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Use of Multiband Acousto-Optic Filters for Spectrally Encoded Signals Generation in Incoherent Optical Communication Systems

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Abstract

New acousto-optical (AO) coder of spectrally optical signals for optical code division multiple access systems (O-CDMA) was proposed and investigated. The coder was developed on a base of multi-frequency acousto-optical filter (MAOF). Control RF signals for MAOF were synthesized taking into account intermodulation distortions and interferences between different carrier frequencies incoming to MAOF. An industrial LED was used under system investigation.

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Keywords: fibre-optic links; acousto-optical filter; acousto-optical coder; code division; multiband filtering; O-CDMA.

1. Introduction

The extensive telecommunication traffic growth and success in commercial usage of code division multiple access systems (CDMA) in RF networks has caused a new investigation stage in the development of O-CDMA [Yin et al. (2007)]. Optical code-division-multiplexed systems, which based on spectral encoding of incoherent sources, have been proposed in article [Kavehrad et al. (1995)]. $LiNbO_3$ waveguide AO technology was used [Zieman et al. (1995)] for O-CDMA with AO coder implementation. However, this technology has principle limitations for grid frequency setting accuracy and for homogeneity of code units (chips) due to specific mode light dispersion effects. M-sequences, Gold codes, Walsh codes and the asymptotically optimal 4-phase codes [Yin et al. (2007)] can be applied to the incoherent spectral amplitude O-CDMA encoding.

In this paper a new AO coder which was developed on the base of MAOF with use of TeO_2 crystal is considered as the key element of O-CDMA system [Proklov (2001)]. The proposed coder will take place among the elements of

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previously proposed general scheme of OCDMA [Proklov et al. (2013, Quantum Electronics)] is shown in Fig.1a. The schemes of AO coder and AO receiver are presented in Fig.1b and 1c.τωΣ≈λ

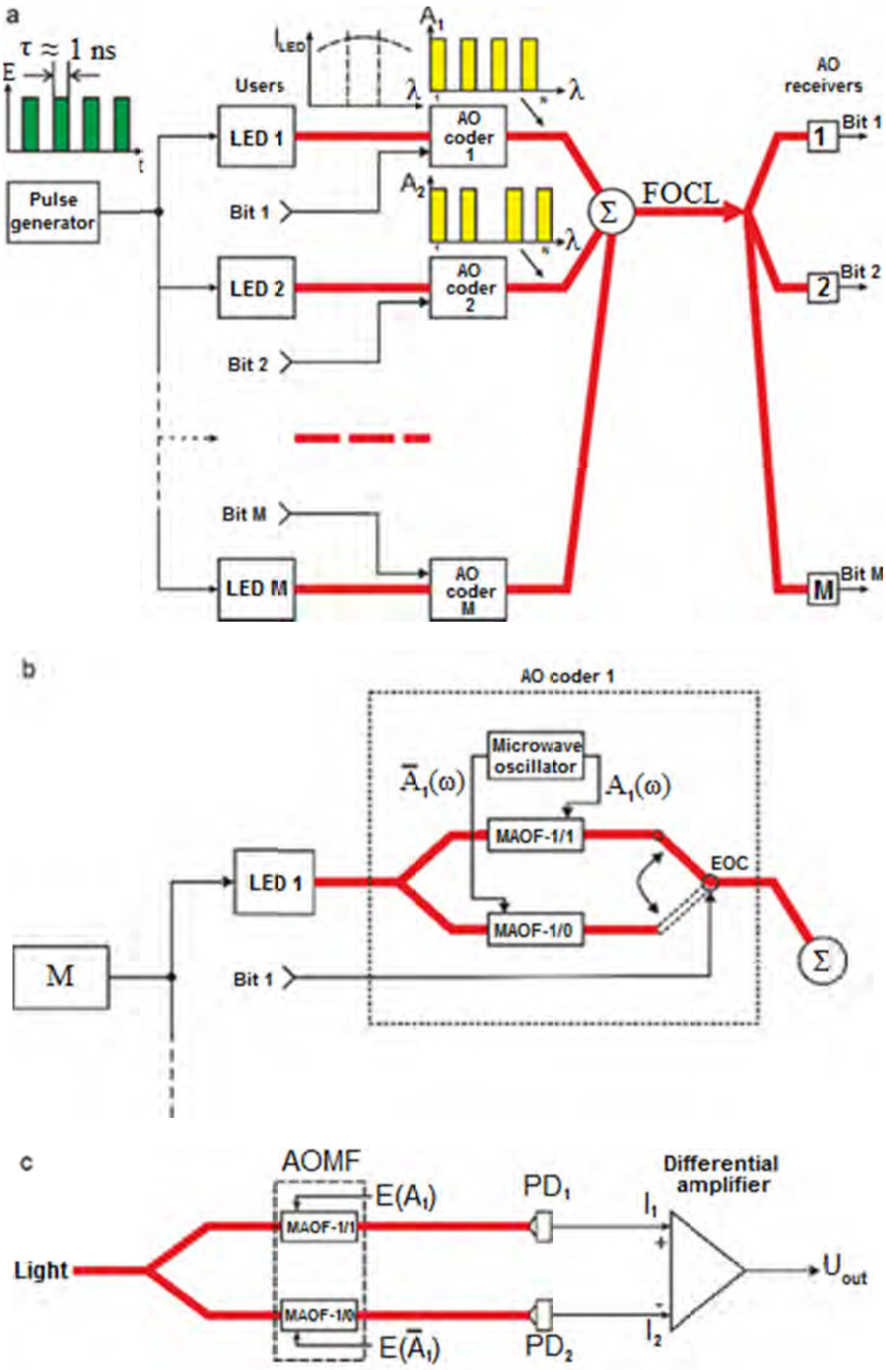

Fig1. Schemes of O-CDMA fiber-optic data transmission line with acousto-optic encoding and decoding the signals spectra.

The principle of operation of the circuit in Fig.1a can be briefly formulated as follows: each of M avaliable subscribers has his "own" AO coder, which is forming an individual code set of spectral lines $A(\lambda)$ from time pulses of incoherent wideband light. This set further comes to the common optical transmission line synchronically with corresponding "individual sets" from other subscribers.

At the output of the line the total optical flow is divided into multiple identical channels, which are then processed in all subscriber receivers through the application of the matched filtering with the use of two identically constructed MAOFs. The MAOF in one of the two channels has instrument function of type $A(\lambda)$, and in the other - the complementary function of type $\overline{A}(\lambda)$. Further optical signals at the outputs of these two channels are registered by photodetectors and summed in balance amplifier. The signal of autocorrelation function $A^2(\lambda)$ (i.e. power) is forming at the output of the amplifier with zeroing at the same time of all the cross-correlation signals.

2. Experimental setup

Experimental setup and its photograph are shown in Fig.2a and Fig.2b. The power supply unit sets the current of 1 A through LED (TSAL6200). The radiation of LED, mounted on a three-coordinate optical table, is collimated by a lens (4) with aperture D = 10cm and focus length F = 10cm. The MAOF with input aperture of 8 cm was placed in the zone of the light beam waist located at the distance ~100 cm from the lens and had a diameter of 6 cm. Control RF signals, formed by a generator (Tektronix AFG3252) (8), after a power amplifier (6) (with a power unit (7)) were fed to the MAOF (5). For improving the output signal-to-noise ratio, the generator (8) modulated control RF signals at a low frequency f = 1 kHz. The 1 kHz electric signal at the output of the spectral complex KSVU-2 was filtered and amplified in Unipan Selective Nanovoltmeter type 237 (9).

The LED's light, transmitted through the AO coder, gets through the monochromator slit (10) into the automated spectral complex KSVU-2 on the basis of a grating monochromator MDR-23. The microscrew (11) adjusts the width of the slit (10). When measuring, the width of the slit (10) was set at 0.2 mm, thus ensuring the accuracy of spectral measurements of 0.26 nm for spectral grating 1200 lines/mm. The computer (12) controls the generator (8), the spectral complex KSVU-2, and also performs collecting, primary processing and visualization of experimental data. A night vision device (13) used for adjustment of the system due to the working spectral LED's band λ = 900-980nm is invisible to the eye.

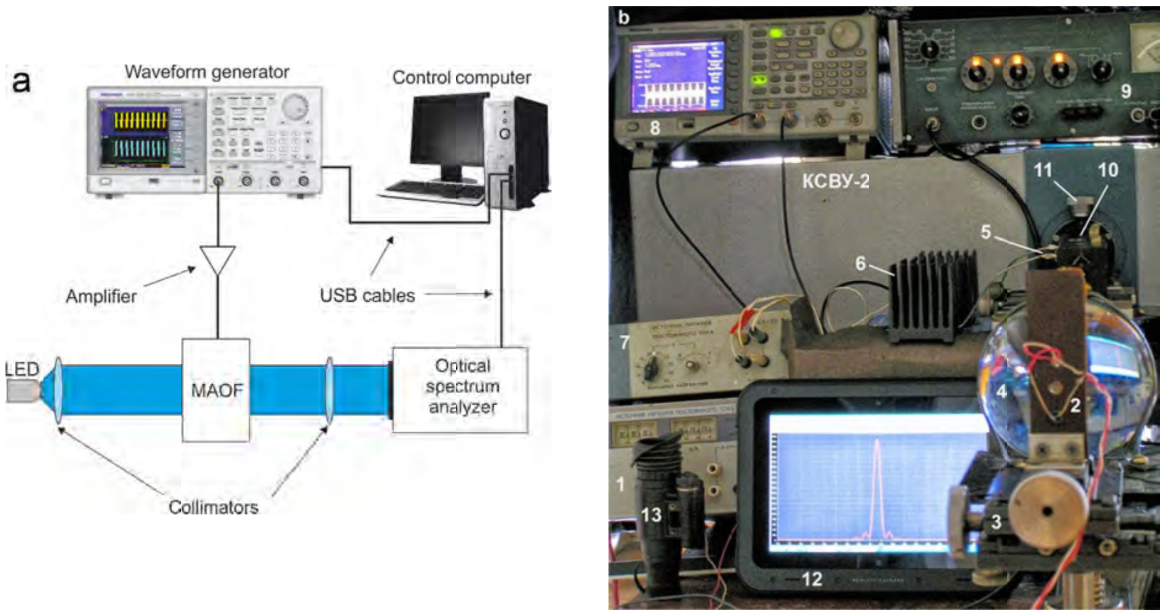

Fig.2. Block-diagram (a) and photograph (b) of the experimental setup.

The MAOF for AO coder was constructed using non-collinear and wide-angle geometry [Chang (1977)], with use of TeO_2 monocrystal. It has the following parameters: spectral range 900-1600 nm, range of control frequencies 55-100 MHz, spectral resolution 2 nm at the wavelength 1152 nm. The AO coder has been investigating in combination with industrial GaAS/GaAlAs LED. The central wavelength is 940 nm; radiated power is 210 mW and divergence angle 17^0.

3. Experimental results and discussion

When designing the new AO coder it has been taken into account the fact that during multi-frequency AO diffraction the distortions of the diffraction field of the first order are highly dependent on the geometry of AO interaction, more precisely, on the Bragg synchronism frequency mismatch. It is known that in the AO deflectors of the monochromatic laser radiation, that use the geometry of the broadband anisotropic interaction with a relatively small frequency mismatch of the synchronism, occur, under high diffraction efficiency, significant spurious signals due to high order diffraction field distortions related to nonlinear inter-modulation effects [Antonov et al. (2008)]. Therefore, to avoid such problems, it is advisable, whenever possible, to use a geometry with a maximum frequency mismatch in the considered MAOF [Chang (1977)]. At the same time, however, when the acoustic frequencies get closer to each other, some spectral optical distortions, caused by the linear superposition of some "adjacent passbands" of spatial optical spectra may arise in MAOF due to closely spaced sound frequencies.

The design was carried out with taking into account the need to suppress the peak factor. For this purpose, a special program, that synthesizes and optimizes the sum of sine waves by reciprocal phase shifts between them, and loads amplitude array of 10000 points into the signal generator, has been developed. In Fig.3a the sum of four sine waves with different frequencies and the reciprocal zero phase shifts is shown to illustrate the output of this program. The sum for the same sinusoids with optimized phase shifts is represented in Fig.3b. Comparing of Fig.3a and 3b shows that the maximum amplitude of the optimized sum signal is about one and a half times less than the same of the non-optimized one. This optimization allows to extend the dynamic range of the AO coder.

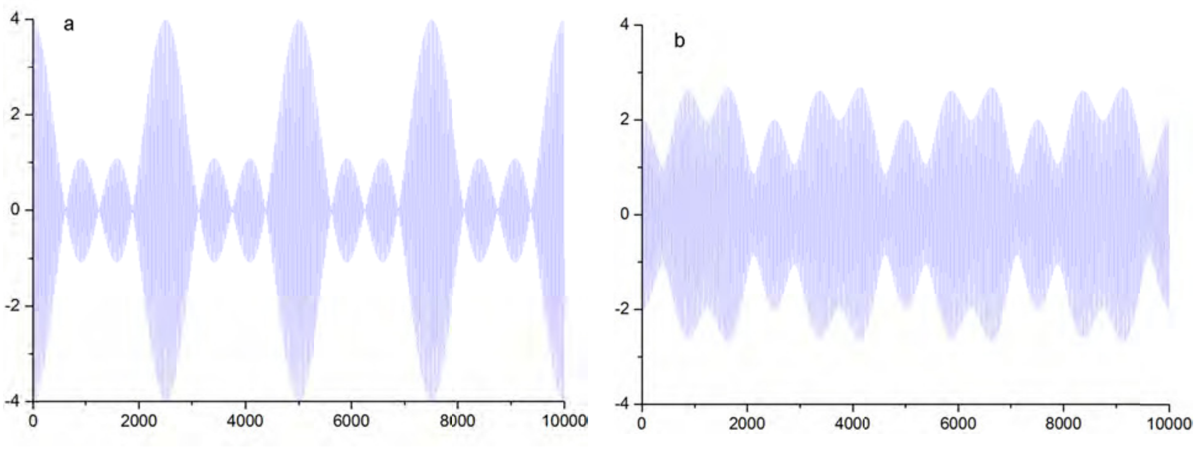

Fig.3. Sequence (10000 points), forming the sum of four frequencies 79.8 MHz, 80.6 MHz, 81.4 MHz and 82.2 MHz, synthesized for loading into the arbitrary waveform generator AFG3252: (a) - with zero phase shifts between the four frequencies, (b) – with optimized phase shifts.

The experimental result of verifying (for four from five possible subscribers) the effectiveness of alignment of direct and complementary sequences bits in AO coder is shown in Fig.4. Walsh 8-bit functions were used for signals coding, where dotted line shows the LED's radiation continuous spectrum measurement results.

The alignment of code units throughout the optical signal band has been achieved by optimal synthesis of multi-frequency acoustic signal with the suppression of intermodulational distortions in accordance with the [Proklov et al.

(2013, J. Communications Technology and Electronics)]. The selection of the frequency set was performed by taking into account the optimal density of the neighboring spectral lines. It is seen that the proposed AO coder reached a very low level of code chips nonequality (less than 5%). Calculations show that this level of coding chips equalization guaranties the expected maximum transmission rate ~ $5 \cdot 10^9$ bits per second with use an appropriate quality of the AO decoder proposed [Proklov et al. (2013, Quantum Electronics)].

4. Conclusion

1. A model of AO coder for O-CDMA systems based on industrial LED and MAOF is proposed and investigated experimentally.
2. Control RF signals for the MAOF were synthesized with the peak factor suppression that provides AO coder dynamic range extension by more than 30%.
3. A very low level of code chips equality (less than 5%) was reached in the investigated AO coder.

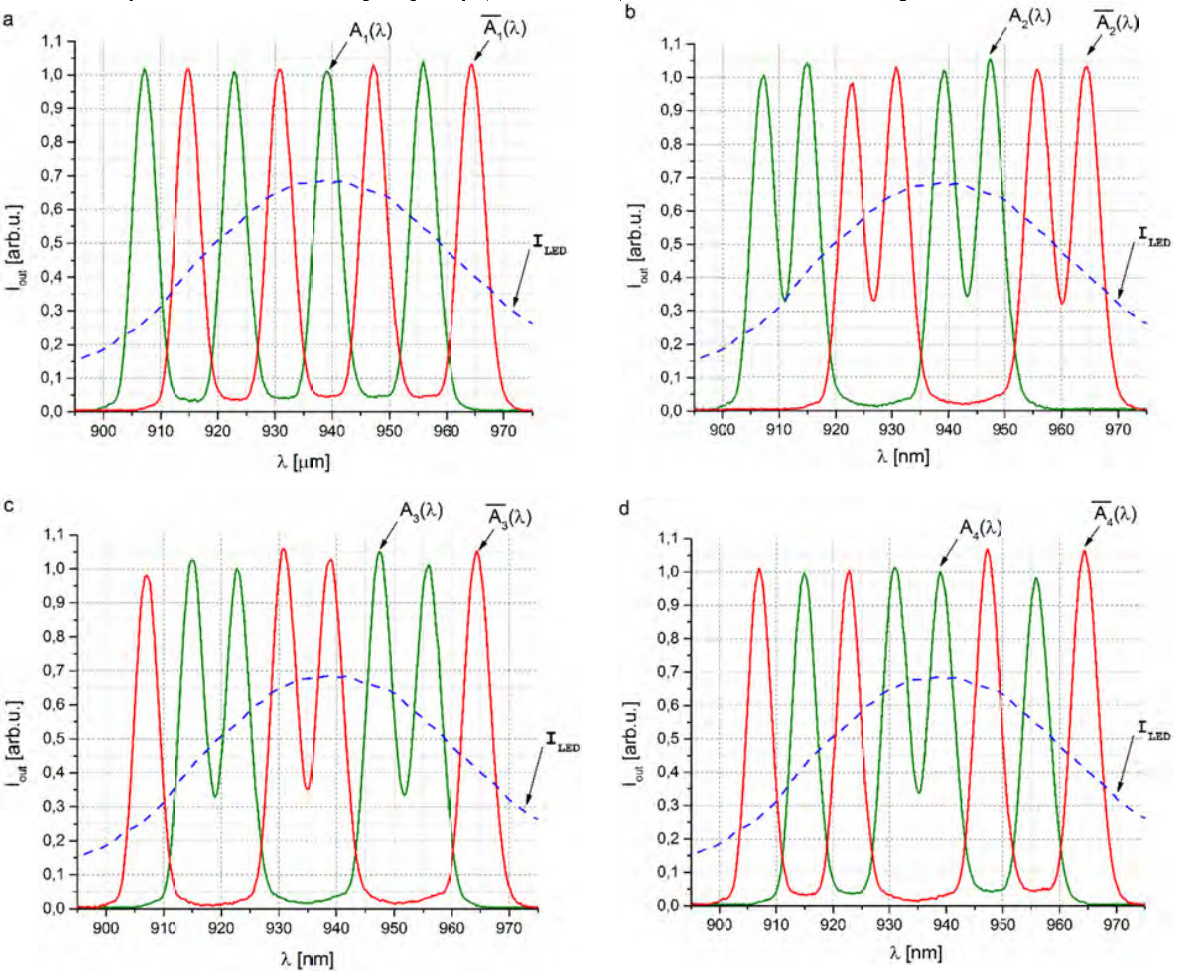

Fig.4. Experimental results of the LED's power spectrum measurements (blue dotted line) and the transformation of this spectrum into the Walsh function codes (green color - the direct code, red - complementary code).

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