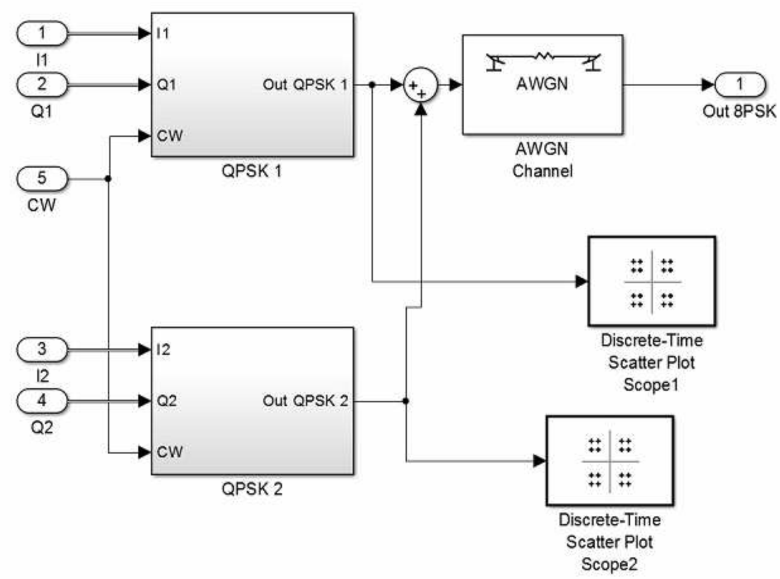

Fig.9: The 8PSK modulator block scheme

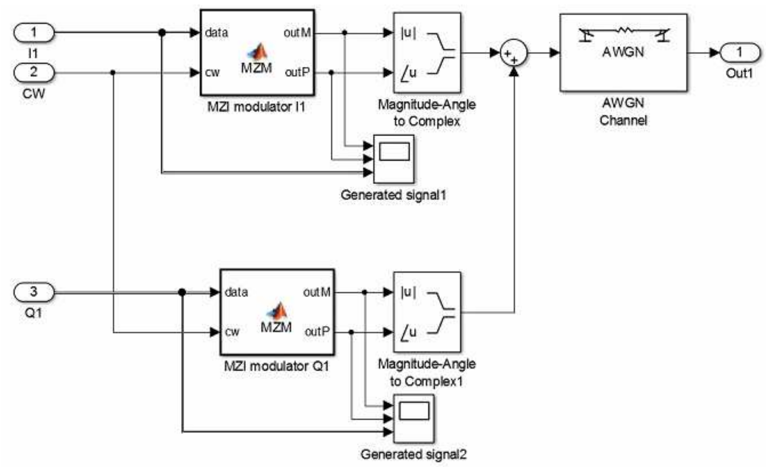

Fig.10: The QPSK 1 modulator block scheme

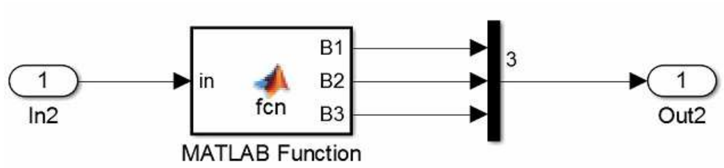

Fig.11: The 8PSK demodulator block scheme

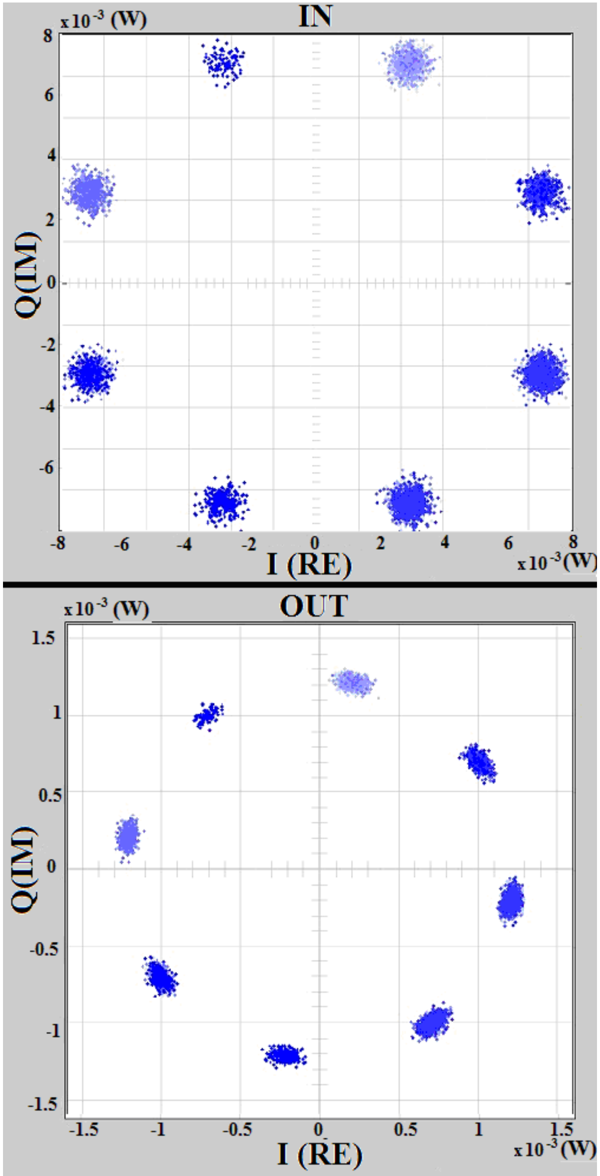

Fig.12: 8PSK constellation diagrams

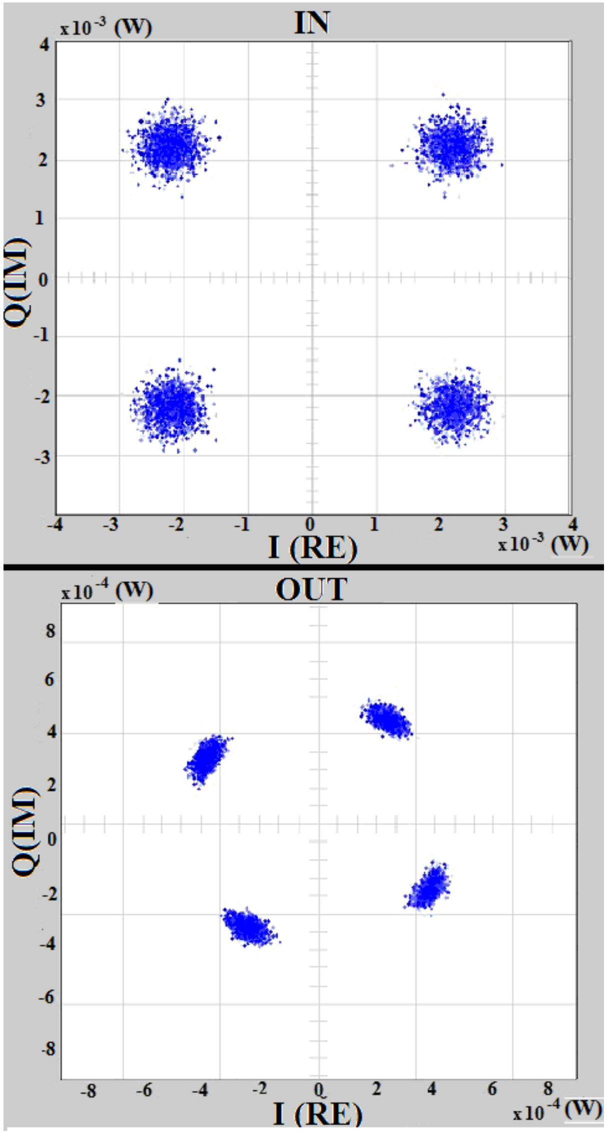

Fig.13: QPSK constellation diagrams

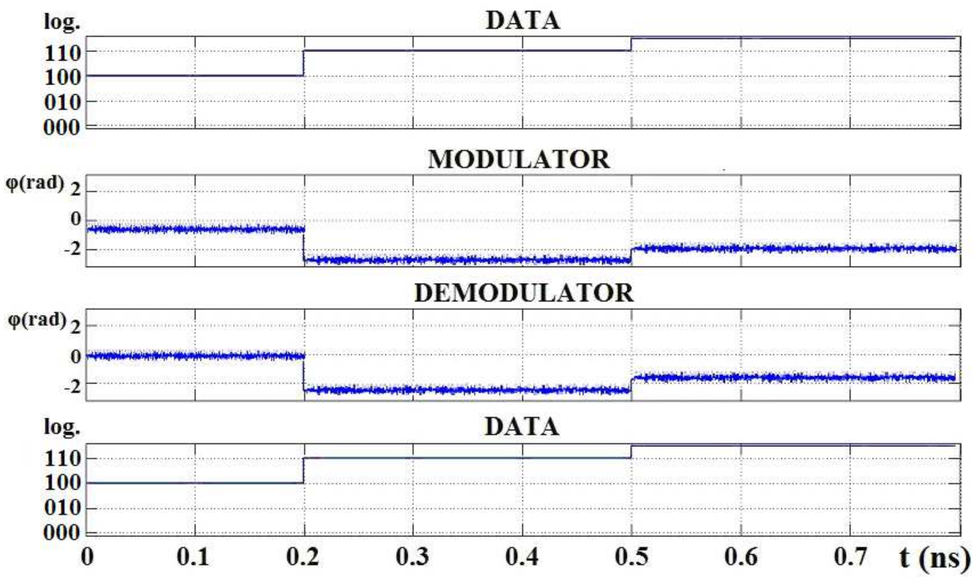

Fig.14: 8PSK optical signals

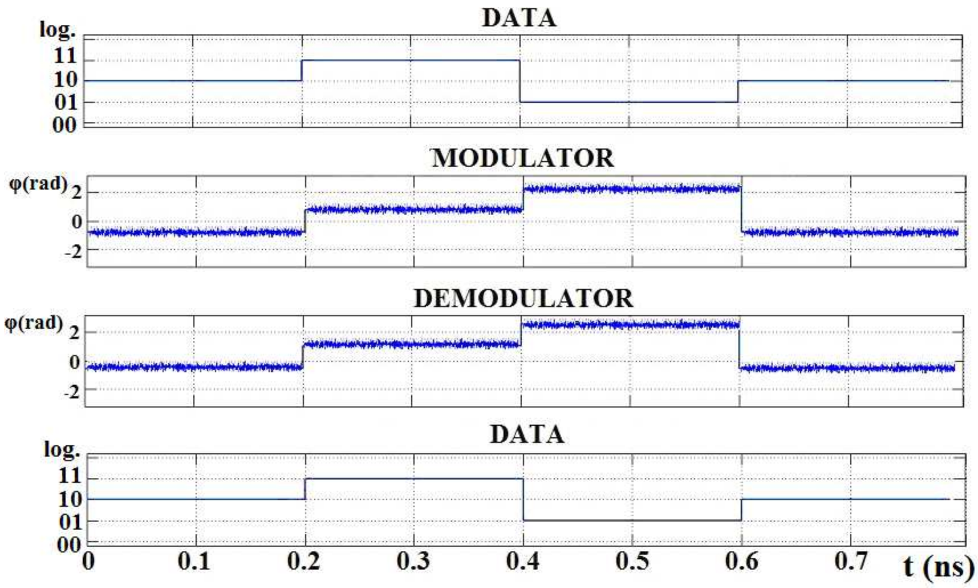

Fig.15: QPSK optical signals

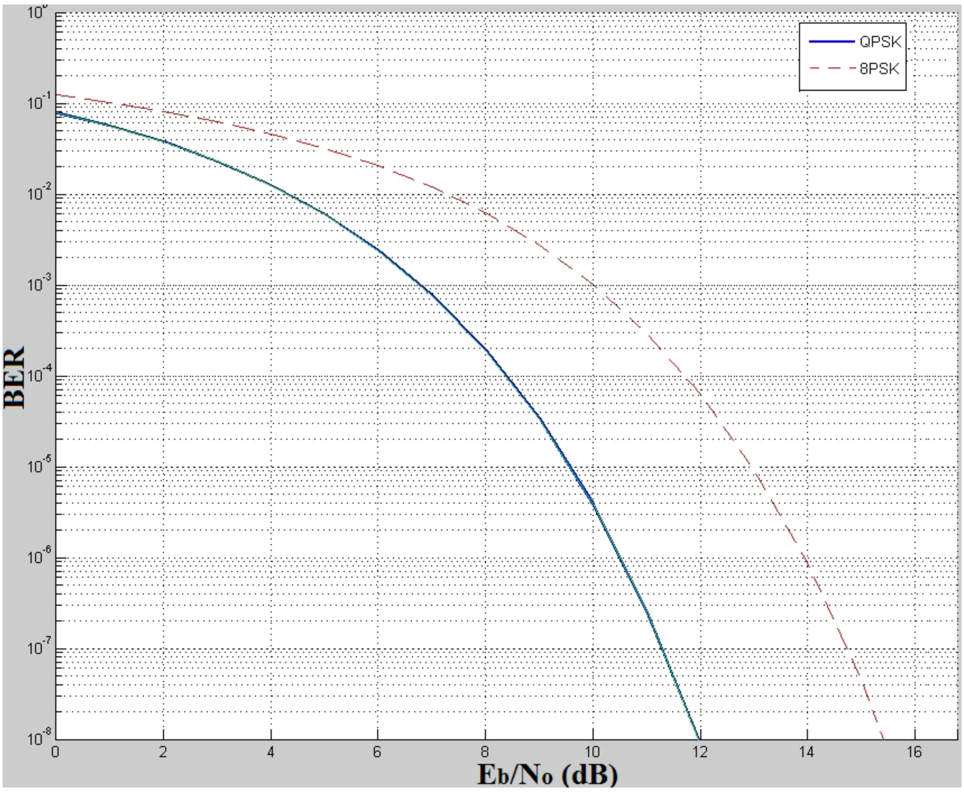

Fig.16: Waterfall curves for the QPSK and 8PSK

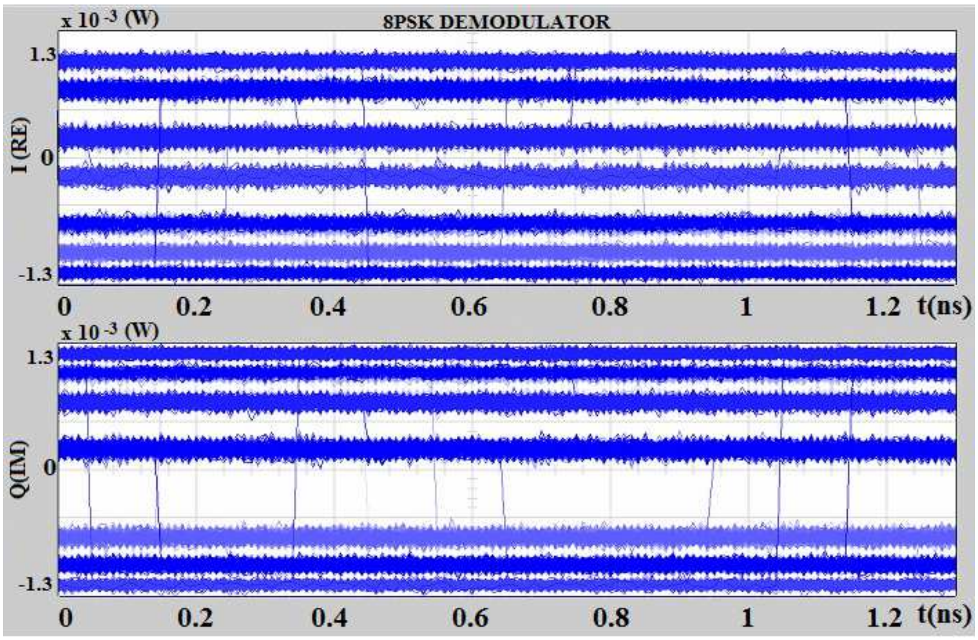

Fig.17: The 8PSK eye diagram

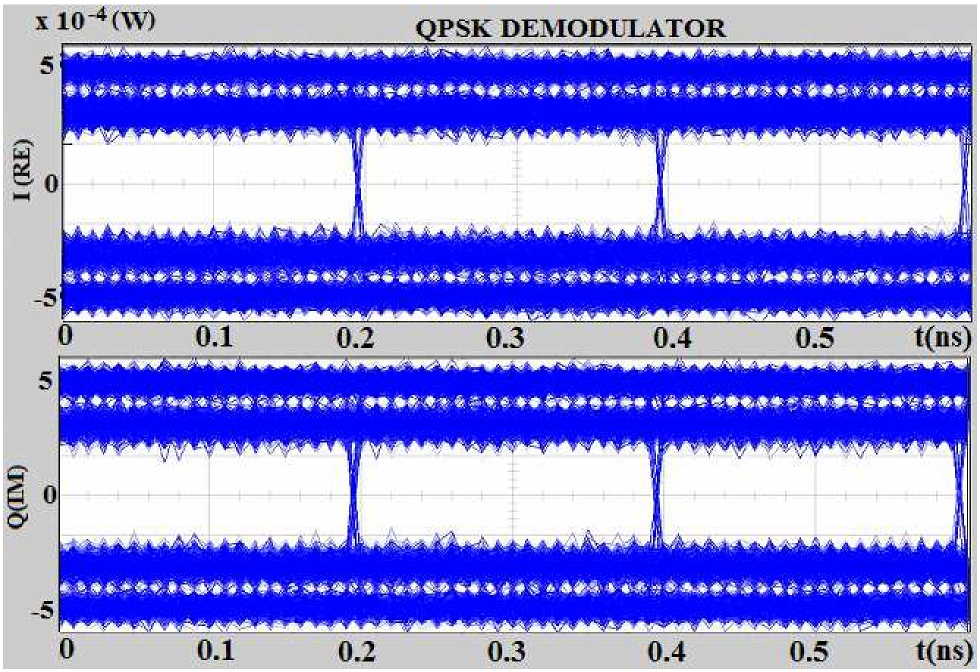

Fig.18: The QPSK eye diagram