Modeling of Environmental Influences at the Signal Transmission in the Optical Transmission Medium

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***Abstract*:**This contribution discusses characteristics of environmental influences on transmitted signals in the optical transmission medium. A main attention is focused on the explanation of simulation methods for substantial linear and nonlinear negative effectsin the optical fiber presented by the proposed simulation model. The paper also presents characteristics of modulation techniques utilized in the optical transmission medium.Finally, a comparison of different modulation techniques affected by various environmental influences in this simulation model is presented.

***Keywords*:**the optical transmission medium, parameters of the optical fiber, OOK, DBPSK and DQPSK modulation techniques

1. Introduction

Nowadays, new technologies in telecommunication, electronic and computer science are developed andalong with the increasing flow of data through the Internet, electronic commerce, computer networks, multimedia, voice traffic, data and video comes a growing need for a transmission medium that offers the possibility to deal with large amounts of information. Optical fibers, with their relatively infinite transmission bandwidth and the transmission quality, have proved to be a solution and the interest in the signal information transmission through optical fibers rapidly increased. Optical transmission systems are mainly used for the signal transmission over the backbone network while the optical technology gradually penetrates into the access network. New technologies have been developed such as DWDM (Dense Wavelength Division Multiplex), CWDM (Coarse Wavelength Division Multiplex) and EDFA (Erbium-doped Fiber Amplifier) in order to further increase transmission speeds to more than terabit per second. The increasing demand for very high-speed data rates through optical transmission systems is not workable by the baseband modulation techniques and deployment of new hardware devices would be either technically unfeasible or costs will be disadvantageously. Therefore, it is possible to think about utilizing of the signal conditioning to obtain aresistance to impacts that mostly degrade the information optical signal and to meet demands placed upon it. Such signal conditioning is called a modulation. However, there are several possible modulations characterized by various parameters.

The paper will be focused briefly on negative influences of the optical environment.The optical transmission path contains linear and nonlinear effects degrading the optical signal's transmission.This contribution also covers modulation techniques utilized at the signal transmission in the optical transmission medium. Then, a simulation program for passing optical signals through the optical transmission medium is introduced.Also, a comparison of these modulation techniques affected by various environmental influences will be presented.

2. Analysis of the optical fiber and it parameters

Each optical fiber represents a transmission system, which is frequency dependent. A pulse propagation inside this transmission system can be described by Nonlinear Schrödinger Equation (NLSE) and this NLSE is derivate from Maxwell equations. The solution for the NLSE is Gaussian pulse:

$$\begin{aligned}\frac{\partial a(z,t)}{\partial z} &= -\frac{\alpha}{2}a(z,t)-\beta_1\frac{\partial a(z,t)}{\partial t}-j\frac{\beta_2}{2}\frac{\partial^2 a(z,t)}{\partial t^2}\\ &+\frac{\beta_3}{6}\frac{\partial^3 a(z,t)}{\partial t^3}+j\gamma\left|a(z,t)\right|^2 a(z,t)\\ &-j\gamma T_R\frac{\partial\left|a(z,t)\right|^2}{\partial t}a(z,t)-\frac{\gamma}{\omega_0}\frac{\partial\left|a(z,t)\right|^2 a(z,t)}{\partial t}\end{aligned}\tag{1}$$

where $a(z,t)$ is process of the intensity of the optical signal in fibers, z is a distance, t is a time, α is the fiber's specific attenuation, β_1, β_2, β_3 are dispersion coefficients of the first, the second and the third place value and γ is the nonlinear coefficient.

Each term of the equation sequentially represents a linear attenuation, a dispersion of the first, the second and the third place value, the Kerr effect, the stimulated Raman scattering and a change of the pulse slope [1].As we can see from the Schrödinger equation, the optical signal is changed by these effects classified as:

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

2.1 Linear Effects

Linear effects represent a majority of losses at the optical signal transmission signal through the optical fiber. These linear effects are mainly caused by the attenuation and the dispersion. The attenuation limits a distance of the optical signal transmission and the dispersion is influenced a distance range of repeaters.

2.1.1 Attenuation

The most important parameter of optical fibers is the attenuation that represents a transmission loss. In practical way, it is a power loss that depends on a length of the transmission path. Total signal attenuation a [dB] is defined for a particular wavelength, which is defined by:

$$a[dB] = 10\log_{10}\frac{P_i}{P_0} \tag{2}$$

whereP_i is the input power and P_0 is the output. The specific attenuation of the optical fiber is marked as α and expressed in units dB/km:

$$\alpha[dB/km] = \frac{10\log_{10}\frac{P_i}{P_0}}{L} = \frac{a}{L} \tag{3}$$

where$L$ is the optical fiber's length in [km].

The attenuation of optical fibers is mainly caused by material absorption losses, radiation scattering and by bending losses.Attenuation curve of the optical fiber is shown on Figure 1 [2],[3].

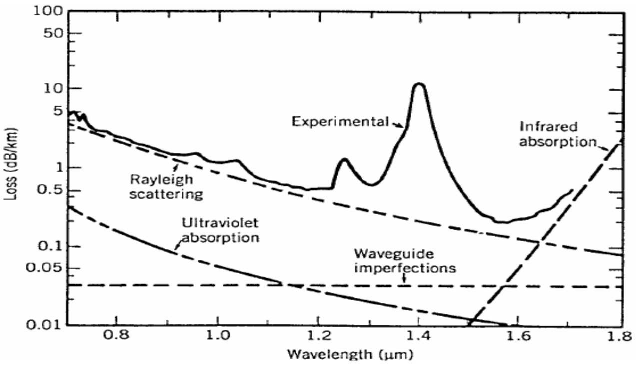

Figure 1. Characteristics of attenuation components

2.1.2 Dispersion

The mode dispersion occurs in multi-mode fibers due to unequal propagation constants of different modes. The mode dispersion is presented only in multi-mode fibers and highly impacts the signal transmission rates. Our work is oriented to the single-mode fiber and long-haul transmission systems, so the mode dispersion is not considered. The chromatic dispersion is caused by the fact that it is impossible to create a completely monochromatic source of the light. The chromatic dispersion depends on spectral width of the pulse, length and is changing with the change of wavelength of the pulse. The smaller the width is, the less dispersion is occurred. The chromatic dispersion is not important in multi-mode fibers. An effect of the chromatic dispersion mainly appears in single-mode fibers. The overall dispersion in single-mode fibers is significantly less than in other types of fiber [3].

The chromatic dispersion is caused by different time of the spreading wave through fiber for a different wavelength and it depends on the spectral width of the pulse. As mentioned before, optical fiber represents the transmission system. Then the system has transfer function $H_0(\omega)$given by equation (4). We assume that$|H_0(\omega)| = 1$ and we can expand phase into the Taylor series as is given by equation (5). If we consider first two coefficients, then we can write transfer function as given by equation (6).

$$\mathrm{H}_0(\omega) = |\mathrm{H}_0(\omega)|.e^{-j.\varphi(\omega)} \tag{4}$$

$$\varphi(\omega) = -\left[\varphi_0 + \frac{d\varphi}{d\omega}(\omega-\omega_0) + \frac{1}{2}\frac{d^2\varphi}{d\omega^2}(\omega-\omega_0)^2 + \frac{1}{6}\frac{d^3\varphi}{d\omega^3}(\omega-\omega_0)^3 \ldots\right] \tag{5}$$

$$\mathrm{H}_0(\omega) = e^{-j.\varphi_0}.e^{-j.\frac{d\varphi}{d\omega}(\omega-\omega_0)}.e^{-j.\frac{d^2\varphi}{d\omega^2}(\omega-\omega_0)^2} \tag{6}$$

where$H_0(\omega)$is a transfer function,$\varphi_0$is an initial phase of the system and ω_0 is an initial angular frequency

After few operations, we can obtain time t from the transfer function, which represents the travel time of the pulse through the fiber, the signal phase shift $\Delta\varphi$ and the Group Velocity Dispersion coefficient (*GVD*). These parameters are described by two equations:

$$t = \frac{1}{2\pi}\frac{d\varphi}{df_m} \tag{7}$$

$$GVD = \frac{1}{2\pi}\frac{d^2\varphi}{df_m^2} \tag{8}$$

The chromatic dispersion causesbroadening and phase changing of the signal. Then pulses at the end of optical fibers may start to overlap and this effect is called as the Inter Symbol Interference (ISI).

The chromatic dispersion consists of the material dispersion and the waveguide dispersion [3],[4]. The equation between chromatic dispersion, material dispersion and waveguide dispersion is defined:

$$D_{CD} = D_{MAT} + D_w \tag{9}$$

Another dispersion that occurs in the single-mode fiber is called polarization mode dispersion (PMD). This PMD is to some extend a random phenomenon. Due to birefringence, the light is spread in waveguide to the two modes in two planes, which are orthogonal. Due to the effect of inhomogenity and noncircularity of the core, light in the two planes has different rates. The fact, that individual modes are spread in two planes with different rates leads to a time delay – Differential Group Delay (DGD). The PMD is described by the parameter D_{PMD}. The D_{PMD} parameter is measured in units of ps/km and is given by the equation:

$$\Delta\tau = D_{PMD}\sqrt{L} \tag{10}$$

The resulting overall dispersion is composed of chromatic dispersion and polarization mode dispersion path and is given by the resulting relation [2],[3],[4],[5]:

$$D = \sqrt{D_{CD}^2 + D_{PMD}^2} \tag{11}$$

2.2 Nonlinear Effects

These effects play an important role in a transmission of optical pulses through the optical fiber. We can classify nonlinear effects:

a) *Kerr nonlinearities*, which is a self-induced effect in that the phase velocity of waves depends on the wave's own intensity. The Kerr effect describes a change in the refractive index of the optical fiber due to an electrical perturbation. Due to the Kerr effect, we are able to describe following effects :
  - Self-Phase Modulation (SPM) - the effect that changes the refractive index of the transmission media caused by an intensity of the pulse.
  - Four Wave Mixing (FWM) - the effect, in which mixing of optical waves rise the fourth wave that, can occur in the same wavelength as one of mixed waves.
  - Cross-Phase Modulation (XPM) - the effect where a wave of the light can be changed by the phase of another wave of the light with different wavelengths. This effect causes a spectral broadening.

b) *Scattering nonlinearities*, which occur due to an inelastic photon scattering to the lower energy photon. We can say that energy of the light wave is transferred to another wave with different wavelengths. Two effects appear in the optical fiber:
  - Stimulated Brillion and Raman scattering - effects that change a variance of the light wave into different waves when intensity reaches certain threshold.

2.2.1 The Four Wave Mixing effect (FWM)

The FWM is a parametric interaction among waves satisfying a particular phase relationship called the phase matching. This nonlinear effect occurs only in systems that carry more wavelengths through the optical fiber and it is classified as a third-order distortion phenomenon. In this case, we are assuming that three linearly polarized monochromatic waves with angular frequencies ω_j (j =1,2,3) are propagating. If we consider the third-order polarization vector P given by equation (12) that characterizes the medium and it is a function of the electrical field, and simplified it, we obtain his components: three components have the frequencies of the input field, the others have and frequency ω_k given by equation (13).

$$\mathrm{P} \approx \varepsilon_0 \left\{ \chi^{(1)} \overline{E} + \chi^{(2)} : \overline{E}\,\overline{E} + \chi^{(3)} \vdots \overline{E}\,\overline{E}\,\overline{E} \right\} \tag{12}$$

where$\chi^{(1)}$ is linear susceptibility, $\chi(2)$,$\chi(2)$ is second and third-order susceptibility and***E***represent vector of electrical field of mode.

$$\omega_k = \omega_1 \pm \omega_2 \pm \omega_3 \tag{13}$$

As we can see from the equation (13), nonlinear interaction generates new frequency components of the material polarization vector, which can interfere with input fields if a phase matching condition is obtain. The most frequency components fall away from our original bandwidth or near it. Frequency components that directly overlap with bandwidth will cause an interference with original waves as we can see on Figure 2.

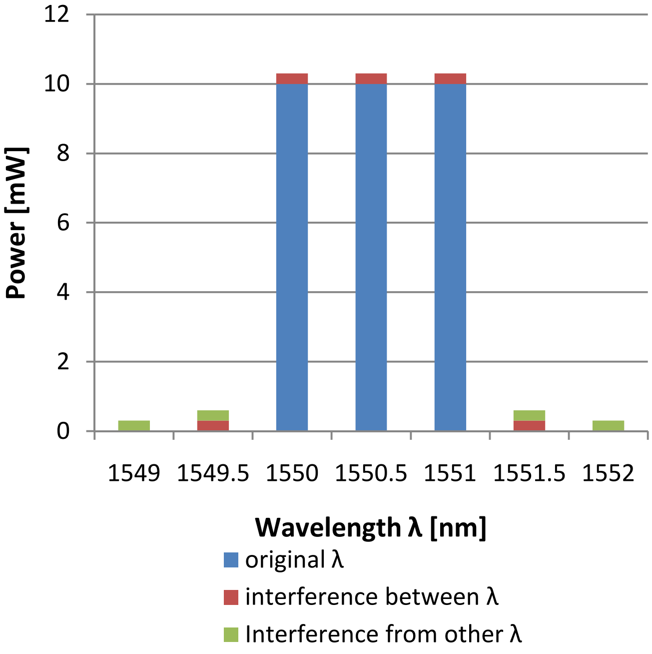

Figure 2. Illustration of the FWM effect

The power of new generated waves can be obtain by solving coupled propagation equations of four interacting waves. We assume that the new generated FWM wave is mainly depended on three nearest waves of the light, so the power A_k^2 at the frequency $\omega_k = \omega_1 + \omega_2 - \omega_3$is given by [6]:

$$A_k^2 = 4\eta\gamma^2 d_e^2 L_e^2 A_1^2 A_2^2 A_3^2\, e^{-\alpha l} \tag{14}$$

where factor η is the FWM efficiency, γ is the nonlinear coefficient, $L_e$is the effective length, $A_1^2(z)$, $A_2^2(z)$, $A_3^2(z)$ are powers of input waves, l is the fiber length, α is the attenuation and d_e the so-called degeneracy factor (equal to 3 if the degenerative FWM is considered, 6 otherwise).

The power of the FWM represents sum of the partial power from interacting waves, which degenerate the signal. This power of the FWM is different for each channel and change with the parameter of interacting signals.

As we can see from the equation (14), the nonlinear effect FWM is mainly rising with increasing powers of interacting signals and the shape of the FWM effect depends on the modulation and the bit rate of these signals. If input powers of signals are too high, the scattering nonlinearities occur and transmission would not be possible. However, the scattering nonlinearities are not presented. The power also depends on the channel spacing and on the dispersion. If we use negative dispersion fibers, the FWM effect will be more intensive and the SNR will fall to values unsuitable to transmit. If we used standard fibers, we can decrease the FWM effect, but we cannot use high bit rates due the dispersion [7],[8],[9].

3. Characteristics of modulation techniques

In a case of digital modulations, we must ensure encoding digital information into the analog form and back – discern digital data from the analog transmission. The modulating signal is represented by time sequences of symbols and pulses, where each symbol has M finite states. Each symbol represents q information bits which are given by equation (15). A change of states is discrete, respectively jumped.

$$q[bit/symbol] = \log_2 M \tag{15}$$

There are several digital techniques that can be divided into two basic groups:

- line codes (in the baseband)
- modulations

3.1 Line codes

Line codes are used for modulation in the baseband for relatively short distances. We can divide them into two kinds – unipolar and bipolar.

We can consider only unipolar signals when using optical transmission because within the bipolar signal we had to consider the negative light which is not feasible. Physical properties are mainly affected in optical transmission in the baseband so we will only consider the optical transmission in the shifted band. We will look at types of modulation techniques used around wavelength 1550 nm. These systems are implemented in a real life or in test mode or in theoretical plane [2],[10].

3.2 Modulations

When using modulations, we change our usable signal so that it will adapt to the transmission media. We change the usable signal by the carrier signal and therefore we get new signal called modulated signal which is suitable for transmission via the optical interface. There are four basic physical attributes that can be adapted to optically transmitted data (carrier modulations) – intensity, phase, frequency and polarization. According to the used parameter which the optical signal has been modulated, we can divide modulations:

- ASK – OOK Amplitude Shift Keying, On/Off Keying
- PSK Phase Shift Keying
- FSK Frequency Shift Keying
- PolSK Polarization Shift Keying
- DUOBINARY modulation

The OOK is characterized by an output signal of the optical flux from the optical generator for logical “1” and the absence of an optical signal for a logical “0”. PSK is characterized by phase change in point of changing logical level. The simplest PSK is in a change of the phase by value π. The information is not hidden in amplitude but in the change of phase [2],[10].

4. Simulation of optical modulation techniques

The presented simulation model comes out from the simulation model for optical communications introduced in [11]. A modeling was performed in Matlab Simulink 2010 and GUI. The whole program is controlled by a main screen, where user is able to perform adequate operations and it required only basic knowledge about optical fibers. A program has two mainly functions (calculation and simulation) representing two independent systems. The calculation part is used for calculating a power of the FWM effect with inserted fiber parameters. This nonlinear effect occurs only in WDM systems, so we occurred that our system is using a WDM system with three optical signals transmitted in the fiber. This part of the program is included into the main screen interface. The simulation part simulates an optical medium with linear and chosen nonlinear effects with different modulation techniques. This part is being set by parameters that were inserted in a main screen and calculated in the calculated part. The simulation part is using the Communication Blockset and Communication tools to simulate and create the optical transmission path. In these tools, already created blocks as modulators, generators, blocks with operation functions and scope blocks are used. This program does not include designed blocks to simulate some of the linear or nonlinear effects in the optical fiber, but the AWGN block partially compensates their functions.

As we mentioned before, a whole program starts with main screen, which is shown on Figure 3. The calculation output is the FWM power for one channel and it is calculated from inserted parameters of the optical fiber by using the NLSE equation (14).

The simulation part allows simulating different modulation techniques at the signal transmission through the optical fiber with given parameters and system performances. To run the simulation part, input parameters and the FWM power parameter must be set. In this section, a signal of adequate modulation technique changed by passing through the optical system is showing. For this purpose, we will consider these system parameters: three channels with source generators that generate powers of 1 mW at wavelengths of 1550 nm, 1550,5 nm, 1551 nm, the fiber length 10 km, the dispersion coefficient 18 ps/(nm.km), the attenuation 0,21 dB/km. The simulation program includes the FWM effect, dispersion and attenuation.

4.1 Simulation of the On/Off Shift Keying (OOK) modulation

The OOK modulation as the simplest type of M-AM modulation can be represented by two signals:

$$s_1(t) = A\cos(2\pi f_c t) \qquad 0 \le t \le T \ \ for \ \ 1 \tag{16}$$

$$s_2(t) = 0 \qquad 0 \le t \le T \ \ for \ \ 0 \tag{17}$$

where logical units “1” and “0” are binary data received uncorrected with the exactly same probability. The complex OOK signal’s envelope is for a time axis equal to:

$$s(t)' = \sum A_k p(t-kt) \qquad -\infty \le t \le \infty \ for \quad k = \langle -\infty, \infty \rangle \quad (18)$$

whereA_k is from the range {0,A}, *p(t)* is the rectangular pulse with amplitude equal to one. The representation of two possible states of the modulated signal is shown on Figure 4.

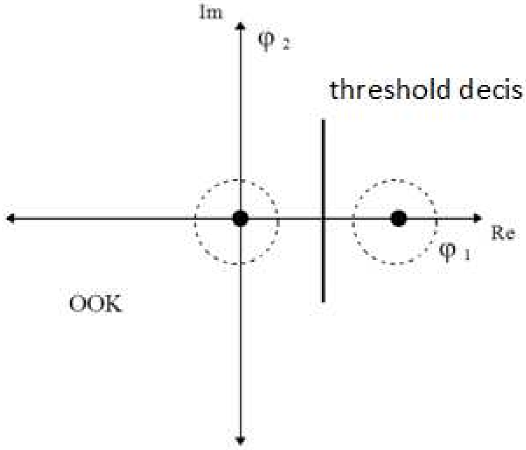

Figure 4. Distribution of symbols for the OOK modulation

This distribution of symbols can be seen in a model where possible linear and nonlinear effects are low. To simulate a signal transmission over the optical fiber, we need to generate a sequence of digital data {0, 1} and then modulate it with an appropriate modulation. The modulated signal is changed after the transmission (shape, magnitude, phase etc.) due to linear and nonlinear effects and, therefore, we can obtain a modulated signal with the noise. A demodulator demodulates this signal into a sequence of digital data and then a decision block can decide what data were transmitted. The OOK modulation schema is shown on Figure 5.

As a source, we can use the Bernoulli generator that generates two pulses “1” and “0”. This generator is used for all possible analyzed modulation techniques. To compare the input signal with the output one, both signals must be brought to the corrector to compensate delaysbetween them. A representation of the ideal generated signal with the involvement scheme is shown on Figure 6.

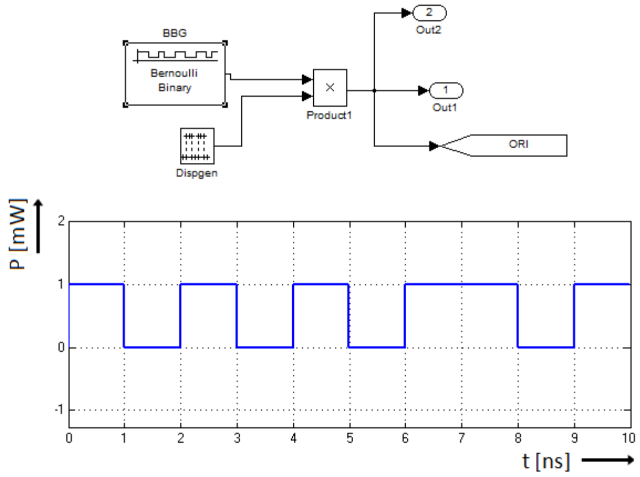

Figure 6. The ideal signal generated by the Bernoulli generator

After being generated, the ideal signal is modulated by the appropriate OOK modulator/demodulator blocks shown on Figure 7 and the OOK modulated is shown on Figure 8.

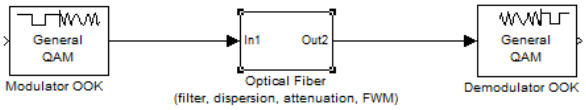

Figure 7. Modulator and demodulator blocks

Assuming a finite bandwidth, we can filter a signal with the appropriate filter block shown on Figure 9. The simulation program involves two options for filtering. The first filtration (Figure 10) changes a signal with the higher rise and fall edge. This kind of the filtered signal is mostly generated with expensive sources used in core networks. The second option showed on Figure 11represents a signal with the slower rise and fall edge. This kind of the filtered signal can be generated with LED diodes.

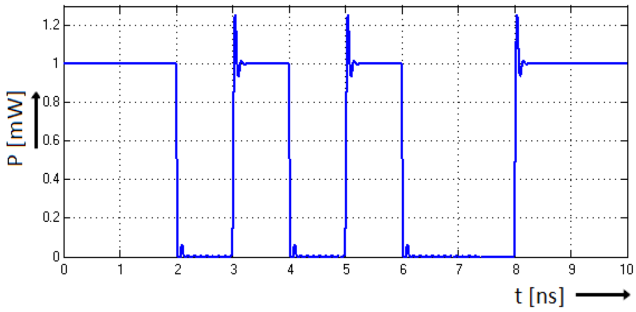

Figure 10. The OOK signal filtered for laser diodes

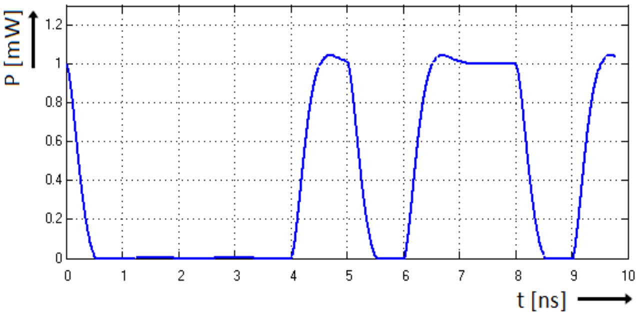

Figure 11. The OOK signal filtered for LED diodes

After filtering, we use a dispersion block that causes an expansion of the original signal in the time domain and moreover a phase shift is occurred due to the chromatic dispersion. For all possible analyzed modulation techniques, the dispersion schema is shown on Figure 12. In this system, the value of dispersion is given by 18 ps/(nm.km). The influence of the dispersion on the OOK signal is shown on Figure 13. In this figure, magnitudes betweenOOK modulated signals without and withdispersionare compared. The power level of OOK signals is attenuated due to bordering of pulses.

For attenuating, a block as the part of the MATLAB Simulink environment is used. For all possible analyzed modulation techniques, the attenuation schema is shown on

Figure 14. In real systems, the attenuation decreases levels of the signal magnitude. In our example, the specific attenuation factor is set to the 0,21 dB/km value. A comparison of OOK signals with and without attenuation is shown on Figure 15.

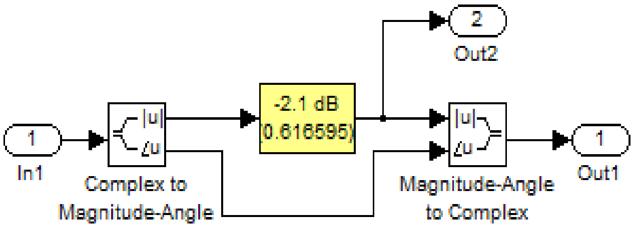

Figure 14. Theattenuation schema for all modulations

After blocks of linear effect, the FWMblock is inserted into the transmission path. This FWM effect occurs in WDM systems and therefore we must generate additional signals modulated with the same modulation technique. Modulated signals are brought into the FWM block where all signals are mixed and the new generated FWM signal is created with the power level given by parameters introduced in the main screen. The FWM schemas shown on Figure 16are similar for all modulation techniques.

The FWM effect differs depending on a power level of the fourth wave and transmission rates of mixed signals. The FWM effect on the OOK modulated signal with the quick rise/fall edge is shown on Figure 17 and the OOK modulated signal with the slow rise/fall edge is shown on Figure 18. We can assume that the FWM effect affects only a magnitude of the OOK signal. We can observe that if the dispersion coefficient value of Standard Single-Mode (SSMF) optical fibers used for long distances is higher than the 10 ps/(nm.km) and the channel spacing is more than 0,5 nm, then the FWM signal power is negligible compared to the optical signal power and the transmission rate per channel is limited to 1 - 10 Gbit/s.

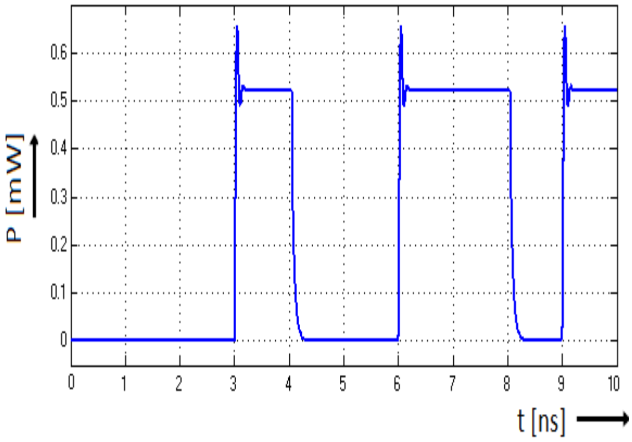

Figure 17. The OOK signal (quick rise/fall edge)with theFWM effect for the SSMF

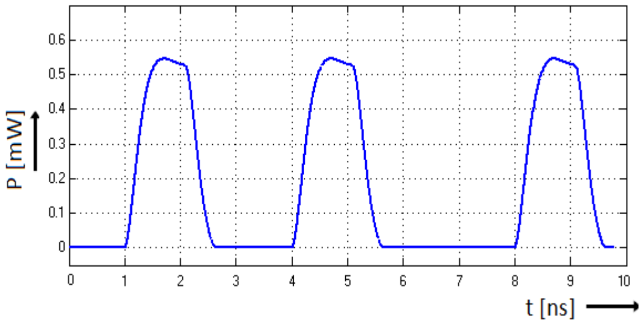

Figure 18. The OOK signal (slow rise/fall edge)withthe FWM effectfor the SSMF

Many optical transmission systems for long haul transmissionsare using Non-Zero Dispersion Shifted (NZDSF) optical fibers where dispersion values are from 0,1 to 6 ps/(nm.km) range. The FWM effect in these kinds of fibers has more negative influence than in SSMF fibers. The FWM effect in NZDSF fibers on the OOK modulated signal with the quick rise/fall edge is shown on Figure 19 and the OOK modulated signal with the slow rise/fall edge is shown on Figure 20. The signal shape is depending on the modulation format used by interacting signals and on their transmission rates.

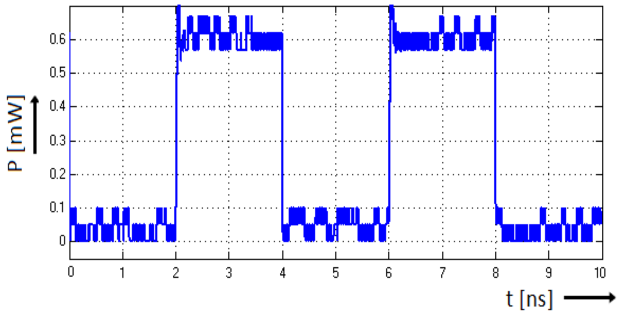

Figure 19. The OOK signal (quick rise/fall edge)with theFWM effect for the NZDSF

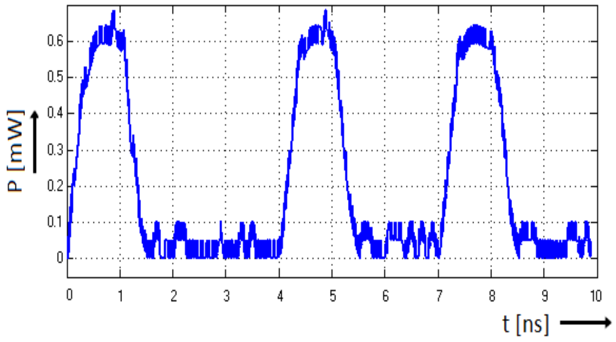

Figure 20. The OOK signal (slow rise/fall edge)withthe FWM effectfor the NZDSF

A signal passing through the optical fiber is getting a delay. To compare input and output signals, both signals must be delayed with the same time. For this reason, we can add the corrector block that delays the original input signal and then the comparison block can compare both signals. For all possible analyzed modulation techniques, the comparison schema is shown on Figure 21. The simulation allows also the Bit Error Rate (BER) measurement for the system by comparing original input with received output data sequences bit by bit. This option can be set in the main screen of the simulation program.

4.2 Simulation of the Differential Binary Phase Shift Keying(DBPSK) modulation

This modulation is created by using a differential encoding for the BPSK modulation. The DBPSK can be demodulated by a coherent demodulation or a differential demodulation. The differential demodulator uses the previous symbol as a reference for demodulating of the current symbol. For this modulation, a front bandpass filter that reduces noise, but preserves the signal phase is used. The DBPSK signal has a constant magnitude during the whole transmission and its phase is changed decently on bits. There are two options of initial signal phase that are 0° or 90° as on Figure 22.

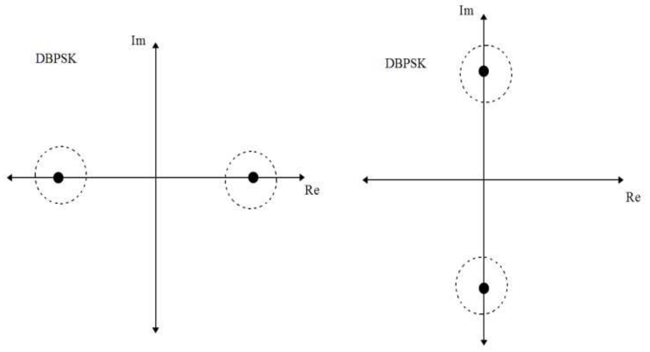

Figure 22. Two options for the DBPSK symbol distribution

The DPBSK simulation design is similar to the OOK design and the DBPSK modulation schema is shown on Figure 23. After generating a digital data sequence, we can modulate it with the DBPSK modulation (Figure 24). As we can see, the DBPSK signal has a constant value of the magnitude and bits are represented by phase shifts. The DBPSK signal constellation is shown on Figure 25.

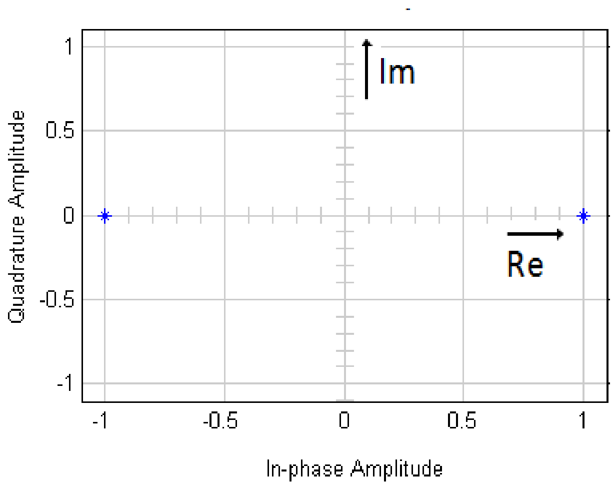

Figure 25. The DBPSK signal constellation

Because the DBPSK signal has a constant value of the magnitude, the filter block has no impact on it. However, a linear effect of the dispersion has a different influence compared to the OOK signal. In this case, only the signal phase shift occurs and the signal broadening is cancelled due to the constant magnitude. The comparison of signal constellations before and after the dispersion block is shown on Figure 26.

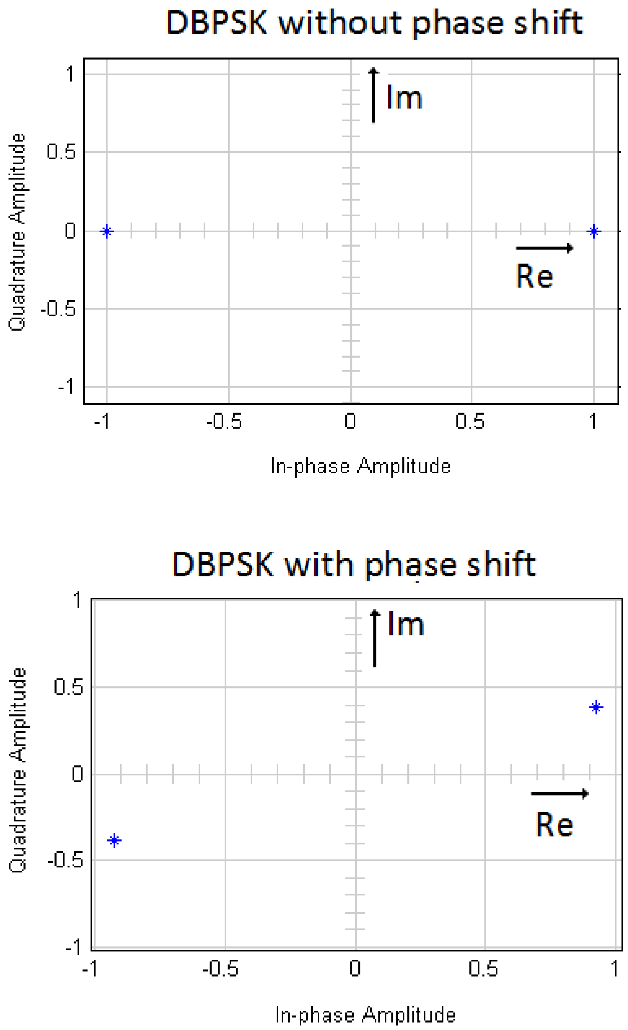

Figure 26.A comparison of signal constellations without and with the dispersionfor theDBPSK modulation

A linear effect of the attenuation decreases a constant value of the magnitude as shown on Figure 27. Then, the DBPSK signal constellation is shown on Figure 28.

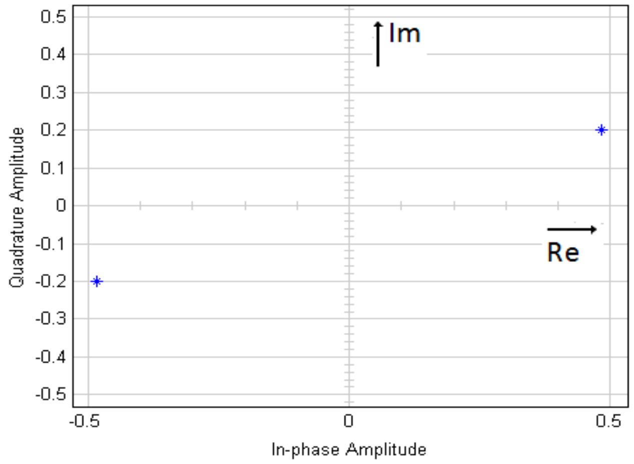

Figure 28. The DBPSK signal constellation after attenuating

The FWM effect changes a magnitude of the signal. We can use same parameters as for the OOK modulation. The magnitude of PSK modulation formats doesn't change and, therefore, we can insert a noise to interacting signals. The impact of the FWM effect on the DBPSK signal in the SSMF fibers is shown on Figure 29 and in the NZDSF fibers is shown on figure 30. As we can see, the FWM effect is negligible for SSMF fibers and is visible for NZDSF fibers.

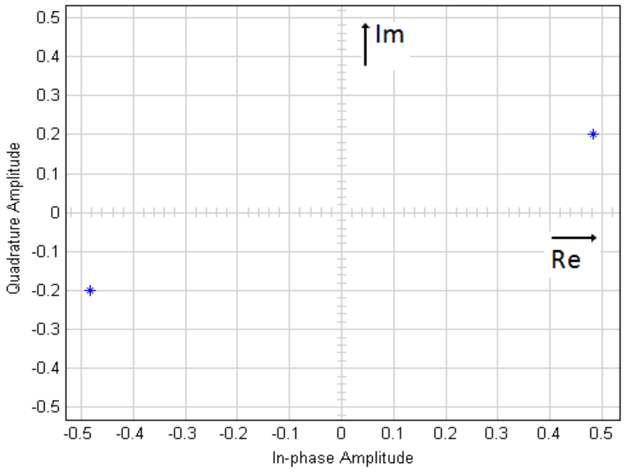

Figure 29. The DBPSK signal withthe FWM effect for the SSMF

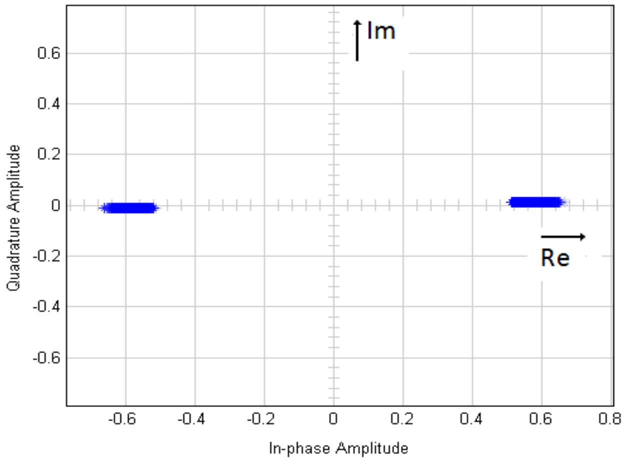

Figure 30. The DBPSK signal withthe FWM effect for the NZDSF

4.3 Simulation of the Differential Quaternary Phase Shift Keying(DQPSK) modulation

The DQPSK is the four level version of the DBPSK modulation. In the DQPSK, a symbol information is encoded as the phase change from one symbol period to the next rather than as the absolute phase. In this case, the receiver has to detect phase changes and not an absolute value of the phase, which avoids the need for a synchronized local carrier.Compared to the QPSK, the phase difference from one symbol period to the next is a function of the input symbol and not an absolute value of the phase itself.

Due this fact, a modulator is almost same as for the QPSK. A difference is that the DQPSK includes two differential coders that must be in each channel. On Figure 31, two options of distribution of symbols - the first has the initial phase equal to 0° and the second to 90° - are shown.

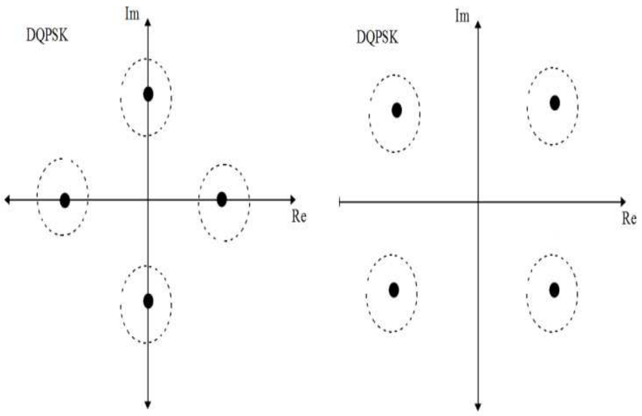

Figure 31. Two options for the DQPSK symbol distribution

The DQPSK simulation design schema is shown on Figure 32. The DQPSK modulation changes a digital data sequence into four levels and information bits are represented by the signal phase and the signal magnitude is constant for the whole transmission. This can raise a system capacity but decreases the signal-to-noise ratio. The DQPSK signal is shown on Figure 33. The DQPSK signal constellation is shown on Figure 34.

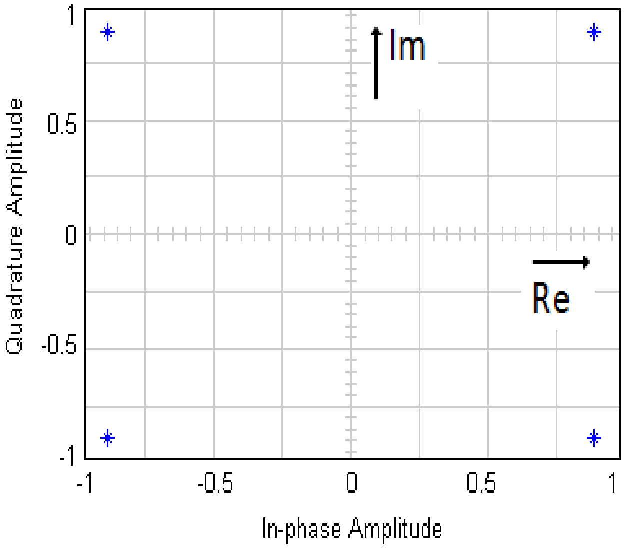

Figure 34. The DQPSK signal constellation

As in a case of the DBPSK, the filter block has no effect on the DQPSK signal. The dispersion changes the DQPSK modulated signal in the same way as in the DBPSK, so only the phase shift occurs. The comparison of signal constellations before and after the dispersion block is shown on Figure 35.

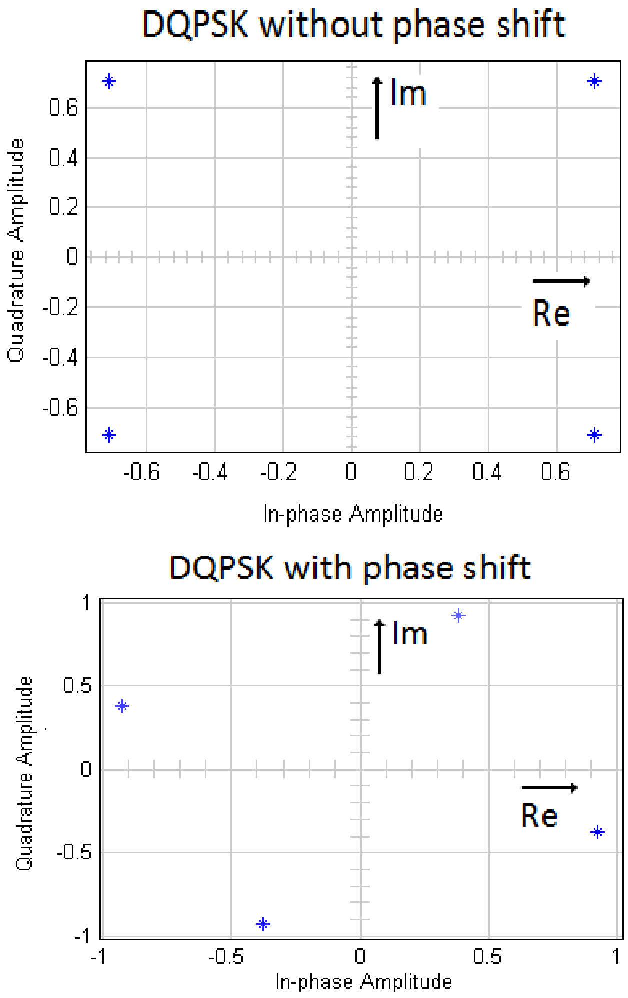

Figure 35.A comparison of signal constellations without and with the dispersion for the DQPSK modulation

The attenuation affects the DQPSK signal as is shown on Figure 36 and, then the DBPSK signal constellation is shown on Figure 37.

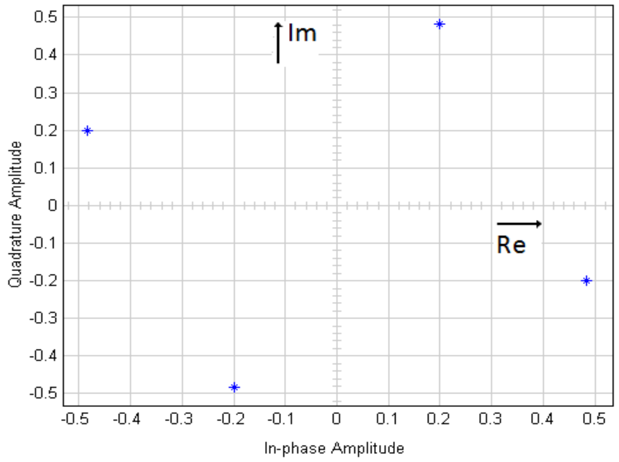

Figure 37. The DQPSK signal constellation after attenuating

The impact of the FWM effect on the DQPSK signal in the SSMF fibers is shown on Figure 38 and in the NZDSF fibers is shown on figure 39. As we can see, the FWM effect has same characteristics as in a case of the DBPSK, but a system capacity is larger in the DQPSK.

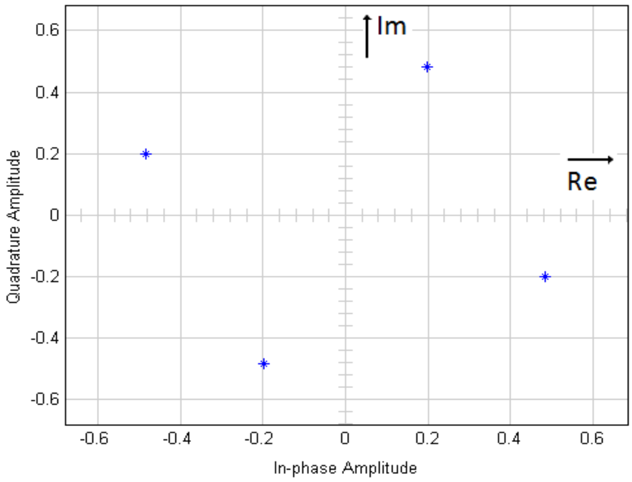

Figure 38. The DQPSK signal withthe FWM effect for the SSMF

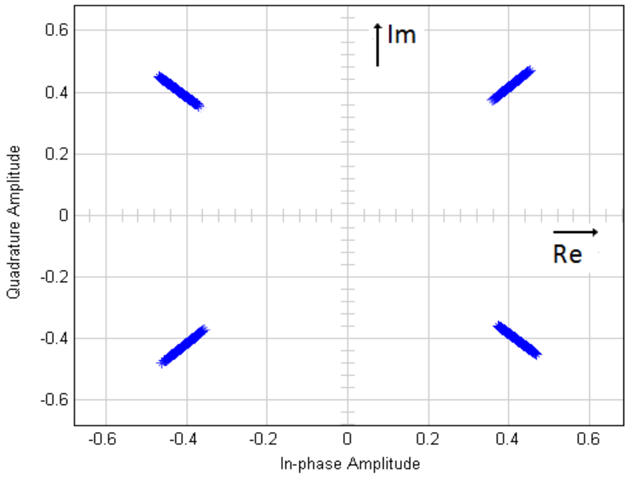

Figure 39. The DQPSK signal withthe FWM effect for the NZDSF

5. Conclusion

This contribution analyzes basic features of the real transmission environment of optical fibers and presents possibilities for modeling and simulating of the information signal transmission in this environment by means of various modulation techniques. We focus on the determination and the analysis of concrete characteristics for substantial linear and nonlinear effects in the optical transmission medium and on the representation of their influences on transmitted information signals. For realizing of individual model blocks, we can concentrate on the choice of appropriate parameters so that these blocks could be adjusted and modified for future demands. Also, characteristics of modulation techniques utilized at the signal transmission in the optical transmission medium are introduced. Finally, a comparison of different modulation techniques affected by various environmental influences in this simulation model is presented by means of the proposed simulation model. In the near future, other techniques of the optical signal processing can be included in our created simulation program for more complex analysis of the information signal transmission.

6. Acknowledgement

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Figure 3. Main screen of the program

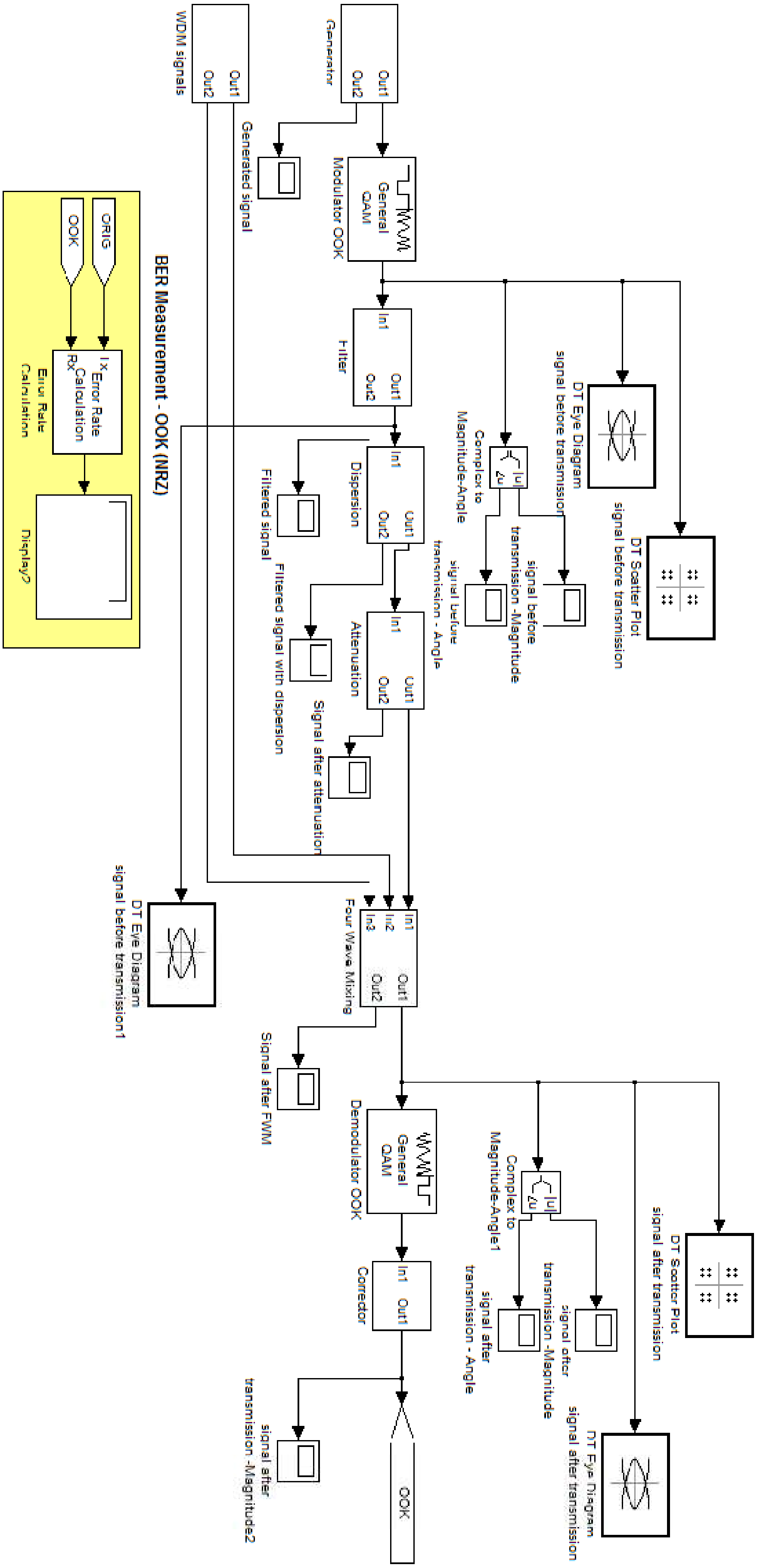

Figure 5. The OOK modulation schema

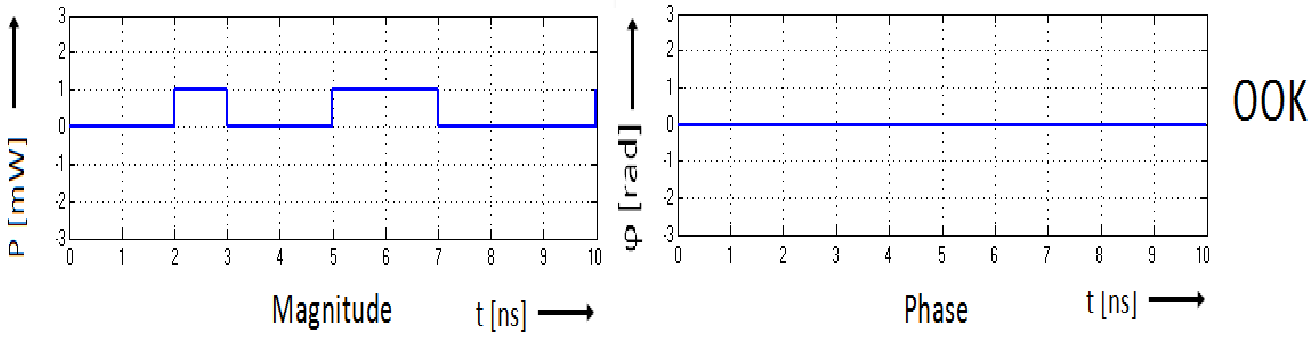

Figure 8. The OOK modulated signal

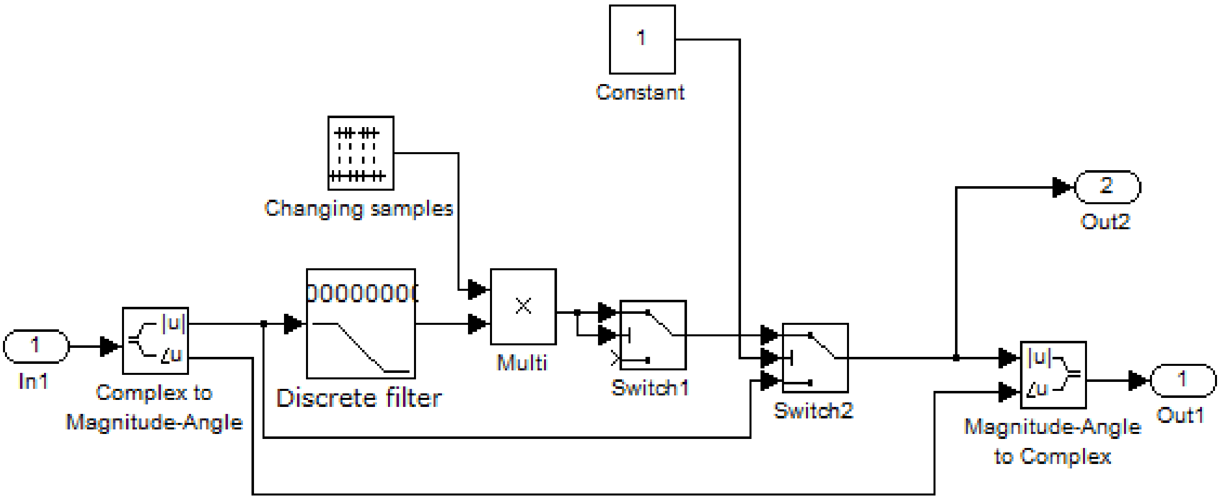

Figure 9. The filter schema for all modulations

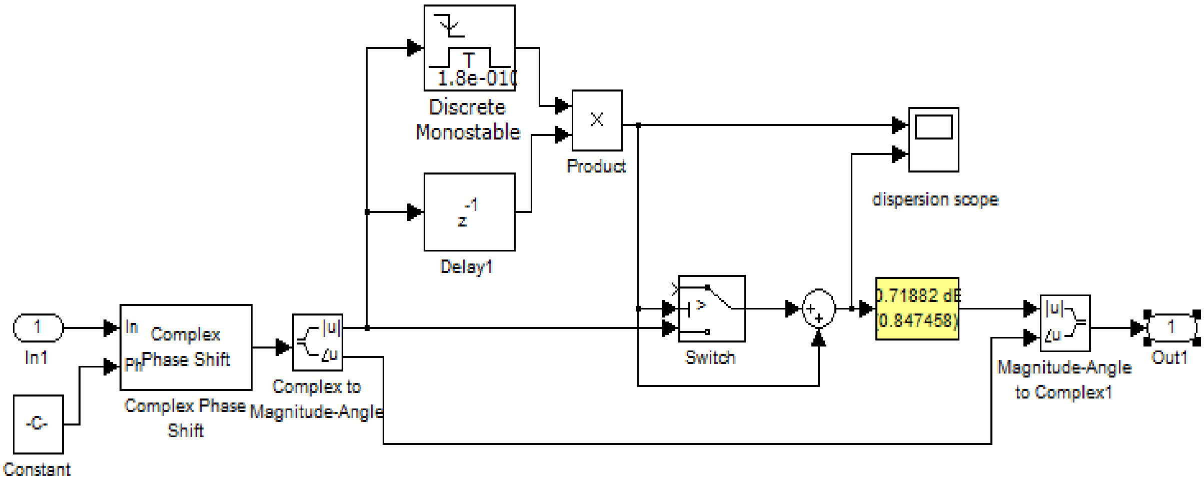

Figure 12. The dispersion schema for all modulations

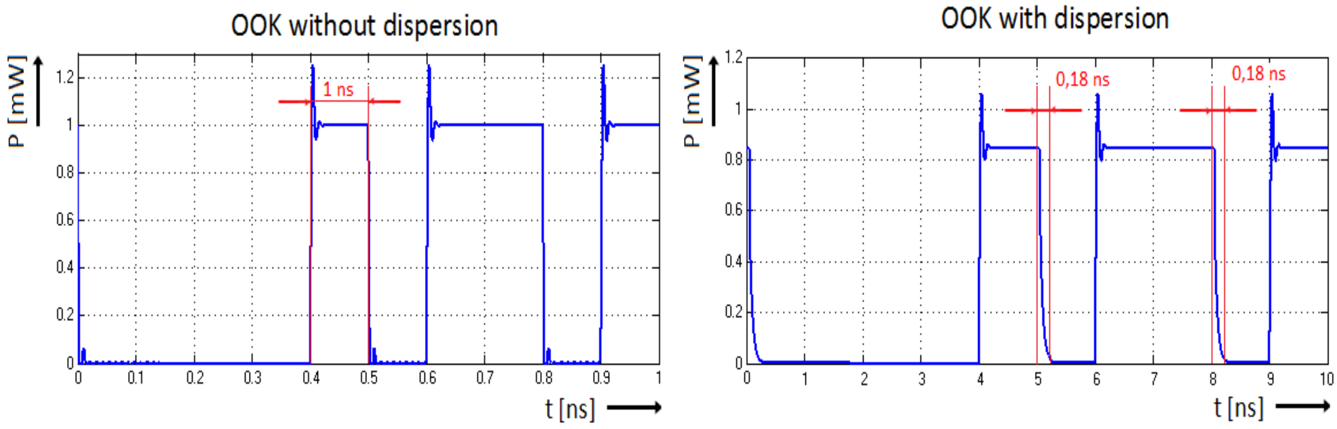

Figure 13. Comparison of signalswithand without the dispersionfor the OOK modulation

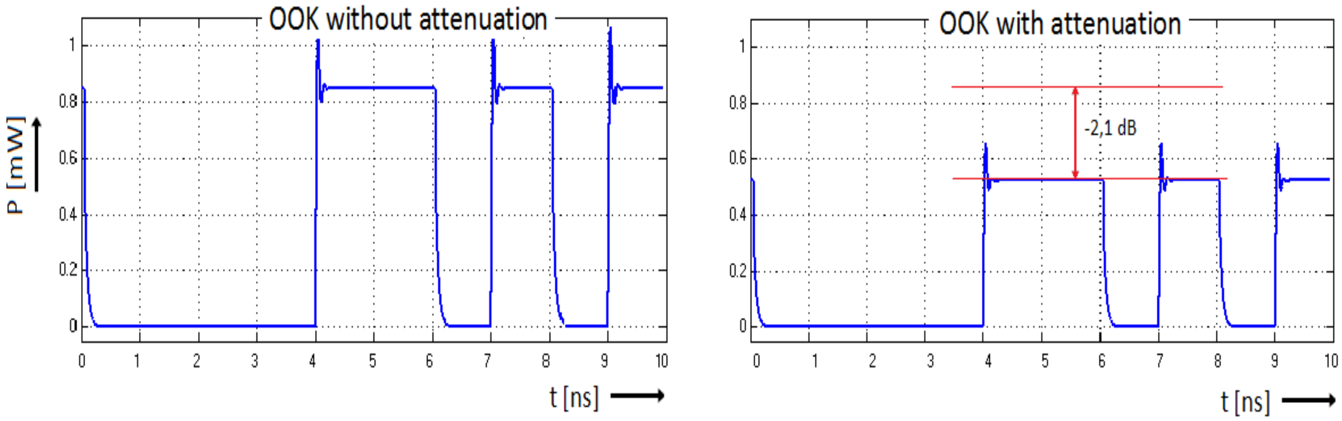

Figure 15. Comparison of signals with and without the attenuation for the OOK modulation

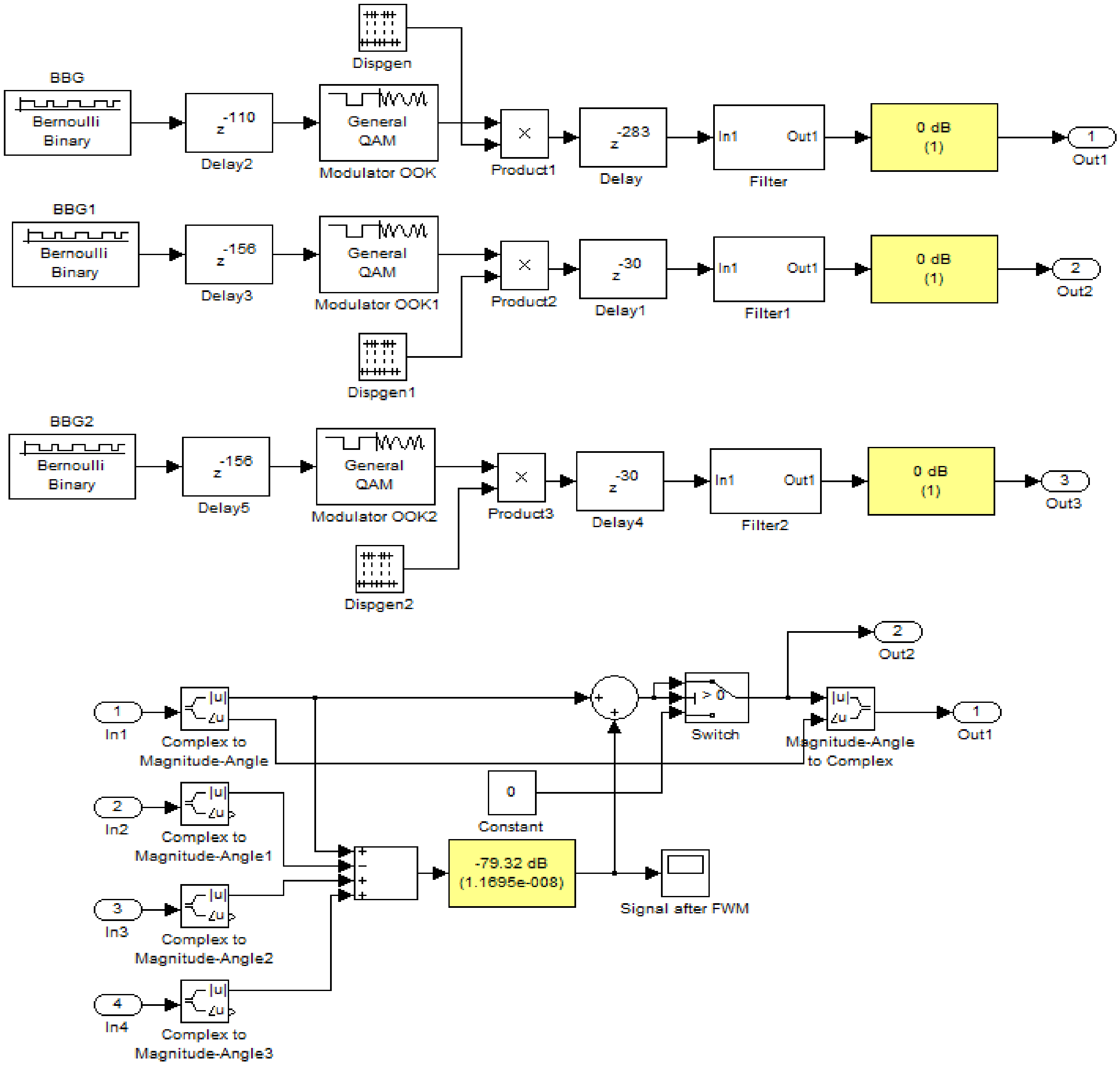

Figure 16. Schemas of the FWM block

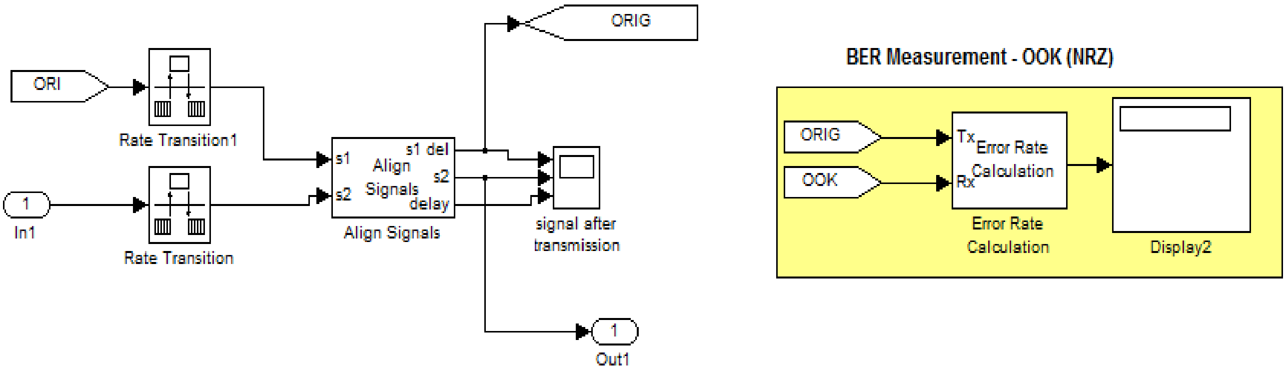

Figure 21. The corrector and the comparison schema for all modulations

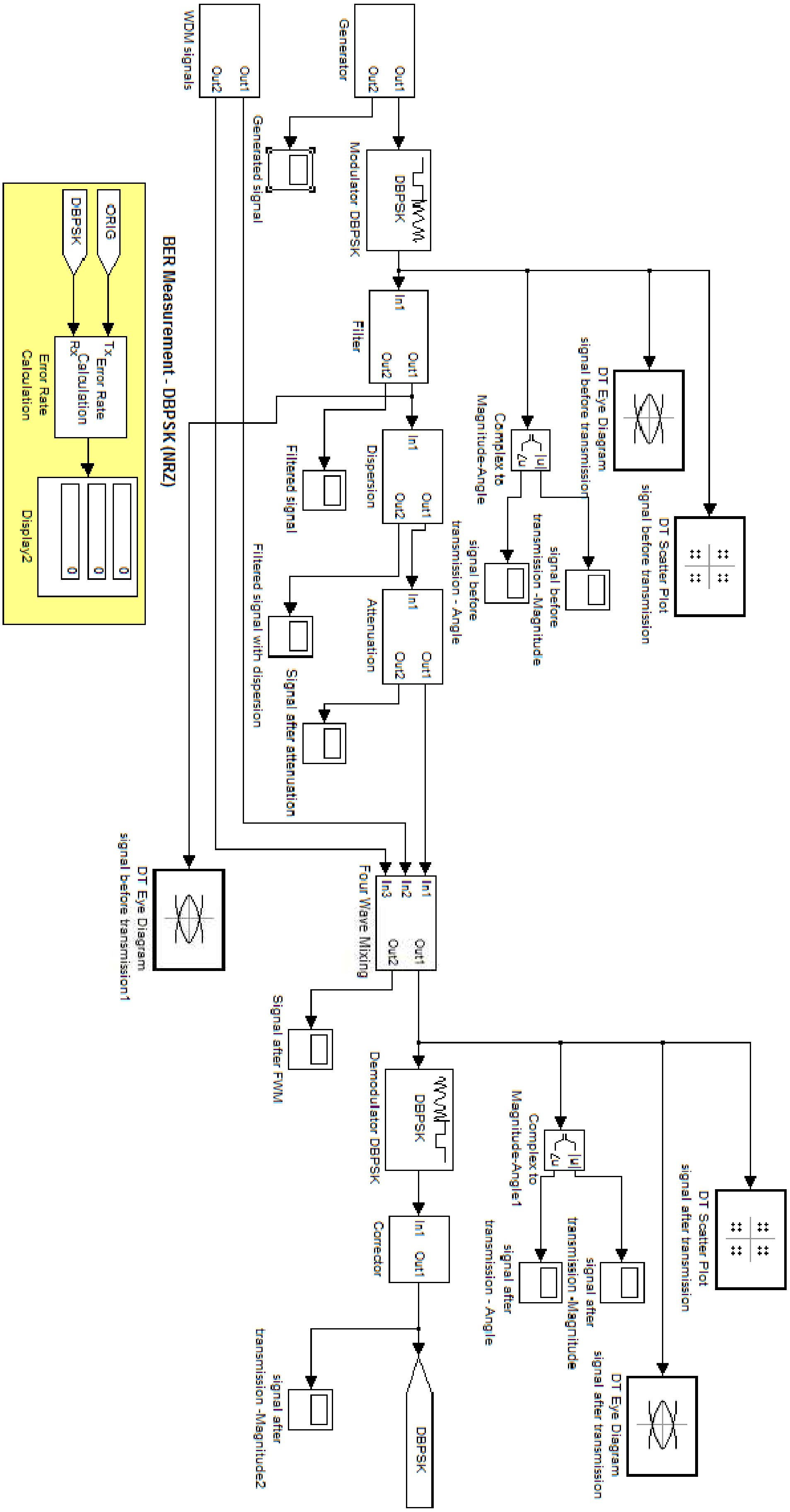

Figure 23. The DBPSK modulation schema

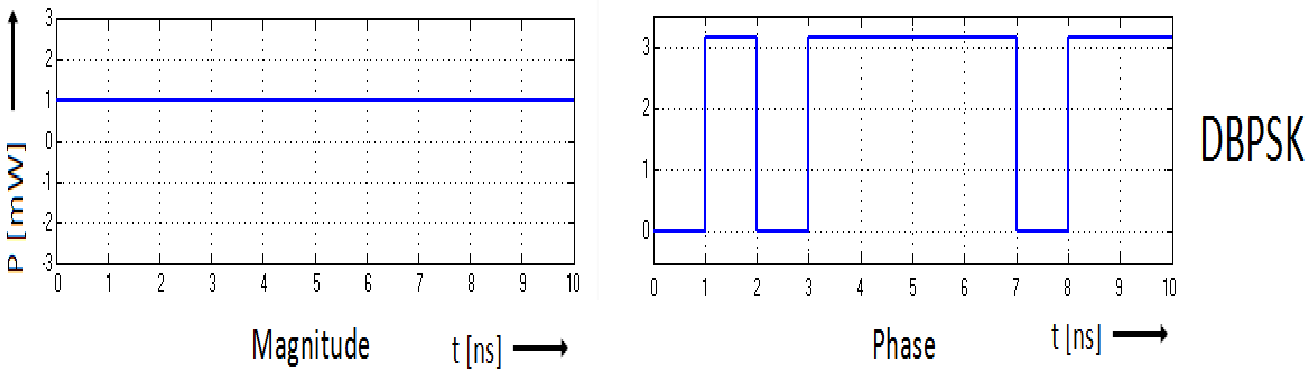

Figure 24. The DBPSK modulated signal

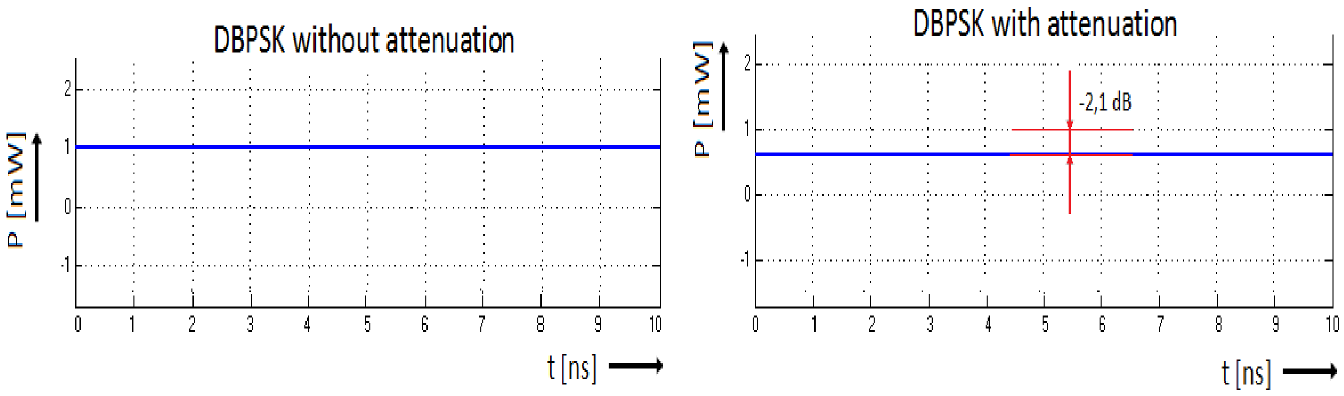

Figure 27.A comparison of the DBPSK signals without and with the attenuation

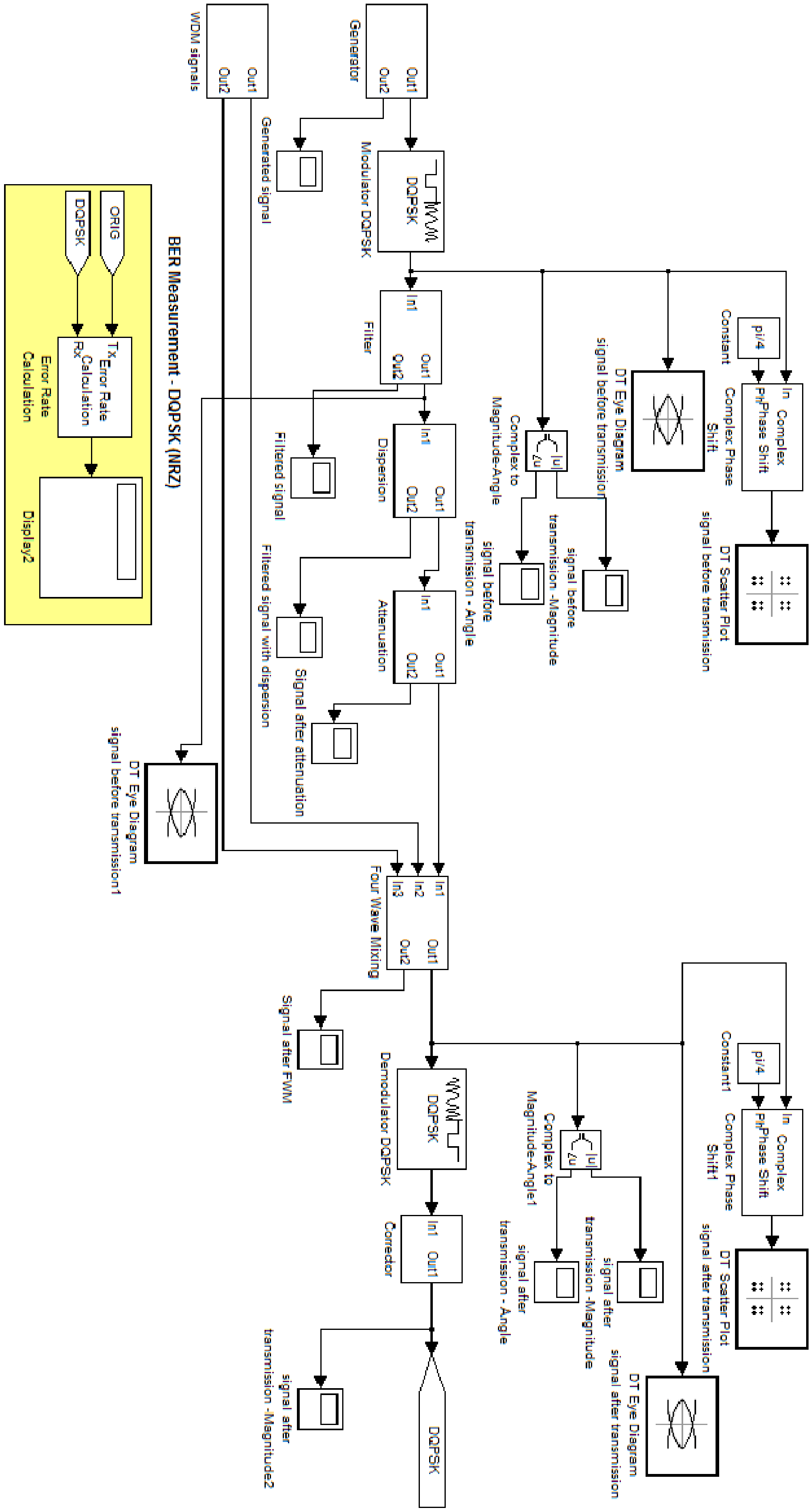

Figure 32. TheDQPSK modulation schema

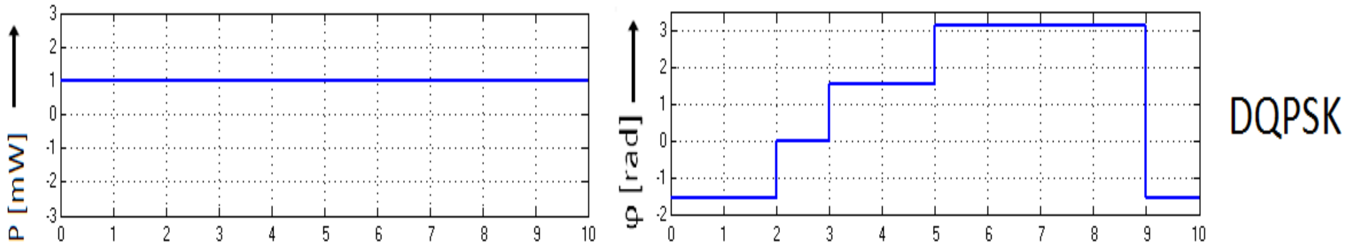

Figure 33. The DQPSK modulated signal

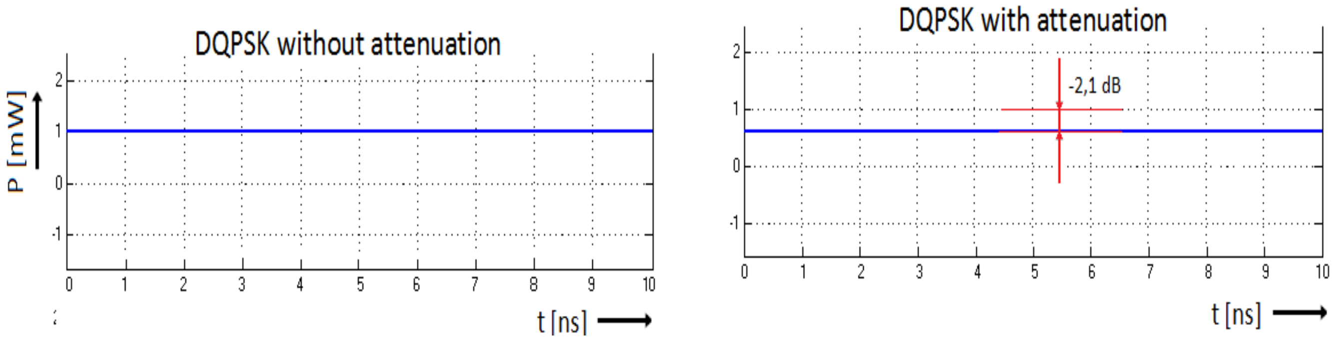

Figure 36.A comparison of the DQPSK signals without and with the attenuation