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DESIGN OF DPSK MODULATOR AND DIRECT DETECTION RECEIVER FOR DWDM BASED OPTICAL COMMUNICATION SYSTEM

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Abstract

In this paper a 16-bit differential phase shift keying (DPSK) modulator is designed for 32 dense wavelength division multiplexing (DWDM) channels. The DWDM channels are designed with 0.8nm separation in wavelength and operated at 4dBm input power. In the DWDM system, these 32 multiplexed signals propagate through a fiber length of 100 km followed by an erbium-doped fiber amplifier (EDFA) inline. The channel is equipped with pre-amplifier and a dispersion compensating fiber for better performance. Also, a threshold detector is designed for both in-phase and quadrature components to detect the input amplitude and provide a quantized output amplitude level. The result shows that, a 16-bit DPSK optical signal is demodulated successfully using direct detection receiver.

Keywords:

Optical System, DWDM, DPSK, EDFA

1. INTRODUCTION

The DWDM optical fiber communication systems can be optimized for better performance and simplicity of implementation by maximizing the spectral efficiency using different digital modulators, detectors and multiplexing techniques [1]. In currently deployed transmission links different modulation formats with high spectral efficiency are attractive choice for upgrading the capacity. Most of the current systems use binary modulation formats, such as on-off keying, phase shift keying etc [2-4].

These types of modulation techniques are able to achieve spectral efficiencies around 0.8bit/s/Hz per polarization under given practical constraints on filters for DWDM systems [5]. In the linear and nonlinear regimes of optical fiber the spectral efficiency varies for various detection and modulation methods [5]. Main challenges an optical signal propagating through the fiber face is linear and non-linear effects. Linear effects include pulse broadening of the signal due to dependence of refractive index on wavelength. This effect of pulse broadening is explained by GVD parameter β_2 in Eq.(1).

$$\beta_2 = \frac{1}{c}\left(2\frac{dn}{d\omega} + \omega\frac{d^2n}{d\omega^2}\right) \tag{1}$$

Major effects of fiber nonlinearity such as Self-Phase Modulation (SPM) and Cross-Phase Modulation (XPM) arise from the instantaneous power modulation. The nonlinear phase angle variation of a signal at ω_1 due to its own power and power of signal at another frequency ω_2 is given by Eq.(2)

$$\phi_{NL} = n_2k_0L(|E_1|^2 + 2|E_2|^2). \tag{2}$$

In dispersion-managed systems utilizing Standard Single Mode Fiber (SSMF) and Dispersion Compensating Fiber (DCF), the positive dispersion of SSMF can be compensated by large negative dispersion of DCF [6]. Nonlinear phase noise is induced by the interaction of fiber Kerr effect and optical amplifier noises when optical amplifiers are used periodically to compensate for fiber loss [7]. A phase modulated signal can overcome SPM and XPM effects by taking advantage of constant transmission power. Recently, Wavelength-Division-Multiplexed (WDM) DPSK systems has been gaining interest in using for long-haul transmission systems [8].

DPSK is facing a problem of nonlinear phase noise introduced by amplitude variation which is caused due to amplified spontaneous emission (ASE) of amplifiers [9]. At lower bit rates higher level modulation techniques can be used to improve the spectral efficiency of DWDM system. In order to improve the tolerance of pulse spreading caused by chromatic dispersion or polarization mode dispersion, non-binary modulation technique employs longer symbol interval [10].

2. SYSTEM DESIGN SETUP

A 16 DPSK modulator is designed using a DPSK encoder, M-ary pulse generator and a quadrature modulator on simulation tool optisystem by optiwave. A sequence of bits is generated at 1Gbps, the symbols are generated using DPSK encoder using 4bits per symbol. When transmitting information, we can vary the phase of a signal according to the source symbols. The phase values are taken from the set of angles given by Eq.(3),

$$ø_{ki} = ø_{k-1} + 2\pi/M\,(i-1) + ø,\ i = 1, 2, \ldots.., M. \tag{3}$$

Here $ø_{ki}$ is the phase value for the current symbol, and $ø_{k-1}$ is phase value for the previous symbol. M is the number of possible sequence of binary digits, calculated according to Eq.(4),

$$M = 2^h. \tag{4}$$

where, h is number of bits per symbol and $ø$ is the phase offset. The in-phase and the quadrature channel will have amplitudes according to Eq.(5) and Eq.(6), respectively,

$$I_{ki} = \cos(ø_{ki}) \tag{5}$$

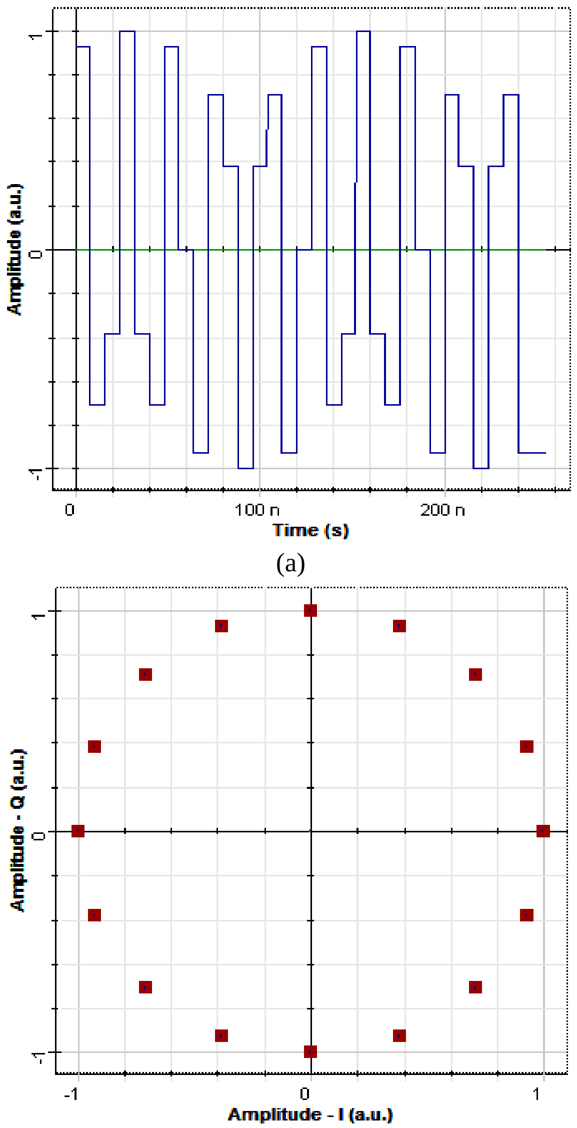
$$Q_{ki} = \sin(ø_{ki}). \tag{6}$$

Assuming $ø = 0$, $h = 4$ for 16 bit DPSK, so $M = 16$. There are 8 quantized values of I and Q for 16 symbols generated given by K. The Table.1 present the quantized value of I and Q.

A quadrature modulator is used for electrical modulation at 550MHz, which modulates a sine and cosine signals using I and Q components, and this modulation is mathematically shown in Eq.(7),

$$V_{out}(t) = G[I(t)\cos(2\pi f_ct + ø_c) - Q(t)\sin(2\pi f_ct + ø_c)] + b. \tag{7}$$

where, G is the parameter Gain, b is the Bias, f_c is the carrier frequency and $ø_c$ is the phase of the carrier.



(a)

(b)

Fig.1. (a) I component of 16 DPSK generated (b) 16 DPSK constellation diagram

Table.1. Quantized value of I and Q components for 16 DPSK

K	Bit Sequence	I	Q
0	0000	1	0
1	0001	0.923	0.382
2	0010	0.707	0.707
3	0011	0.382	0.923
4	0100	0	1
5	0101	-0.3826	-0.923
6	0110	-0.707	-0.707
7	0111	-0.923	-0.3826
8	1000	-1	0
9	1001	-0.923	-0.3826
10	1010	-0.707	-0.707
11	1011	-0.3826	-0.923
12	1100	0	1
13	1101	0.3826	0.923
14	1110	0.707	0.707
15	1111	0.923	0.3826

The Fig.1 shows the '*I*' component of symbol levels generated after encoding and the 16 DPSK constellation diagram. The Fig.2 shows the subsystem of quadrature modulator diagram designed on the optisystem by optiwave.

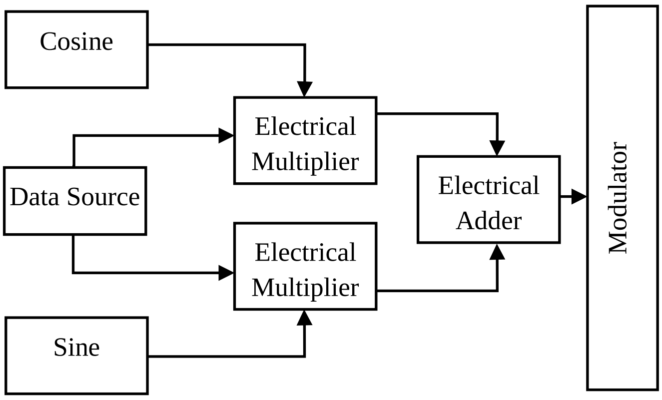


Fig.2. Quadrature modulator subsystem

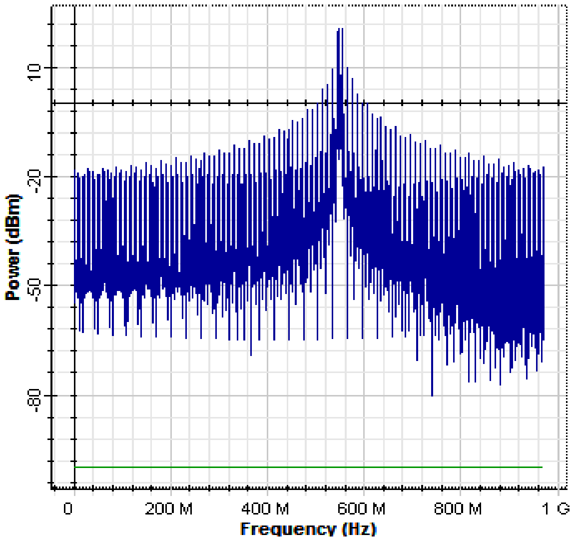


Fig.3. Quadrature modulated signal at 550MHz

The optical signal is generated using CW laser at 4dBm. Simulation modeling has shown that for the 50-500km optical line 3-6dBm input signal level is optimum [11]. The Fig.3 shows the quadrature modulated signal. This optical signal is modulated by quadrature modulated signal using Mach-Zehnder Modulator (MZM), which is an intensity modulator working on interferometric principle. The refractive indices in the waveguide branches can be varied by an externally applied voltage using electro-optic effect. The variation of the output signal corresponding to the input signal is governed by Eq.(8),

$$E_{out}(t) = E_{in}(t)\cos(\Delta\theta t)\exp(j\Delta\phi(t)) \quad (8)$$

where,

$\Delta\theta$ is the phase difference between the two branches

$\Delta\phi$ is the signal phase change that is defined as,

$$\Delta\theta(t) = \frac{\pi}{2}(0.5 - ER(m(t) - 0.5)) \quad (9)$$

$$\Delta\phi(t) = SC \cdot \Delta\theta(t) \cdot {}^{(1+SF)}\!\big/_{(1-SF)} \quad (10)$$

where, SC can be -1 or 1 depending upon whether the negative signal chirp is true or false respectively. The extract is the extinction ratio, SF is the symmetry factor, and $m(t)$ is the electrical input signal. The electrical input signal is normalized between 0 and 1. The spectrum of modulated signal at 1550 nm after MZM is shown in Fig.4. All external modulators have some insertion loss, a power penalty occurs whenever an external modulator is used. It can be reduced to below 1dB for monolithically integrated modulators [12].

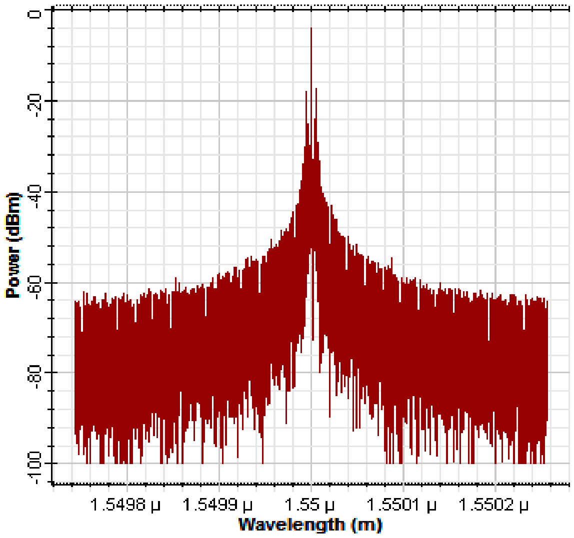


Fig.4. The spectrum of 16 DPSK modulated signal after optical modulation at 1550 nm

The same procedure is followed for 32 channels supporting the 32 signals in the wavelength range of 1534nm to 1558.8nm with channel spacing of 0.8nm and the spectrum of multiplexed signal is shown in Fig.5. The signal propagates through a 100km SMF and is amplified using EDFA which works on the principle of stimulated emission, has properties of gain flattening in C-band. The signal is pumped at 980nm having a gain of 22dB and Noise Figure of 6dB. EDFA is used because of its low noise performance and high output power capabilities [9].

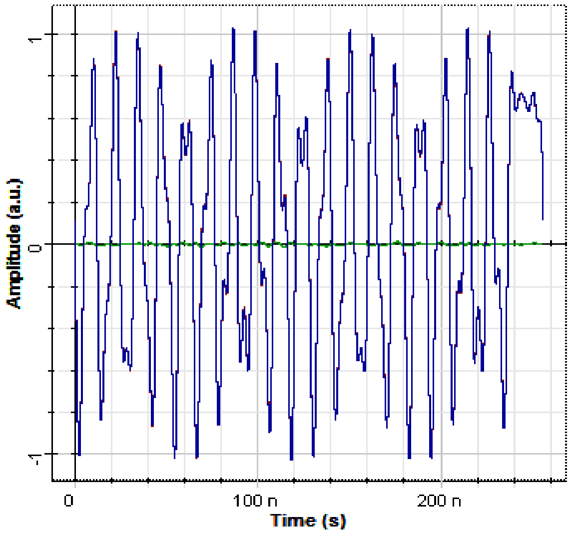
It is followed by DCF and EDFA as a preamplifier, which improves the receiver sensitivity. The main source of noise in DWDM system is amplified spontaneous emission (ASE) from amplifiers. In the low power region, the ASE noise limits the system performance [12].

The optical signal after de-multiplexing is converted to the electrical domain using PIN photo-detector. The responsivity and dark current of PIN diode are taken as 1A/W & 10nA respectively and a 4th order filter is used with depth 100dB in the receiver unit as reported in [13]. A quadrature demodulator at 550MHz is used for electrical demodulation, which produces I and Q as per Eq.(11) and Eq.(12) respectively.

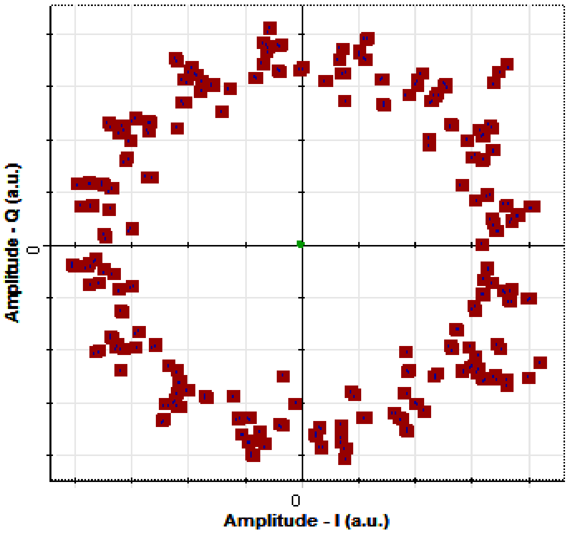
$$I(t) = Gv_{in}(t)\cos(2\pi f_c t + \phi_c) \times h_{low}(t) \quad (11)$$

$$Q(t) = -Gv_{in}(t)\sin(2\pi f_c t + \phi_c) \times h_{low}(t) \quad (12)$$

where, $h_{low}(t)$ is the time response of low pass filter. The received signal visualization is shown in Fig.6(a) and corresponding constellation diagram in Fig.6(b).



(a)



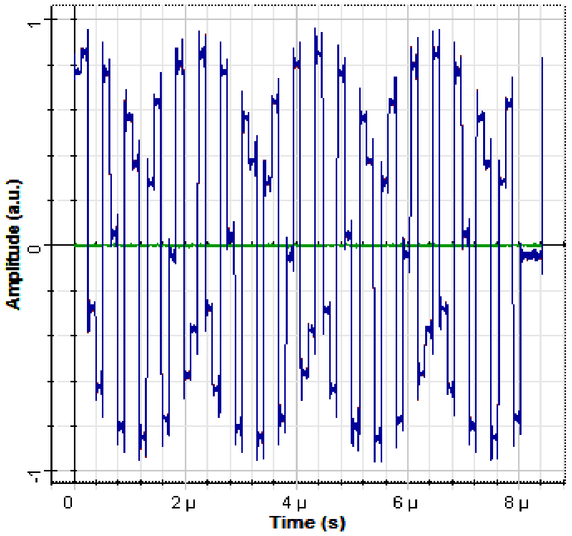
(b)

Fig.6. (a) Oscilloscope visualization after quadrature demodulation at 1Gbps (b) Constellation diagram

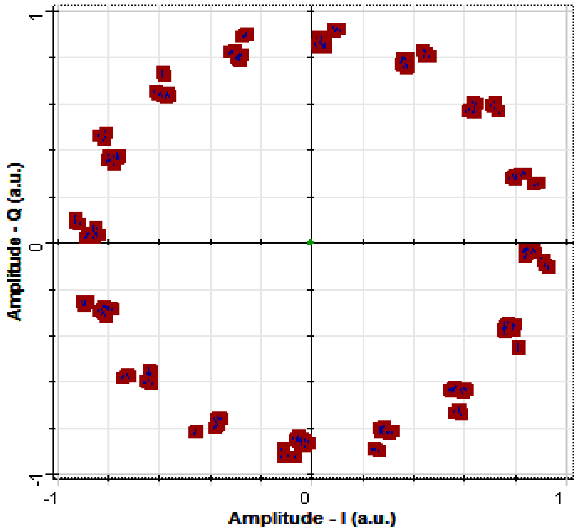
I and Q are detected using M-Array threshold detector and produce quantized level values corresponding to each symbol given in Table.1. The input threshold ranges and output amplitudes for 16 DPSK M-Array threshold detectors are shown in Table.2.

Table.2. 16 DPSK Threshold Detector Values

Parameter	**Values**
Threshold amplitudes	-0.95, -0.85, -0.5, -0.2, 0.2, 0.5, 0.85, 0.95
Output amplitudes	-1, -0.923, -0.707, -0.3826, 0, 0.3826, 0.707, 0.923, 1



(a)



(b)

Fig.7. (a) Oscilloscope visualization of quadrature demodulation at 30.375Mbps (b) Constellation diagram of 16 bit DPSK Signal

If input range of signal level is between -0.85 and -0.95, set the output amplitude level at -0.923. A DPSK decoder is designed with 4 bits per symbol and its working is in reverse order of DPSK encoder i.e. from amplitudes of *I* and *Q* the symbols of bits are generated. It has been observe from Fig.6(a) and Fig.6(b) that the symbols get distorted at 1Gbps, and the signal amplitude variations decrease due to which error in detection increases.

At lower bit rates of 30.375Mbps, the received signal diagram and corresponding constellation diagram is shown in Fig.7(a) and Fig.7(b), respectively. The difference between two cases is now quite clear. As the bit rate increases, the rate of error increases. It is also confirmed by BER value, which is $8.96e^{-14}$ at 1Gbps and $9.03e^{-25}$ for 30.375Mbps. The BER value considered to be suitable for transmission is 10^{-9}.

3. CONCLUSION

A design of DWDM system using 16 DPSK modulation technique and detected using direct detection technique is proposed. The system is checked for 32 channels with 0.8nm channel spacing and 4dBm input power. It is observed that symbol representation and oscilloscope visualization of the signal is same at transmitter and receiver, but with some distortion due to fiber linear and non-linear effects. EDFA is used for amplification and to improve receiver sensitivity. When tested, the received error rate increases with increasing bit rate. The BER value at 1Gbps is within an acceptable limit. In future, the system can be checked for varying channel count, channel spacing, amplifier combinations, higher bit rates, other wavelength range etc.

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