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Features of construction of fiber-optic communication lines with orthogonal frequency-division multiplexing

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Abstract. The necessity of studying the features of building fiber-optic communication lines with multiplexing using orthogonal frequency division of channels is substantiated. The main properties of such systems are considered, as well as ways to improve operational characteristics to improve the quality of communication and economic benefits are studied. The necessity of developing such systems for future use in optical transport networks, cloud and high-performance computing systems is substantiated.

Keywords: large volumes of information, fiber-optic communication line, multiplexing, non-linear distortions, system bandwidth

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Особенности построения волоконно-оптических линий связи с ортогональным частотным разделением каналов

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Аннотация. Обоснована необходимость исследования особенностей построения волоконно-оптических линий связи с мультиплексированием с использованием ортогонального частотного разделения каналов. Рассмотрены основные свойства таких систем. Отмечены способы улучшения их эксплуатационных характеристик для повышения качества связи и финансовой рентабельности. Обоснована необходимость разработки таких систем для будущего использования в оптических транспортных сетях, облачных и высокопроизводительных вычислительных системах.

Ключевые слова: большие объемы информации, волоконно-оптическая линия связи, мультиплексирование, нелинейные искажения, пропускная способность системы

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Introduction

The development of scientific and technological progress required the transfer of large amounts of information to solve various tasks [1–8]. To implement communication systems, channels have been developed using various principles for transmitting information [4, 9–15]. The most widely used fiber-optic communication lines (FOCL), since them use allows you to transfer large amounts of information at high rate [16–22]. The communication channel with FOCL is resistant to various external influences, which allows it to be used in various systems [20–29]. The constant increase in requirements for the speed of information transfer and an increase in its volume has led to the search for new solutions.

Recently, there has been an increased interest in the transmission of signals with orthogonal frequency multiplexing along the optical path, since this method has a well-developed hardware and software implementation of signal transmission and high spectral efficiency [30–33]. The features of OFDM signal generation lead to large signal outliers and, as a consequence, to the output of signal amplitudes from the linear section of the transmission characteristics of optoelectronic components of the optical path and to the transition of these devices to a nonlinear mode of operation. Consequently, there are nonlinear distortions that fall into the frequency band of the channels of the OFDM signal subcarriers and worsen the signal-to-noise ratio.

With the development of access networks to increase bandwidth, the use of frequency multiplexing technology of orthogonal subcarrier channels may become an alternative to traditional passive optical networks. In such networks, it is economically advantageous to use direct modulation of the laser diode radiation intensity on the transmitting side and direct photodetector detection of the signal on the receiving side. In the considered fiber-optic transmission system, the formation of an optical signal occurs in a technically simple way – the OFDM signal is created in the electrical range and then "transmitted" to the optical range with the modulation power according to the intensity of the optical carrier.

Features of optical systems with frequency division of channels

One of the unique and most attractive properties of OFDMA networks is its asynchronous nature. Unlike TDM networks, it does not require time coordination between receiver and transmitter. Asynchronous FDMA allows subscribers to send their signals at any time without prior time coordination. The amount of noise interference will randomly change during the bit length of time in accordance with the relative positions of the cross correlations with the required autocorrelation peak, as shown in Figure 1.

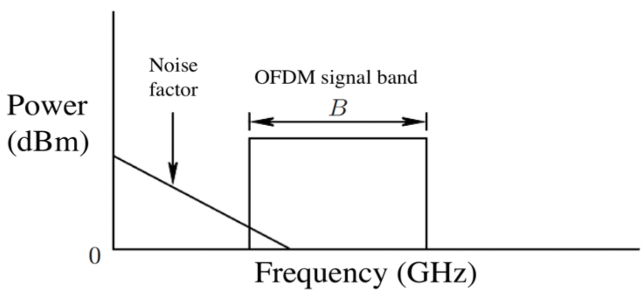

Fig. 1. The spectrum of signal at the output of the photodetection

To ensure spectral efficiency in the optical range, the methods of single-band modulation of the optical carrier and the technology of dense spectral multiplexing are used. However, with the single-band implementation of the OFDM signal and its transmission over an optical fiber, not only the distortion of the subcarrier levels occurs due to chromatic dispersion, but also during photodetection, there are beat noises between subcarriers that are located in the low-frequency region in the photocurrent spectrum. These noises do not allow the use of the entire bandwidth of the fiber-optic linear path.

Experimental implementation of the OFDM network

Figure 2 shows the relative emission spectrum of a laser diode when modulated by an OFDM signal in the frequency band from 4.096 GHz to 8.192 GHz (the frequency range is 64 MHz, the number of subcarriers is 128). As can be seen from Fig. 2, the OFDM signal is distorted due to interference falling into the bandwidth of subcarrier channels. The source of such interference is clipped pulses that occur when the level of the OFDM signal exceeds the threshold value of the modulation current. It is possible to avoid these interferences and improve the energy budget of access networks by using external modulation of the optical carrier with an OFDM signal. An even greater increase in spectral efficiency can be achieved by using single-band external modulators, for example, based on the Mach-Zender.

The influence of quadrature nonlinearity with respect to the field during the conversion of an optical signal into an electric one was also studied. By analogy with Fig. 2, when the OFDM photo signal is detected, noises also appear in the low frequency region in the photocurrent spectrum, these noises are caused by beats between subcarriers.

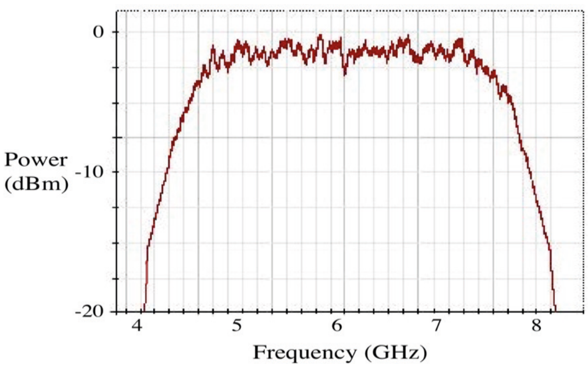

Fig. 2. The spectrum of signal at the output of the laser diode

Figure 3, *a* shows the radio frequency spectrum of the signal on the transmitter side, where the radio frequency power is approximately −12 dBm. Figure 3, *b* shows the radio frequency spectrum on the receiver side after 50 km of SMF fiber. The radio frequency power decreases to −50 dBm, this decrease in power is associated with an increase in the length of the fiber, which increases attenuation.

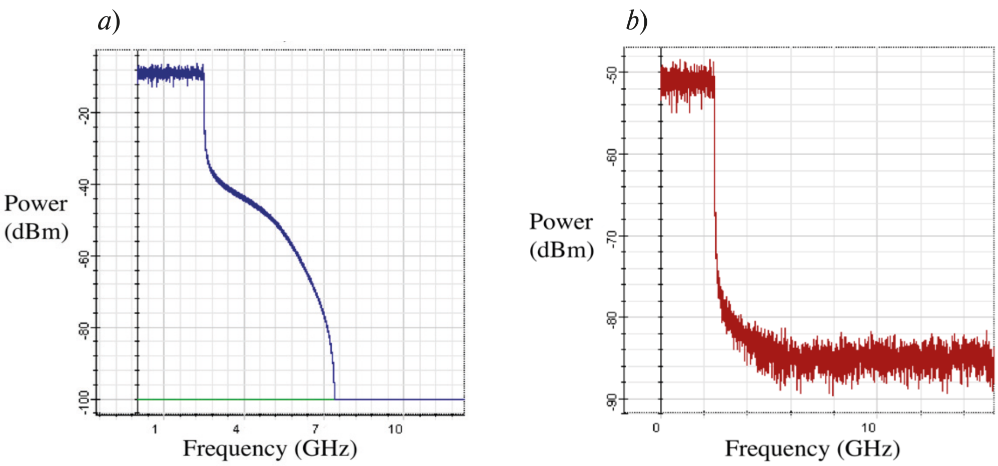

Fig. 3. Radio frequency spectrum of the signal on the transmitter side (*a*); radio frequency spectrum of the signal on the receiver side (*b*)

Figure 4, *a* shows an example of optical carrier phase fluctuations during one sample when transmitting N = 128 subcarrier channels of the QPSK format with a frequency interval between them of 64 MHz. It can be seen that FCM leads to the appearance of high-frequency (relative to channel frequencies) phase fluctuations. In Figure 4, *b* shows the phase distribution density as a histogram.

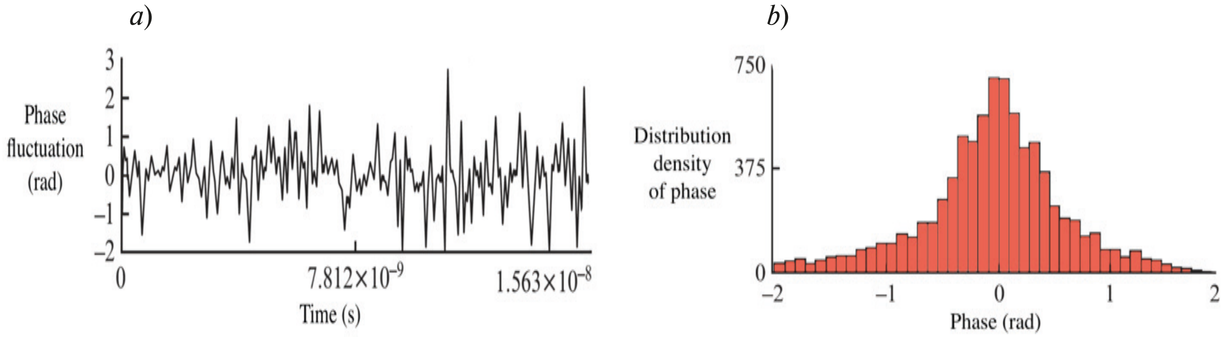

Fig. 4. Phase fluctuation due to FCM during one sample (*a*); the phase distribution density when transmitting N = 128 subcarrier channels of the QPSK format with a frequency interval between them of 64 MHz (*b*)

The analysis shows that the average value of the fluctuating phase tends to zero, and its standard deviation – to 0.707, which indicates the independence of the standard value of XPM from the number of channels at N > 32.

Conclusion

The main factor limiting the frequency band in access networks is the use of a direct photodetector according to technical and economic indicators. Note that an increase in the frequency band of the OFDM signal is possible due to the elimination of interference in the low-frequency spectrum of the photocurrent using circuit solutions in the receiving part of the equipment. In addition, it is possible to use methods of correcting coding in subcarrier channels, allowing to overcome strong interference in the channels. However, these and other technical solutions can increase the cost of equipment, so they require justification of economic feasibility when implemented in access networks.

The simulation results show that high-frequency channels with subcarriers are most susceptible to distortion due to chromatic dispersion. These distortions manifest themselves in the form of a decrease in the signal level in these channels. It is shown that the limiting factors of the bandwidth are the total frequency band occupied by the OFDM signal and the value of the specific chromatic dispersion coefficient of the optical fiber at the operating wavelength.

The simulation results showed that for access networks where a standard optical fiber with a length of 50 km is used in the optical infrastructure, the total frequency band of the OFDM signal at a wavelength of 1.55 microns should not exceed 8 GHz.

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