UDC 654:679.76

Rozorynov G.N., Sc. D.; **Aymen Fendri Mohamed, Skryl'ov V. Yu.,** applicants
(State University of Telecommunications, Kiev. +380 (63) 248 95 27. grozoryn@gmail.com)

DEVELOPMENT OF MODULATION FORMATS IN OPTICAL FIBER COMMUNICATION CHANNEL

Розорінов Г. М., Аймен Фендри Мохамед, Скрильов В. Ю. Розвиток форматів модуляції у волоконно-оптичних каналах зв'язку. Аналізуються оптичні формати модуляції, що дозволяють збільшити швидкість передачі інформації в телекомунікаційних DWDM системах, без істотних спотворень сигналу із-за нелінійностей і різних видів дисперсії. Використання амплітудної модуляції не дозволяє збільшувати спектральну ефективність, яка є єдиним шляхом збільшення швидкості передачі в майбутніх телекомунікаційних мережах. Перспективно використовувати формат PSBT і багаторівневі формати в DWDM системах. Вони дозволяють збільшувати спектральну ефективність і стійкість до різних видів дисперсії в оптоволокні.

Ключові слова: амплітудна модуляція, щільне хвильове мультиплексування, цифрова волоконно-оптична передача, модуляція зсувом фази, формат модуляції

Розоринов Г. Н., Аймен Фендри Мохамед, Скрылев В. Ю. Развитие форматов модуляции в волоконно-оптических каналах связи. Анализируются оптические форматы модуляции, позволяющие увеличить скорость передачи информации в телекоммуникационных DWDM системах, без существенных искажений сигнала из-за нелинейностей и различных видов дисперсии. Использование амплитудной модуляции не позволяет увеличивать спектральную эффективность, которая является единственным путем увеличения скорости передачи в будущих телекоммуникационых сетях. Перспективно использовать формат PSBT и многоуровневые форматы в DWDM системах. Они позволяют увеличивать спектральную эффективность и устойчивость к различным видам дисперсии в оптоволокне.

Ключевые слова: амплитудная модуляция, плотное волновое мультиплексирование, цифровая волоконно-оптическая передача, модуляция сдвигом фазы, формат модуляции

Rozorynov G. N., Aymen Fendri Mohamed, Skryl'ov V. Yu. Development of modulation formats in optical fiber communication channel. We analyze optical modulation formats allowing to increase information bit rate in telecommunication systems based on DWDM without essential signal distortion because of non-linearity and different types of dispersion. Usage of amplitude modulation prevents increase of spectral efficiency, which will be the only way for future telecommunication networks to increase total rate of transmission. It is perspective to use PSBT format and multilevel formats in DWDM networks. They allow to increase spectral efficiency and stability to different types of dispersion in optical fiber.

Keywords: amplitude shift keying, dense wavelength division multiplexing, digital fiber transmission, phase shift keying, modulation format

I. Introduction. There are two ways to make telecommunication systems more effective. They are based on dense wavelength division multiplexing (DWDM): reduction of distance δ between channels and increase of channel rate R [1, 2].

The second way is more cost-effective because the increase R leads to reduction of cost of information unit. At current rates the increase of channel rate in four times reduces cost of information unit in 2,5 times, so as while fixed value of γ increases distance between channels, reduces requirements to stability of emission wavelength of lasers and spectral characteristics of multiplexers.

However, along with mentioned advantages, increase of information bit rate is followed by growth of distortions of digital signals in communication line. Particularly, distortions caused by chromatic dispersion grow in proportion to square of channel bit rate R^2, distortion because of impact of polarization mode dispersion (PMD) at first approximation are proportional to the first stage of channel bit rate R. Noise power is also proportional to bit rate. Thus with increase of bit rate it is necessary to move on to transmission formats that are less sensitive to dispersion and non-linear distortions [3...6].

The purpose of the work is the research of modulation formats allowing to increase information bit rate without essential distortions of signal because of non-linearity and different types of dispersions.

II. Main part. Spectral efficiency γ is a numeric measure of efficiency for usage of operating spectrum of DWDM telecommunication networks for data transmission, determined as ratio of channel bit rate R to distance between DWDM channels δ (Fig.1):

$$\gamma = \frac{R}{\delta} . \quad \textbf{(1)}$$

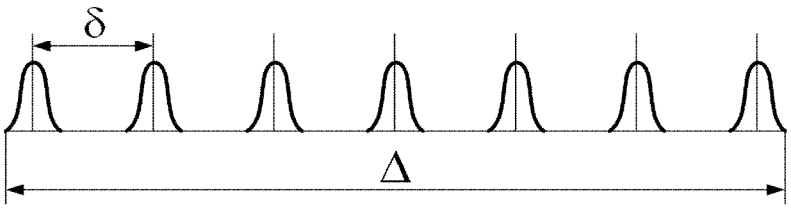

Fig. 1. Schematic layout of optic channels in operating frequency range

At fixed width of operating spectral range Δ used for signal transmission, maximal total rate R_Σ, which equals product of channel rate R and channel number n, is determined as:

$$R_\Sigma = \gamma\Delta . \quad \textbf{(2)}$$

Therefore, it is necessary to raise R_Σ spectral efficiency for increase. To reach that it is possible to either reduce distance between channels δ or raise channel rate R. Also it is possible to reach the increase R_Σ with the help of enlargement of spectral range Δ, in other words by addition new channels on new frequencies, but this is not always possible, because spectral line of DWDM networks can be limited by the type of used amplifiers or by any other reason.

The most often used modulation formats can be divided by type of electromagnetic wave that is used for modulation. It is formats in which for the information mapping amplitude modulation is used (ASK – Amplitude Shift Keying) and phase modulation is used (PSK – Phase Shift Keying). Herein it is necessary to remember, that range of formats using amplitude modulation include some phase modulation that doesn't carry any information.

Meanwhile, multilevel formats are already used in radiotechnics. Information in such formats is displayed both as amplitude (intensity), and as phase of electromagnetic wave. Modulation, used in formats of such type is sometimes called quadrature modulation. Such formats are often denoted as ASK-PSK**.**

The most popular amplitude formats are binary formats, which have two informative values of power matching on/off state of transmitter. So these formats are often denoted as OOK (On/Off Keying). In optic networks all phase modulation formats use differential (phase shift keying) modulation, so as in optical range it is unpractical to identify absolute value for phase of light carrier of received signal. So information is embedded in relative phase shift of carriers of two consecutive pulses. This phase shift has to be transformed in amplitude modulation with the use of optic time delay lines and interference. The appropriate denotation for these formats is – DPSK (Differential Phase Shift Keying).

From theoretical point of view fiber-optic systems can be considered as classical band systems, which are applicable to well-developed for classical radiocommunication modulation theory. The difference between optic and radio-microwave systems lies in the range of carrying frequencies (~200 THz against few MHz or GHz) and in characteristics of components able to generate or modulate signals in these ranges, and also in characteristics of diffusion medium - optic fiber in case of optic networks.

On Fig. 2,а we can see the formation scheme for signal with the help of phase modulator, and on Fig. 2,б – the formation scheme using Mach-Zehnder modulator with equal intensity levels of “1” and “0” symbols.

If information lies in phase change from symbol to symbol (Table 1), then signal that operates phase modulator has to be previously transformed.

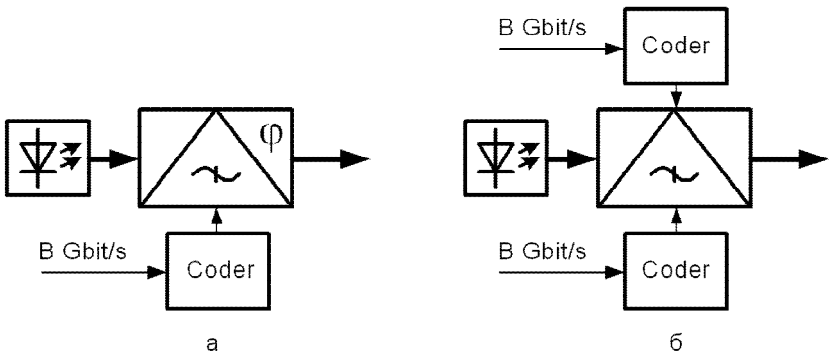

Fig. 2. Formation scheme of binary signal with the help of phase modulator (a) and with the help of Mach-Zehnder modulator (б)

Matching of phase values of two sequent impulses with transmission symbol

Table 1

φ_1	φ_2	Symbol
0	0	0
0	π	1
π	0	1
π	π	0

For example, in Table 2 it is shown that $c(0)=1$ and coding is made by second method. It means that current bit of code $c(k)$ equals 1, if message bit $m(k)$ matches with previous bit of code $c(k-1)$, otherwise $c(k)=0$.

Formation of differential DPSK signal

Table 2

Discretization parameter, *k*	0	1	2	3	4	5	6	7	8
Information signal, *m(k)*		1	1	1	0	0	1	0	0
Differential signal, *c(k)*	1	1	1	1	0	1	0	0	1
Phase shift, $\theta(k)$	π	π	π	π	0	π	0	0	π

Then the coded sequence $c(k)$ transforms into phase shift sequence $\theta(k)$, where informative "one" is represented by phase shift on π, and "zero" is zero phase shift. In detection process received signal is compared with reference signal, which represents delayed on one bit received signal. This operation can be made, for example, by passive all-fiber Mach-Zehnder interferometer, where delay time in one shoulder is bigger than delay time in other shoulder on one bit period. Therefore, during each bit interval the phase of received symbol is being compared to the phase of previous symbol. If they match, then the informative "1" is being detected, but if phase difference is equal π, then logical "0" (Table 1).

Usage of two parallel operating photodiodes in the receiver allows to reduce probability of mistake occurrence and increase receive sensitivity on about 3 dB. On 40 Gbit/s bit rate it is possible to transmit DPSK signals on long distances with less losses, than signals of other formats. However, this requires expensive terminals.

There is one more way to increase bit rate in DWDM systems. It is usage of such named DuoBinary Transmission (DBT). This is transmission of signals with three levels: +1, 0, -1. One of the variety of such transmission is Phase Shaped Binary Transmission (PSBT), it is highly

recommended for DWDM systems. PSBT signals have narrower spectrum in comparison with RZ and NRZ signals. These signals are formed with the help of coding schemes with levels +1, 0, -1, which have different phase shift (Fig. 3).

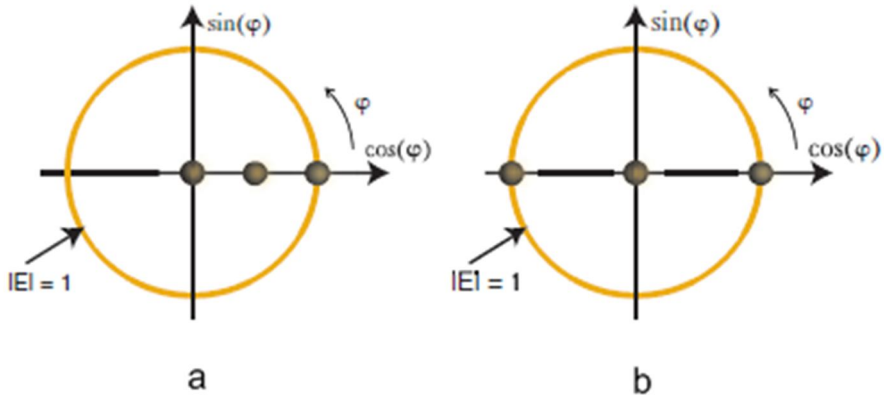

Fig. 3. Constellation diagram of three symbol signals: a – DBT, b – PSBT;
E, φ – magnitude and phase of electric field strength accordingly

System with PSBT is around 3 times more stable to chromatic dispersion than NRZ or DBT formats. Phase shift in PSBT also helps to reduce negative effect of inter-channel non-linear effects on 40 Gbit/s rate. Usage of such format increases sensibility of photoreceiver and also doesn't reduce the difference of levels of detected signals while usage of ordinary binary photoreceivers [7].

Usage of ASK formats with permanent growth of transmission data volume prevents from further increase of carrying capacity of transmission line, because modulation frequency of electric signal is limited by value 40 Gbit/s. Moreover, high-rate binary modulation is characterized by low spectral efficiency and low dispersion tolerance.

To some extent these problems can be solved by multilevel coding of signals, for example, four-level in formats ASK and PSK (or, in particular, QPSK – Quaternary Phase Shift Keying). However, realization of four-level scheme is relatively complex.

Increasing number of signal levels leads to worse matching by receiver because of bad expansion of eye diagram. For example, the eight-symbol mixed amplitude-phase format ASK-QPSK was considered in the work [8]. This format is a mixture of two-level amplitude format ASK and four-level phase format QPSK. On Fig.4 we can see 8 symbols of signal (A, B, C, D, a, b, c, d) of format ASK-QPSK.

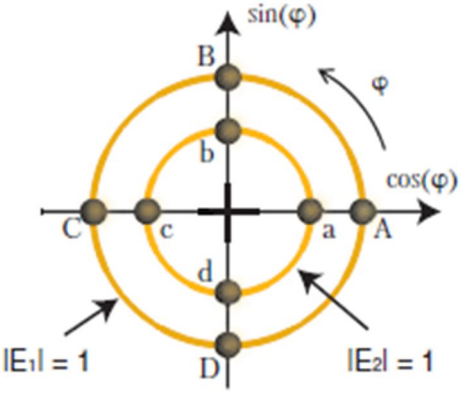

Fig. 4. Constellation diagram of eight symbols ASK-QPSK signal;
E_1, E_2 – magnitudes of electric field strength, φ – phase of electric field strength

One symbol represents 3 bits of information, so bit rate appears to be 3 times more than symbol rate. Signal has 2 levels of amplitude E_1, E_2 and 4 values of phase $0, \pi/2, \pi, 3\pi/2$. The receiver technology is shown on Fig. 5.

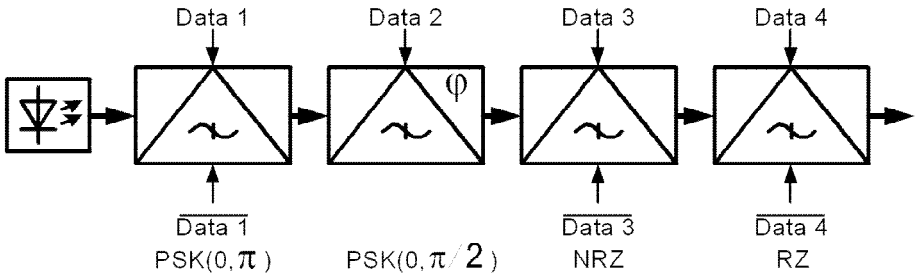

Fig. 5. ASK-QPSK former

Bicyclic Mach-Zehnder modulator that doesn't create chirp modulates phase of continuous light wave, that gets out of laser diode forcing it to take a value of 0 or π.

Optic phase modulator adds phase shift of 0 or $\pi/2$. Thus four phase values appear. The next stage is NRZ or RZ modulation. Bicyclic Mach-Zehnder modulator is required for NRZ modulation, when the second modulator transforms NRZ signal into RZ signal. Power decreases to zero value on bounds of RZ-QPSK bit, so this signal is more stable to chromatic dispersion than NRZ-QPSK signal (proved by experimental results).

III. Conclusion. Despite growth of capacity of transmitted data in fiber, ASK remains the major modulation format, because of its simple realization and low cost of transmit/receive equipment. But usage of amplitude modulation prevents increase of spectral efficiency γ, and increase γ will be the only way for future telecommunication networks to increase total rate of transmission.

It is perspective to use PSBT format and multilevel formats in DWDM networks. They allow to increase spectral efficiency and stability to different types of dispersion in optical fiber.

References

1. Фриман Р. Волоконно-оптические системы связи / Р. Фриман ; пер. с англ. под ред. Н. Н. Слепова. – Москва : Техносфера, 2003. – 448 с.

2. Розорінов Г. М. Високошвидкісні волоконно-оптичні лінії зв'язку / Г. М. Розорінов, Д. О. Соловйов. – [2-е вид., перероб. і допов.]. – Київ : Кафедра, 2012. – 344 с.

3. Conradi Jan. Bandwidth-Efficient Modulation Formats for Digital Fiber Transmission Systems. Optical Fiber Telecommunications, 2002, vol. IV B, p. 862.

4. Winzer P.J. and Essiambre R.J. Advanced optical modulation formats. ECOC-IOOC 2003 Proceedings, vol. 4, pp. 1002–1003, Rimini, 2003.

5. Величко М. А. Новые форматы модуляции в оптических системах связи / М. А. Величко, О. Е. Наний, А. А. Сусьян // Lightwave Russian Edition. – 2005. – № 4. – С. 21-30.

6. Idler W. et al. System Performance and Tolerances of 43Gb/s ASK and DPSK modulation formats // ECOC-IOOC 2003 Proceedings, vol. 4, pp. 1006-1007, Rimini, 2003.

7. Величко М.А. Двойной фазомодулированный бинарный формат / М. А. Величко, А. А. Сусьян // Lightwave Russian Edition. – 2004. – № 4. – С. 26-29.

8. Hayase S. et al. Proposal of 8-State per Symbol (Binary ASK and QPSK) 30-Gbit/s Optical Modulation / Demodulation Scheme // ECOC-IOOC 2003 Proceedings, vol. 4, pp. 1008–1009, Rimini, 2003.

Дата надходження в редакцію: 04.02.2014 р. Рецензент: д.т.н., проф. О. О. Манько