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Features of the implementation of optical superchannels in flexible optical networks

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Abstract. This article examines the current problems of using fiber-optic communication systems for efficient long-distance data transmission. Special attention is paid to the concept of optical super channels, which combine several optical channels to increase transmission capacity and range. The article discusses the theoretical and practical aspects of the implementation of optical superchannels, including methods for generating multichannel signals, the use of optical precompensation of nonlinear effects and dispersion, as well as technologies for multiplexing orthogonal subcarrier channels. The prospects for the development of flexible optical networks to increase productivity and optimize the use of resources in modern telecommunications networks are considered.

Keywords: flexible optical networks, fiber-optic transmission system, dense wavelength division multiplexing, orthogonal frequency division multiplexing, transceiver.

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Особенности реализации оптических суперканалов в гибких оптических сетях

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Аннотация. В статье рассматриваются проблемы использования волоконно-оптических систем связи для эффективной передачи данных на большие расстояния. Особое внимание уделяется концепции оптических суперканалов, которые объединяют несколько оптических каналов для увеличения пропускной способности и дальности передачи. В статье обсуждаются теоретические и практические аспекты реализации оптических суперканалов, включая методы формирования многоканальных сигналов, использование оптической предкомпенсации нелинейных эффектов и дисперсии, а также технологии мультиплексирования ортогональных поднесущих каналов. Рассматриваются перспективы развития гибких оптических сетей для повышения производительности и оптимизации использования ресурсов в современных телекоммуникационных сетях.

Ключевые слова: гибкие оптические сети, волоконно-оптическая система передачи, плотное мультиплексирование с разделением длин волн, ортогональное мультиплексирование с разделением частот, трансивер

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Introduction

Superchannels represent an optimal solution for extending transmission reach and increasing channel speed in optical communication networks [1–3]. A super channel is essentially a composite channel that combines multiple carrier frequencies, often referred to as optical subcarriers. These subcarriers are closely spaced within the optical spectrum. By integrating super channels into optical networks, it becomes feasible to establish flexible and resilient optical infrastructures [4–5]. This capability allows for dynamic allocation and reallocation of bandwidth resources based on traffic demands and network conditions [6].

The method of implementing a superchannel in an optical line

The process of forming optical subcarrier waves within a superchannel typically occurs within a nonlinear or linear optical medium [5, 6]. Once these subcarrier waves are generated, they are separated using a splitter and subsequently modulated with information signals. These modulated subcarrier frequencies are then combined using an optical router based on a arrayed waveguide grating (Fig. 1).

The resulting superchannels are then combined by an optical multiplexer to form a coherent optical signal group with a protective band separating individual superchannels. For the subcarriers to maintain complete orthogonality, it's essential that the bandwidth of the data modulators matches the total bandwidth encompassing all subcarriers.

An important condition for minimizing crosstalk between subcarriers is the precise time alignment of signals entering each modulator. This alignment ensures that the frequency range of the subcarriers corresponds correctly to the symbol rate within each data channel, effectively reducing interference and optimizing signal integrity across the superchannel.

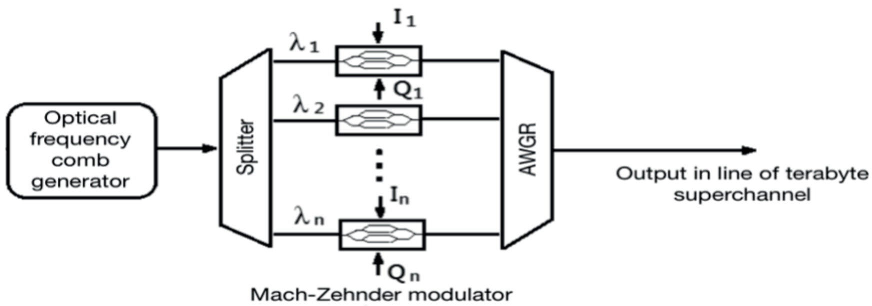

Fig. 1. Block diagram of an optical OFDM transmitter with four subcarriers

The transmitter design consists of three layers of plates. In the first layer, the function of a basic optical pulse divider is performed. The second layer functions as an inverse Fourier transform, introducing a series of phase shifts where each shift depends on a specific input waveguide and its corresponding output waveguide. Consequently, each waveguide receives a phase-weighted combination of signals from the four modulators' outputs. The third layer combines the signals from the second layer with different time delays. This process results in each input pulse being transformed into a sequence of eight output pulses. Each of these output pulses represents a phase-weighted combination of the outputs from all the modulators.

The signal entering the receiver input is partitioned into multiple equal segments, each segment experiencing a specific time delay. The difference in length ΔL between two waveguides roughly corresponds to the time interval ΔT between successive counts, as described by formula 1. Furthermore, the divider matrix and the waveguide array function together to convert the serial signal into a parallel one (Fig. 2).

$$\Delta L \approx \Delta T \cdot \frac{c}{n_g}, \tag{1}$$

where c is the speed of light, n_g is the lattice index of the waveguide.

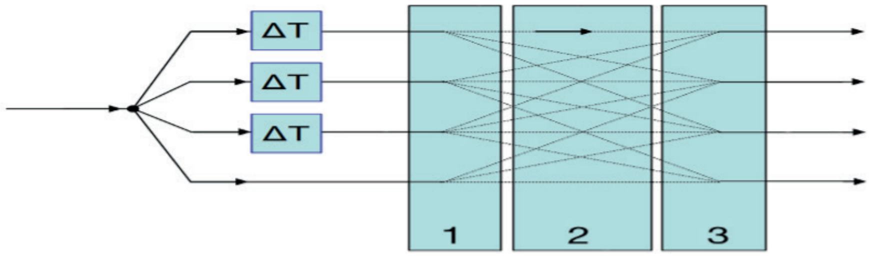

Fig. 2. Block diagram of an AWGR receiver with four subcarriers
(1. Matrix of splitters, 2. Matrix of phase delays, 3. Matrix of splitters)

The second layer, represented by a matrix of phase delays, is defined by equation 3, which expresses transmission coefficients between the outputs of waveguides with time delay m and the lattice outputs labeled n (carrying the subcarrier signal k). In equation 2, the phase shift matrix incorporates exponential terms, while the divider matrix executes summation operations for each subcarrier frequency. Together, these components facilitate the implementation of parallelization and phase adjustments crucial for signal processing within the transmitter system.

$$V_{sc,k} = \sum_{m=0}^{N-1} V_{in}(m) \cdot \exp\left(\frac{-2\pi jkm}{N}\right), \tag{2}$$

where $V_{in}(m)$ is the value of the input signal at the sample points m, N is the number of subcarriers.

$$\theta_{m,n} = 2\pi m \cdot \frac{n_s d}{\lambda R} n d_0, \tag{3}$$

where n_s is the lattice index, d is the distance between the waveguides, λ is the central wavelength, R is the focal length of the lattice,d_0 is the distance between the waveguides at the output.

Each output signal from the Arrayed Waveguide Grating Router (AWGR) is formed as a weighted sum of four consecutive samples of the input data. This operation effectively implements a discrete Fourier transform that operates on discrete samples over time. However, it's important to note that the inputs and outputs of the AWGR are continuous signals.

Therefore, the AWGR performs a sliding discrete Fourier transform, where the time intervals between successive transformations are infinitesimally small. To ensure valid output data, all input samples must belong to the same OFDM symbol. This necessitates that the AWGR output signal be sampled either in the optical domain or after conversion to the electrical domain. The assumption is that sampling is instantaneous, although any bandwidth limitations of the baseband will affect this process.

Experimental

To maintain orthogonality in an AWGR, it is crucial that the power transfer from the input to the output through any of the waveguides remains uniform. In a 4-waveguide device, achieving this uniformity is primarily dependent on balancing the power distribution between the external waveguides relative to the central waveguides, assuming some form of symmetry.

Figure 3 presents simulation results illustrating the Q factor values for four channels, which vary based on the unevenness of power distribution across the AWGR's waveguides. This unevenness can stem from various factors, including differences in bandwidth or inherent characteristics of the AWGR.

Typically, internal channels are more susceptible to crosstalk, regardless of whether this crosstalk arises due to bandwidth limitations or uneven power distribution within the AWGR structure. Maintaining uniform power transfer helps mitigate these issues and ensures the integrity of signal orthogonality and quality in optical communication systems utilizing AWGR technology.

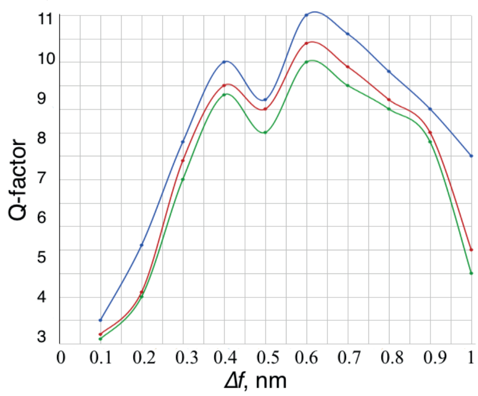

Fig. 3. The effect of AWGR bandwidth on Q. The electrical bandwidth of the signal is 25 GHz (blue), 50 HZ (red), 75 Hz (green)

Conclusion

The analysis has demonstrated that even with fewer waveguides and a narrower free spectral range, a standard AWGR can effectively multiplex and demultiplex subcarriers in an OFDM optical system. This capability hinges on ensuring that the electrical bandwidth in both the transmitter and receiver matches the total bandwidth of the combined subcarriers.

The AWGR functions as a serial-to-parallel converter, followed by a phase shift matrix, mirroring the digital implementation of Fourier transformation. To enhance transmitter bandwidth, modulators can be overloaded to achieve signal alignment, while receiver bandwidth can be reduced through optical sampling techniques.

Moreover, it is crucial for the AWGR design to guarantee uniform transmission regardless of the light path, ensuring consistent performance across all channels. This uniformity is essential for maintaining signal integrity and orthogonality, critical in optical communication systems employing AWGRs for efficient multiplexing and demultiplexing of subcarriers.

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