UDC 621.395

FORMATION OF A LOW-FREQUENCY COMPONENT OF AN OPTICAL SIGNAL BY PULSES OF A GAUSSIAN FORM

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Background. Increasing the spectral efficiency of fiber-optic transmission systems (FOTS) is a topical problem. Currently used single-wave FOTS on the basis of equipment type STM allow the transfer of data at rates up to 40 Gbit/s. Given the available optical bandwidth of approximately from 175 THz till 375 THz, the bandwidth of the possible transmission band is about 200 THz. The value of the spectral efficiency index is about 0.005 bits/Hz. Usage of DWDM systems with widely spaced carriers allows increasing the spectral efficiency approximately an order of magnitude, which in principle does not solve the initial problem. Experimental developments are known in which the transmission rate is reached up to 160 Tbit / s. A special optical fiber with 348 transparency windows is used. The spectral efficiency of such systems reaches unity. The problem with the widespread use of such systems is the need to replace an already mounted optical cable. For comparison, in industrial mobile communication systems, the spectral efficiency is of the order of 0.5 till 5 bits / Hz.

Objective. Development of theoretical ideas on the formation methods of optical signals with a given structure that allows increasing the bandwidth of FOTS taking into account the dispersion factors and the dependence of the attenuation coefficient on the frequency. These theoretical studies have the ultimate goal of increasing the spectral efficiency of the FOTS using the existing cable infrastructure.

Methods. The formation of a low-frequency component of an optical signal with a given shape under conditions when the basic optical pulses are formed by a pulsed laser in the state of locking mode. In this case, the spectral composition of the optical signal can be formed in such a way as to balance the effects of dispersion and distortion of the spectrum due to the dependence of the damping coefficient on the frequency.

Results. The theoretical substantiation of the principle possibility of approximating processes of a certain form by a sequence of Gaussian pulses is given. Convergence estimates of the corresponding functional series are obtained. The results are valid for narrowband transmission channels with a width of the order of 100 GHz and for the length of the regeneration sections of the order of 100-300 km.

Conclusions. There is a fundamental possibility of short optical signal generation with a given shape using Gaussian impulses. Pulses of approximately Gaussian shape give the laser in the state of locking mode**.**

Keywords: Fourier transform; Gaussian pulse; state of locking mode; convergence; Jon Tikhiy.

1. Introduction

Optical signals in the transmission channel are distorted due to the noise component, attenuation and dispersion. The high protection of the FOTS against the external interferences requires consideration of the components due to noise amplifiers, losses on line inhomogeneities and so on. This component of the distortions within the framework of the present paper is negligibly small.

In principle the attenuation of the optical signal is compensated at repeater sections. The greatest influence on the length of the regeneration sections and the rate of data transfer is rendered by dispersion. Its influence in the simplest representation [1] leads to an increase of the duration of the optical pulse (OP) during its moving along the optical fiber (OF). In more precise representations [2], the distortion of the distribution of the electric and magnetic components of the OP is considered.

The simple dispersion, causing distortion of the OP form in the time domain, does not lead to a distortion of its energy spectrum. Moreover, the symmetry property of OP is invariant even to high-order dispersion [3]. This provision provides the prerequisites for the creation of a FOTS, in which on the receiving side the signal recognition is recognized by comparing their energy spectra with reference spectra [4].

Dependence of the attenuation coefficient on the frequency also leads to an increase of the pulse duration [5]. This factor also leads to a distortion of the energy spectrum of the OP on the receiving side.

To significantly increase the bandwidth of the FOTS, it is necessary to take into account all the factors mentioned. In this case, it is possible to increase the spectral efficiency by the generation of signal alphabet that has approximately the same increase of duration at the receiving end. This statement follows from the fact that the data rate using signals with different structures will be determined by a signal that is subject to the greatest expansion during its moving along the OF.

Previously local results for different signal systems possessing the property of equal dispersion increase of duration are obtained [6]. As the alphabet of signals the model of amplitude modulation and frequency manipulation of the electric field component is adopted:

$$E_k(t) = U_k(t)\cos(\Delta\Omega_k\ t)\exp(j\omega_0 t), \quad (1)$$

where $U_k(t)$ – low-frequency component (LFC) of k alphabet signal, $\Delta\Omega_k$ – small frequency deviation relative to the carrier ω_0.

By choosing the shape of the LFC and the frequency deviation parameter, it is possible to achieve a condition of approximately the same increase of the duration of the OP of the alphabet (1) at the receiving end. In this case, a small detuning of the carrier frequency (about 50-100 GHz) does not present a technical problem. For relatively large duration of OP (about 10-100 ns), the solution of the problem of amplitude modulation based on the usage of electrical devices is also known [7].

However, for the formation of ultrashort optical signals (of the order of 1-100 ps) with a given shape of the LFC, other physical principles are required.

In this article, it is considered the option of the formation of LFC of optical signals using ***exclusively optical*** components that provide the highest speed of signal generation and transformation.

2. Model of the OP field in the time domain

The electric field generated by a pulsed laser in the multimode regime can be represented by the formula [8]:

$$E(t) = E_0 \frac{\sin[(2N+1)\Delta\omega t/2]}{\sin(\Delta\omega t/2)}\exp(j\omega_0 t), \quad (2)$$

where $2N+1$ – number of generated modes, $\Delta\omega$ – frequency interval between adjacent modes, ω_0 – central frequency of laser radiation.

It can be seen from formula (2) that for a significant number of axial modes the field in the neighborhood of an individual mode is approximately described by a function of the form

$$E(t) \approx E_0\,\mathrm{sinc}(\alpha t). \quad (3)$$

The function (3) has the form of a function of readings by the Kotel'nikov theorem. If allocate a separate pulse of this kind, then it is possible to obtain the possibility of approximating an arbitrary LFC of optical signal by individual readings. However, it will be difficult to filter an individual pulse.

In the state of locking mode of the OP without chirping at a certain spatial point with high accuracy is described by the Gaussian approximation [10]:

$$E(t) = U(t)\exp(j\omega_0 t), U(t) = A\exp\left(-\frac{1}{2T^2}t^2\right), \quad (4)$$

where T – effective duration of the OP.

Further, it is assumed as an axiom that the LFC of the OP generated by the laser in the state of locking mode corresponds to a Gaussian function $U(t)$ from formula (4).

3. Formation of the LFC with a given form

Historically, electronic and optoelectronic modulators were the first devices which solved the problems of the LFC formation [7]. Advantages of such devices are relatively low cost, compactness and the possibility of adaptive rearrangement for the LFC formation with a different form. Disadvantages – the presence of nonlinear effects and noise, as well as a relatively large inertia.

Optical devices for the LFC formation with a given shape use a double spectral transformation of the original OP [10]. The Fourier transform of the input OP is performed. The resulting spectral density is transformed by a specified manner. Then the inverse Fourier transform is performed.

A significant advantage of such schemes is their high speed, which makes it possible to form ultrashort OP with a given shape. The effective duration of the OP can be reduced to a few femtoseconds.

A certain disadvantage of such modulators is the rigidity of tuning to a certain shape of the LFC of the OP.

Intermediate position between the modulators considered above occupy the proposed devices, the basic scheme of which is shown in Fig. 1.

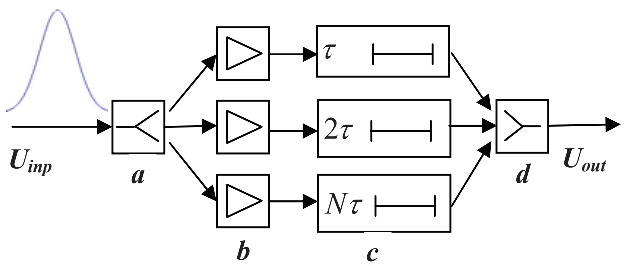

Fig. 1. Schematic diagram of the LFC formation, which implements the approximation by the reading functions: *a* - optical demultiplexer (splitter); *b* - optical amplifiers; *c* - precision delay lines; *d* - optical multiplexer (adder)

In this case, it is assumed that the effective duration of the input OP is 1-10 fs. To approximate a given LFC, 10-100 OP should be used. Thus, the duration of the signal at the output can be 0.01-1.0 ps. To ensure maximum bandwidth of the FOTS, such a time can be considered acceptable. In this case, the device can adaptively be rearranged by changing the transmission coefficients of optical amplifiers.

The implementation of such devices is constrained not so much by technical difficulties as by the insufficient development of a scientific and methodical apparatus for approximating functions of arbitrary form by Gaussian impulses.

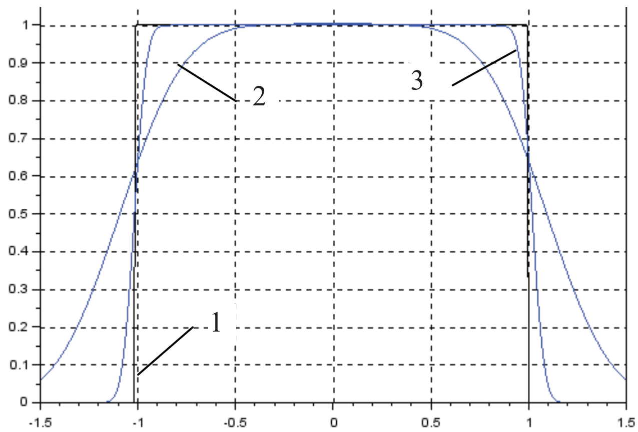

Fig. 2. Approximation of a rectangular pulse by Gaussian pulses:
1 - rectangular pulse; 2 - approximation by the sum of 8 Gaussian pulses; 3-approximation by 40-Gaussian pulses

The application of numerical simulation methods shows that there is a high rate of convergence of a series of Gaussian sample functions to a certain smooth function $u(t)$ on the interval $t \in [-1,1]$

$$\underbrace{\lim}_{M\to\infty} A \sum_{m=-M}^{M} u(m\tau)\, \exp\left(-\frac{(t-m\tau)^2}{2\beta^2} \right) = u(t), \quad (5)$$

with an appropriate choice of the step of the relative delay of the sampling functions τ and the parameter β characterizing the effective pulse duration.

Example of approximation of a rectangular pulse $u(t) = \mathrm{rect}[-1,1]$ is shown in Fig. 2. At $M = 200$ the graphs of the approximating series and the approximated function become visually indistinguishable. As values of the approximation parameters (5) are accepted: $\tau = \beta = 1/M$, parameter A is chosen from the condition for minimizing the index of the relative quadratic error of the model

$$\delta = \int (u(t) - u_M(t))^2 dt \Big/ \int u^2(t) dt, \qquad (6)$$

where $u_M(t)$ – approximating series.

The error values (6) for some variants of approximations by different number of pulses M are given in Table 1.

Table 1 Dependence of the approximation error

M	M=10	M=50	M=100	M=150	M=200
δ	0,05	0,011	0,0057	0,0031	0,0019

Analysis of the data of Table 1 shows the high rate of convergence of the approximating series to the original function. Note here that a rectangular pulse is extremely "inconvenient" for approximation by continuous functions, since it has singular points -1 and 1.

The purpose of the following presentation is the justification of the convergence of series (5) and an estimate of the rate of such convergence.

4. Basic provisions

In this section we consider a number of fairly simple and, for the most part, well-known propositions, which are the starting points for further analytical studies.

Position 1. In the space of Riemann-integrable functions on the interval $T = [-1,1]$ $u = u(t) \in \Phi$ define the metrics

$$L_p = (\int_T |u_1 - u_2|^p dt)^{1/p},\ L_{\max} = \max_T |u_1 - u_2|. \quad (7)$$

Equivalent are the metrics L_x and L_y, if there are such numbers $C_1, C_2 > 0$, that at $\forall u_1, u_2 \in \Phi$

$$C_1 L_x(u_1,u_2) \le L_y(u_1,u_2) \le C_2 L_x(u_1,u_2). \quad (8)$$

It can be shown that all the metrics (7) are equivalent.

Convergence in equivalent metrics is also equivalent: if a sequence of functions converges in a metric L_x, then it converges in an equivalent metric L_y. Similarly, the divergence property.

We note that convergence in the metric $L_{\max}$ means pointwise convergence of functions.

Position 2. A number of functions

$$u_M = \sum_{m=-M}^{M-1} u(m\,\delta_t) \frac{1}{\delta_t} \mathrm{rect}[m\delta_t, (m+1)\delta_t],$$

$\delta_t = 1/M$, converges in any metric (7) to the function $u(t)$ on the interval $T = [-1,1]$. The proof of this proposition follows from the definition of the Riemann integral.

Here it would be possible to stop the formal analysis, taking as the counting functions impulses of a rectangular shape. Unfortunately, lasers do not know how to generate such pulses.

Position 3. To shorten the entries we use the notation: $F(\omega) = F(u(t))$ for a direct Fourier transform and $u(t) = F^{-1}(F(\omega))$ for the inverse Fourier transform. Also, if this does not cause uncertainty, ***convergence*** will be understood as convergence in the sense of any of the metrics (7), since they are equivalent. The essence of position 3 reduces to the assertion that convergence in the time domain implies convergence in the frequency domain. The converse is also true.

Because of the importance of this provision, we give its simple proof. Let there be given two functions u_1 and u_2 such that their difference $u_2 - u_1 = \delta_u$ slightly. Because of the linearity of the integral transformations

$$F(u_2) - F(u_1) = F(\delta_u) = \delta_F,$$

but with the Parseval identity $\|\delta_u\| = \|\delta_F\|$. In this case, the definition of the norm is used $\|g\| = L_2(g,0)$. If $\|\delta_u\| \to 0$, that $\|\delta_F\| \to 0$. The converse is also true, as was proved.

Position 4. The spectral density of a function $u(t) = A\,\mathrm{rect}[-\tau/2, \tau/2]$ is real and has the form $F(u) = A\tau\,\mathrm{sinc}(\omega\tau/2)$. If $\tau/2 = 1$, then $F(u) = 2A\,\mathrm{sinc}(\omega)$.

It follows from 1-4 that if some series of functions approximates a rectangular pulse, then it can approximate an arbitrary smooth function on the interval $T = [-1,1]$, and thus, on an arbitrary interval. In the latter case, the problem is solved by scaling the argument.

Position 5. The sum of the first terms of the geometric progression:

$$Q(N) = b + bq + bq^2 + \cdots + bq^N = \frac{b(1-q^{N+1})}{1-q}. \quad (9)$$

5. The theorem on the approximation of unity

With a certain choice of parameters A, τ, β sequence of functions

$$u_M(t) = A\sum_{-M}^{M} \exp\left[-\frac{(t-m\tau)^2}{2\beta^2}\right] \quad (10)$$

converges to a function $u(t) = \mathrm{rect}[-1,1]$.

Evidence. We perform the Fourier transform of the function (9). Taking into account the lag theorem

$$F(u_M) = F_0(\omega)\sum_{m=-M}^{M} \exp(-jm\tau\omega), \quad (11)$$

$$F_0(\omega) = A\int_{-\infty}^{\infty} \exp\left(-\frac{t^2}{2\beta^2}\right)\exp(-j\omega t)dt. \quad (12)$$

Let's consider separately the factors in (11). The sign of the sum contains the terms of a geometric progression. In accordance with formula (9), taking formula (11) into account, we set $N = 2M$, $b = \exp(jM\omega\tau)$, $q = \exp(-j\omega\tau)$. Then for the sum in formula (11)

$$Q = \sum_{m=-M}^{M} \exp(-jm\tau\omega)$$

obtain:

$$Q = \exp(jM\omega\tau)\frac{1-\exp[-j\omega\tau(2M+1)]}{1-\exp(-j\omega\tau)}. \quad (13)$$

Applying the identity in (13) to the numerator and the denominator:

$$1-\exp(-\varphi) = [\exp(\varphi/2) - \exp(-\varphi/2)]/\exp(\varphi/2)$$

after identical transformations we obtain:

$$Q = \frac{2\sin(M\omega\tau + \omega\tau/2)}{2\sin(\omega\tau/2)}. \quad (14)$$

To determine the result of the Fourier transform (12), we use the tabular integral [11, p. 344]:

$$\int_{-\infty}^{\infty} \exp(-px^2 - qx)dx = \sqrt{\frac{\pi}{p}}\exp\left(\frac{q^2}{4p}\right), \quad \mathrm{Re}\, p > 0.$$

In our case $p = 1/2\beta^2$, $q = j\omega$, then:

$$F_0(\omega) = A\beta\sqrt{2\pi}\exp(-\frac{\beta^2}{2}\omega^2). \quad (15)$$

Combining formulae (14) and (15), we obtain the formula for the function (11):

$$F(u_M) = A\beta\sqrt{2\pi}e^{-\frac{\beta^2\omega^2}{2}}\frac{\sin(M\omega\tau + \omega\tau/2)}{\sin(\omega\tau/2)}. \quad (16)$$

For the subsequent analysis, we define the parameters β and τ in formula (16). Assume the value of the parameter $\tau = 1/M$. In this case, it is ensured that the maxima of the sample functions belong to the approximation interval $[-1,1]$ and the absence of such maxima outside the given interval, as illustrated in Fig. 3.

Parameter β define in the form $\beta = \gamma/(M\sqrt{2\pi})$, where the coefficient γ has the order of unity.

It takes into account that for the argument $x \to 0$

functions in formula (16) tend to the limits: $\sin(x) \to x, \exp(x) \to 1$. Performing the limit transitions for the components of the function (16) for some fixed value of the parameter ω and at $M \to \infty$ obtain a chain of corollaries:

$$F(u_M) \to A\frac{\gamma\sqrt{2\pi}}{M\sqrt{2\pi}}\frac{\sin(M\omega / M + \omega / 2M)}{\sin(\omega / 2M)} \to$$

$$\to A\frac{\gamma}{M}2M\frac{\sin(\omega)}{\omega} \to F(u_\infty) = F(A\gamma\,\mathrm{rect}[-1,1])$$

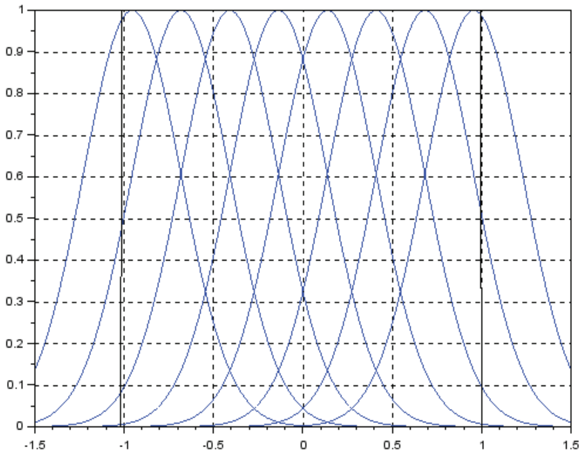

Fig. 3. Selecting the step of the count functions

Taking into account in the last formula $A\gamma = 1$ that the series (11) converges pointwise to the function $2\,\mathrm{sinc}[-1,1]$. On the basis of position 1, this series also converges in all the metrics (7). Then, on the basis of position 4, the inverse image of this series (10) also converges to the original function:

$$u_M(t) \to u_\infty(t) = u(t) = \mathrm{rect}[-1,1],$$

which was to be proved.

6. Estimation of accuracy of approximation and speed of convergence

The accuracy of the approximation depends on the number of samples M, the relations between the parameters A and γ, and also on the properties of the approximated function $u(t)$. The performed calculations show that the acceptable values of the parameters $\gamma = \sqrt{2\pi}$, $\beta = 1/M$.

The number of samples M depending on the properties of the function $u(t)$ with sufficient accuracy for applications should be chosen in the range from 20 to 100. Thus, the approximation of a quadratic function $u(t) = rect[-1,1](1-t^2)$ with only 9 pulses is already very accurate (Fig. 4).

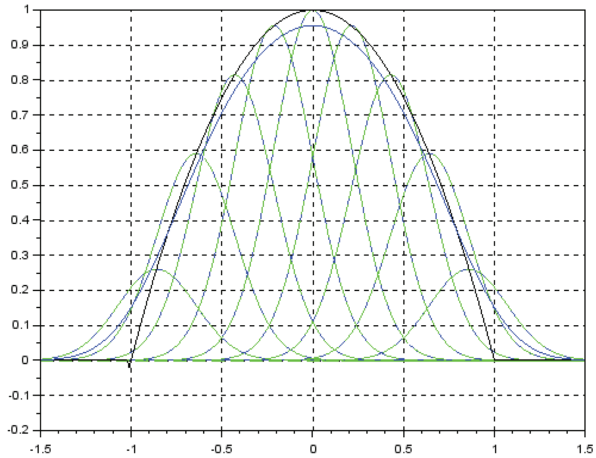

Fig. 4. Approximation of the quadratic function for M=9

In Fig. 5 and Fig. 6 for the same number of samples on the interval $[-1,1]$ the graphs of the functions $\mathrm{sinc}[-1,1]$ and $\exp(-t^2/0{,}5)$ are given. Note that already at $M = 30$ the graphs of the approximating and initial functions in Fig. 4-6 become visually indistinguishable.

The values of exponent (6) of the approximation accuracy for the functions in Fig. 4-6 are given in Table 2.

Table 2 Accuracy of approximation of functions

M	$(1-t^2)$	$\mathrm{sinc}(t)$	$\exp(-t^2/0{,}5)$
10	8,0379E-03	7,9372E-02	4,8660E-03
50	7,6528E-05	1,6681E-04	2,0916E-05
100	4,2279E-05	1,0716E-04	1,5541E-05

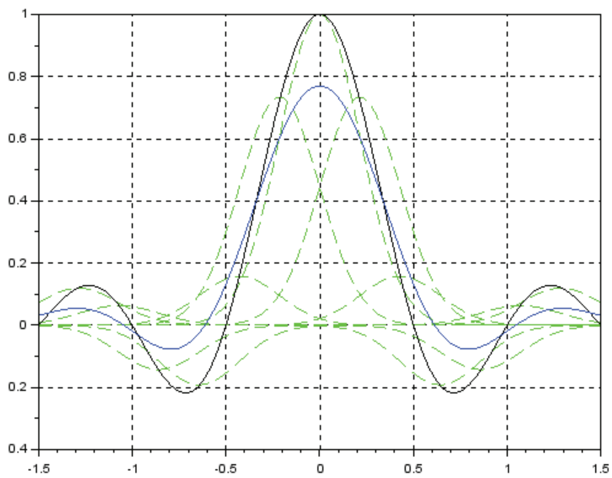

Fig. 5. Approximation of the function $\mathrm{sinc}(t)$ at M=9

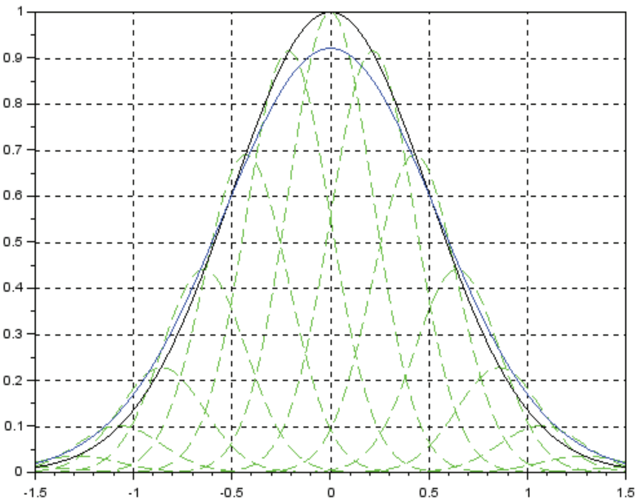

Fig. 6. Approximation of the function $\exp(-t^2/0{,}5)$ at M=9

Analysis of Table 2 shows the high accuracy of approximation of various smooth functions $u(t)$ by series of sample functions of the form

$$u_M(t) = A\sum_{-M}^{M} u(m\tau)\exp\left[-\frac{(t-m\tau)^2}{2\beta^2}\right]. \quad (17)$$

The study of the rate of convergence of series of the form (17) is obviously connected with the study of the convergence of sequences of the form

$$Q_{sq}(M) = \sum_{m=-M}^{M} q^{m^2}, \quad 0 < q < 1, \quad (18)$$

which will later be called quadratic-geometric progressions.

Reference literature gives a formula for $Q_{sq}(M \to \infty)$ [11, p. 719]:

$$\sum_{m=-\infty}^{\infty} q^{(m+a)^2} = \theta_3(\pi a, e^{\pi^2/\ln q})\ln^{-1/2}\frac{1}{q}, \quad (19)$$

where θ_3 – elliptic theta-function of the third kind.

A formula for the last function is also known [11, p. 792]:

$$\theta_3(v,x) = 1 + 2\sum_{m=0}^{\infty} e^{-m^2\pi^2 x}\cos(2mv\pi). \quad (20)$$

Comparison of formulae (19) and (20) shows that at the results it came to the same thing with which to begin: to the same quadratic-geometric progression, only in an even less convenient form for analysis.

Yyon Tikhiy faced to a similar situation, discovering the following brief definitions in the explanatory dictionary:

“SEPULETS - an important element of the civilization of the ardrites (see) from the planet Enteropia (see). See the SEPULCHER”. I followed this advice and read: "SEPULCHER - a device for the SEPARATION (see)". I looked "SEPARATION"; there it was: "SEPUATION - occupation of the ardrites (see) from the planet Enteropia (see). See SEPULETS”.

Since we could not find closed formulae for the sum of series of the form (18), we use the following arguments to estimate the fact and the rate of convergence. First, we represent the series (18) in the equivalent form:

$$Q_{sq}(M) = 1 + 2Q_S(M), \quad Q_S(M) = \sum_{m=1}^{M} q^2. \quad (21)$$

Thus, the problem being solved reduces to investigating the convergence of series $Q_S(M)$ from formulae (21).

We show that the quadratic-geometric progression $Q_S(M)$ is majorized by a geometric progression

$$Q_g(M^2) = q + q^2 + \cdots + q^{M^2-1} + q^{M^2}. \quad (22)$$

In fact, the progression (22) in addition to terms of the form q^{m^2} contains also terms of the form $q^{m^2+k}, 1 < k < (m+1)^2$, so:

$$Q_S(M) \le Q_g(M^2). \quad (23)$$

Equality in formula (23) is achieved only when $M = 1$. The geometric progression (22) in accordance with the formula (9) has a limit $q/(1-q)$. Thus, taking into account the inequality (23), the quadratic-geometric progression is monotonically nondecreasing and bounded from above. By the Weierstrass theorem this means that it is convergent and has a finite limit.

To estimate the rate of convergence of the quadratic-geometric progression to the limit, we use inequality (23).

To this end, from (9) we obtain the estimate of the remainder of the geometric progression:

$$\Delta Q_g = Q_g(\infty) - Q_g(M^2+1) = q^{M^2+2}/(1-q).$$

Hence, taking into account inequality (23), the remainder of the series of the quadratic-geometric progression follows:

$$Q_S(\infty) - Q_S(M) \le q^{M^2+2}/(1-q), \quad (24)$$

which completes the investigation of the convergence of series of the form (18).

7. Conclusions

The main conclusion is that it is possible to form a low-frequency component of optical signals with a given shape. In this case, Gaussian pulses can be used as sampling functions.

With an effective duration of such pulses of the order of 1-10 fs, optical signals with the duration of the order 0.1-1 ns can be generated with high accuracy.

The systems of approximating functions considered in this paper are not orthonormal. However, it is shown that with their help it is possible to approximate sufficiently smooth functions with high accuracy at a reasonably limited number of samples.

Unfortunately, it was not possible to obtain closed formulae for the limits of the quadratic-geometric sequences considered. At the same time, analytical estimates of the rate of convergence are obtained and the very fact of the convergence of such sequences is proved.

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Received in final form on March 5, 2018

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Формування низькочастотної складової оптичного сигналу імпульсами гаусом форми

Проблематика. Актуальною є проблема підвищення спектральної ефективності волокно - оптичних систем передачі (ВОСП). Використовувані в даний час однохвильови ВОСП на основі обладнання типу STM дозволяють передавати дані зі швидкістю до 40 Гбіт / с. З урахуванням доступної смуги оптичних частот приблизно від 175 ТГц до 375 ТГц ширина можливої смуги передачі становить близько 200 ТГц. Значення показника спектральної ефективності становить, таким чином, приблизно 0,005 біт / Гц. Застосування систем DWDM зі значно рознесеними оптичними несучими дозволяє збільшити спектральну ефективність приблизно на порядок, що принципово не вирішує вихідну проблему. Для порівняння в системах мобільного зв'язку спектральна ефективність має порядок 0,5 - 5 біт / Гц.

Мета досліджень. Розвиток теоретичних уявлень про методи формування оптичних сигналів заданої структури, що дозволяють підвищити пропускну здатність ВОСП з урахуванням присутніх факторів дисперсії і залежності коефіцієнта загасання від частоти.

Методика реалізації. Формування низькочастотної складової оптичного сигналу заданої форми в умовах, коли базові оптичні імпульси формуються імпульсним лазером в режимі синхронізації мод. При цьому спектральний склад оптичного сигналу може бути сформований таким чином, щоб врівноважити ефекти дисперсії і спотворення спектра за рахунок залежності коефіцієнта загасання від частоти.

Результати досліджень. Дано теоретичне обгрунтування принципової можливості апроксимації процесів певної форми послідовністю гаусових імпульсів. Отримано оцінки збіжності відповідних функціональних рядів.

Висновки. Існує принципова можливість формування коротких оптичних сигналів заданої форми з використанням імпульсів гаусом форми. Імпульси приблизно гауссовой форми дає імпульсний лазер в режимі синхронізації мод.

Ключові слова: перетворення Фур'є; гаусів імпульс; режим синхронізації мод; збіжність; Іййона Тихий.

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Формирование низкочастотной составляющей оптического сигнала импульсами гауссовой формы

Проблематика. Актуальной является проблема повышения спектральной эффективности волокно – оптических систем передачи (ВОСП). Используемые в настоящее время одноканальные ВОСП на основе оборудования типа STM позволяют передавать данные со скоростью до 40 Гбит/с. С учетом доступной полосы оптических частот приблизительно от 175 ТГц до 375 ТГц ширина возможной полосы передачи составляет около 200 ТГц. Значение показателя спектральной эффективности составляет, таким образом, приблизительно 0,005 бит/Гц. Применение систем DWDM со значительно разнесенными оптическими несущими позволяет увеличить спектральную эффективность приблизительно на порядок, что принципиально не решает исходную проблему. Для сравнения в системах мобильной связи спектральная эффективность имеет порядок 0,5 – 5 бит/Гц.

Цель исследований. Развитие теоретических представлений о методах формирования оптических сигналов заданной структуры, позволяющих повысить пропускную способность ВОСП с учетом присутствующих факторов дисперсии и зависимости коэффициента затухания от частоты.

Методика реализации. Формирование низкочастотной составляющей оптического сигнала заданной формы в условиях, когда базовые оптические импульсы формируются импульсным лазером в режиме синхронизации мод. При этом спектральный состав оптического сигнала может быть сформирован таким образом, чтобы уравновесить эффекты дисперсии и искажения спектра за счет зависимости коэффициента затухания от частоты.

Результаты исследований. Дано теоретическое обоснование принципиальной возможности аппроксимации процессов определенной формы последовательностью гауссовых импульсов. Получены оценки сходимости соответствующих функциональных рядов.

Выводы. Существует принципиальная возможность формирования коротких оптических сигналов заданной формы с использованием импульсов гауссовой формы. Импульсы приблизительно гауссовой формы дает импульсный лазер в режиме синхронизации мод.

Ключевые слова: преобразование Фурье; гауссов импульс; режим синхронизации мод; сходимость; Ийон Тихий.