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RESEARCH OF METHODS TRANSFER CHARACTERISTICS FIBER-OPTICAL COMMUNICATION LINES

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ABSTRACT
Fiber-optic communication lines and fiber-optic transmission systems using fiber-optic cable, receiving and transmitting optical modules based on WDM and DWDM technologies are studied. A method for calculating the transmission characteristics fiber-optic communication lines is proposed and relationships are obtained that establish an analytical relationship between the length of the regeneration section and the transmission rate.

Keywords: attenuation, transfer characteristics, optical signal, WDM and DWDM.

I. INTRODUCTION
The intensive development of next generation NGN (Next Generation Network) multiservice telecommunication networks based on modern fiber-optic communication lines (FOCL) and fiber-optic transmission systems (FOTS) requires the creation distributed optical transmission systems[1, 2] using fiber-optic cable (FOC), receiving and transmitting optical modules (ROM and TOM).

The conducted researches and the analysis have shown [1, 3, 4], that ROM, FOC and TOM based on FOCL are mainly characterized by important parameters of the optical signal transmission system. These parameters are the transmission characteristics of the fiber-optic link and determine the possibilities of practical use of the FOC.

However, the transmission characteristics FOCL mean the following indicators optical signal transmission systems: refractive index, numerical aperture and normalized frequency, bit rate of optical signals, types of attenuation, variance types and bandwidth of the FOC.

Our research is devoted to solving the problem creating methods for calculating the transmission characteristics fiber-optic communication lines using the ROM, FOC and POM, which makes it possible to ensure the transmission and reception optical signals efficiently.

II. GENERAL STATEMENT OF THE PROBLEM
Analyzed [1-6], it was determined that the main stimulus for the development fiber-optic communication lines, as mentioned in [3, 4, 5], was the possibility using them as a transmission medium in both backbone and distributed communication systems using optical WDM and DWDM technologies (Wavelength Division Multiplexing & Dense WDM, ITU-T, G.692, ..., G.697).

Studies [3, 6, 7] show that ineffective use of bandwidth limits both the maximum optical data transmission rate, the signal-to-noise ratio at the output of the regeneration section under the influence of chromatic dispersion, and the distance over which the signal can be transmitted. The transmission characteristics of fiber optic links are an important indicator.

In addition to the wavelength of the radiation, the main factors affecting the fiber-optic link efficiency and the nature of the propagation light $\lambda_i, i = \overline{1, n}$ in the fiber are attenuation, dispersion types, and the bandwidth of the FOC.

It is known [3, 7-9] that a small attenuation and a small dispersion of the signal make it possible to build sections communication lines without regenerators with a length up to 100 km or more, i.e. the maximum distance $L_p \to L_{p.\max}$ to which optical signals can be transmitted without intermediate regenerators with optical amplifiers.

To solve this problem, it is proposed to create methods for calculating the transmission characteristics fiber-optic links, taking into account the ROM, FOC and TOM indicators, as well as the capacity of the FOTS.

III. CREATION METHODS FOR CALCULATING THE TRANSMISSION CHARACTERISTICS FOCL

Based on the study transmission characteristics FOCL, it is established that the formalization of the problem of the efficiency of the operation optical signal transmission systems based on WDM&DWDM technologies can be represented as a set performance indicators for each of the subsystems:

$$E_{ef.}(\lambda_i) = W_1\{\max[V_b, \Delta F(\lambda_i), L_p]\}\ ,\ \ i = \overline{1,\ n} \tag{1}$$

Expressions (1) determine the primary parameters of the transmission characteristics of the fiber-optic link and characterize the bit rate optical signals V_b over the fiber optic link, the length of the FOC L_{foc} and the bandwidth of the FOTS, $\Delta F(\lambda_i)$.

Taking into account the parameters of the FOC and the relative difference in the refractive indices of the fiber core Δ_b , the bit rate optical signal V_b transmission over the FOCL is determined as follows:

$$V_b = \frac{1}{L_{foc}} \cdot \frac{n_2^2}{n_1^2 \cdot \Delta_b} \cdot C_{\max}(\lambda, L_p),\quad \text{bit/s}\ \ , \tag{2}$$

where L_{foc} – the length of the FOC; n_1- is the refractive index of the fiber core; n_2- is the refractive index of the shell; $C_{\max}(\lambda, L_p)$ – the maximum value of the bandwidth of the FOTS with wavelengths λ and is determined by the following expression:

$$C_{\max}(\lambda, L_p) = V_b \cdot [\eta_{ie}(n_1, \lambda, n_2, L_p)]^{-1}, \tag{3}$$

here $\eta_{ie}(n_1, \lambda_i, n_2, L_p)$ – is the coefficient effective use FOCL, taking into account their transfer characteristics and $\eta_{ie}(n_1, \lambda_i, n_2, L_p) \le 1$; L_p – the length of the regenerative section FOCL with spectral separation ($L_p \to L_{olk}$) channel communications.

It follows from expression (2) and (3) that one the key parameters is the bit rate optical signals, which significantly affects the transmission characteristics FOCL using WDM and DWDM technologies.

Studies of calculation methods have shown [3, 5] that an important characteristic transmission lines is the control of the attenuation of the optical signal in fiber-optic cables and the types dispersion FOCL that significantly affect the efficiency FOTS with wavelength λ_i :

$$E_{ef.}(\lambda_i) = W_2\{\min[\alpha(L_p, \lambda_i), \tau(L_p, \lambda_i)]\}\ ,\ i = \overline{1,\ n} \tag{4}$$

where $\alpha(L_p, \lambda_i)$ – the attenuation of the optical fiber signal FOCL with wavelengths λ_i and the length of the regeneration section L_p ; $\tau(L_p, \lambda_i)$ – dispersion FOCL with wavelengths λ_i and the length of the regeneration section L_p .

IV. ESTIMATION ATTENUATION PARAMETERS FOR FOCL IN THE TRANSMISSION OPTICAL SIGNALS

Investigations of the physical values of the fiber attenuation parameters FOCL in the transmission optical signals show [3, 5] that the attenuation an optical signal in FOCL is an important factor that is necessary for the creation efficient optical transmission systems.

The main types of attenuation in fiber optic cables used on FOCL, which determine the main types fiber loss [6, 7, 8] and are divided into four groups: a) Own losses; b) Cable loss;
c) Absorption losses; c) Losses in scattering.

It should be noted that the fiber optic attenuation in the optical fiber determines the measure of attenuation of the optical power propagated along the fiber optic path between its two cross sections at a given wavelength λ_i. The attenuation in the FOC is determined by the expression [3]:

$$\alpha(\lambda_i) = 10\lambda g[P_{out.}(\lambda_i) / P_{in.}(\lambda_i)] \text{ , } i = \overline{1,\ n} \text{ , dB} \tag{5}$$

It follows from (5) that part of the power entering the fiber input $P_{in.}(\lambda_i)$, is scattered because of the change in the direction of the propagated rays in irregularities and their emission to the surrounding space, the other part of the power is absorbed by the OB material in the form of polarization of the dipoles FO, by extraneous impurities, which manifests itself in the form of joule heat, as a result of which the power at the input $P_{out.}(\lambda_i)$ decreases.

Various types signal attenuation in the linear path, such as kilometric, residual and transient attenuation for estimating the parameters of an optical fiber are investigated. Among them, kilometric attenuation occupies a special place in the telecommunications system using ROM, FOC and TOM based on modern WDM and DWDM technologies, and the unit of measurement is expressed in dB/km.

Considering the main types of losses in fiber, the FOC attenuation coefficient is determined by the intrinsic fiber losses and is expressed as follows:

$$\alpha(\lambda_i) = \alpha_{\text{рр}}(\lambda_i) + \alpha_{\text{пм}}(\lambda_i) + \alpha_{\text{ик}}(\lambda_i) + \alpha_{\text{пр}}(\lambda_i) \text{, dB/km ,} \tag{6}$$

where $\alpha_{\text{рр}}(\lambda_i)$, $\alpha_{\text{пм}}(\lambda_i)$, $\alpha_{\text{ик}}(\lambda_i)$, $\alpha_{\text{пр}}(\lambda_i)$– - are the components of the attenuation coefficient due to rayleigh scattering, absorption in the fiber material, infrared absorption, and absorption by FOC impurities, respectively.

Based on the studies carried out, it is established [3, 8] that for the estimation of kilometric damping parameters there are certain points in the FOCL where the main losses in the FOC arise. It was found that the main losses arise [4, 6, 9, 10, 11]:

- when optical signals are input to the FOC, $\alpha_{\text{вв}}(\lambda_i)$, $i = \overline{1,\ n}$;
- when optical signals are transmitted directly to the FOC itself, $\alpha_{\text{вок}}(\lambda_i)$;
- when connecting - in detachable and non-detachable places, $\alpha_{\text{c}}(\lambda_i)$.

Thus, based on [1, 3], the attenuation coefficient FOCL is determined as follows:

$$\alpha_{об.з}(\lambda_i) = \alpha_{вв}(\lambda_i) + \alpha_{вок}(\lambda_i) + \alpha_c(\lambda_i) \text{ , dB/km} \tag{7}$$

The investigation showed [1, 3, 5] that in order to increase the efficiency FOCL, it is necessary to study methods for estimating the dispersion parameters are conducted and the transmission bandwidth optical information transmission systems.

V. INVESTIGATION DISPERSION AND PASSBAND PARAMETERS FOCL

The intensive development optical information transmission systems using TOM, FOC and ROM requires a systematic approach to studying the transfer characteristics FOCL. At the same time, an important parameter FOCL, using the technology spectral separation channels -WDM and DWDM, is dispersion and bandwidth.
It is known [3, 5] that the dispersion FOCL is the pulse broadening, i.e. the dispersion has the dimension of time and is defined as the quadratic difference between the pulse durations at the output and the FOC input of length L_p by formula

$$\tau(L_p, \lambda_i) = [t^2_{вых}(\lambda_i) - t^2_{вх}(\lambda_i)]^{0,5} \le 0,25/V_b \text{, ps, } i = \overline{1,\ n} \tag{8}$$

It should be noted that when the broadening is sufficiently large, the pulses begin to overlap, so that their isolation becomes impossible when optical signals are received.

The FOCL variance is generally characterized by three main factors, like the transfer characteristics ROM, FOC and TOM [9-11]:

- the difference in the propagation velocities of the guided modes-the intermode mode, $\tau_{мод}(\lambda_i)$;
- dispersion by the guiding properties of the light guide structure-waveguide dispersion, $\tau_{вв}(\lambda_i)$
- properties of the material of the optical fiber-material dispersion math, $\tau_{мат}(\lambda_i)$.

In this case, the resulting dispersion $\tau_{р.дис.}(\lambda_i)$ with wavelengths λ_i is determined from the formula [5, 6]:

$$\tau_{р.дис.}(\lambda_i) = \tau_{мат}(\lambda_i) + \tau^2_{хр}(\lambda_i) + \tau^2_{пмд}(\lambda_i) = \tau^2_{мод}(\lambda_i) + [\tau_{мат}(\lambda_i) + \tau_{вв}(\lambda_i)]^2 + \tau^2_{пмд}(\lambda_i) \quad (9)$$

For FOCL, the dispersion is generally calculated per 1 km and measured in ps/km.

Given the above, it is possible to determine the chromatic dispersion, which is related to the specific chromatic dispersion by a simple ratio

$$\tau_{хр}(L_p, \lambda_i) = D_{хр}(\lambda_i) = D_{хр}(L_p, \lambda) \cdot \Delta\lambda_i, \quad ps/нм \cdot km, \quad (10)$$

where $\Delta\lambda_i -$ width of the radiation spectrum of the source, μm, $i = \overline{1, n}$.

As a result, analysis of the transfer characteristics FOCL determined that in the wavelength $\lambda_i = (1{,}25{,}...{,}166)\mu m$ range chromatic dispersion can be determined by the following functional dependence: $D_{хр}(\lambda_i) = W[L_p, \lambda_i, V_b]$.

Figure 1 shows the graphical dependence of the chromatic dispersion on the wavelength λ_i using FOC, G.652 and G.656, $\lambda_i = (1{,}31{,}...{,}1{,}55)\,\mu m$.

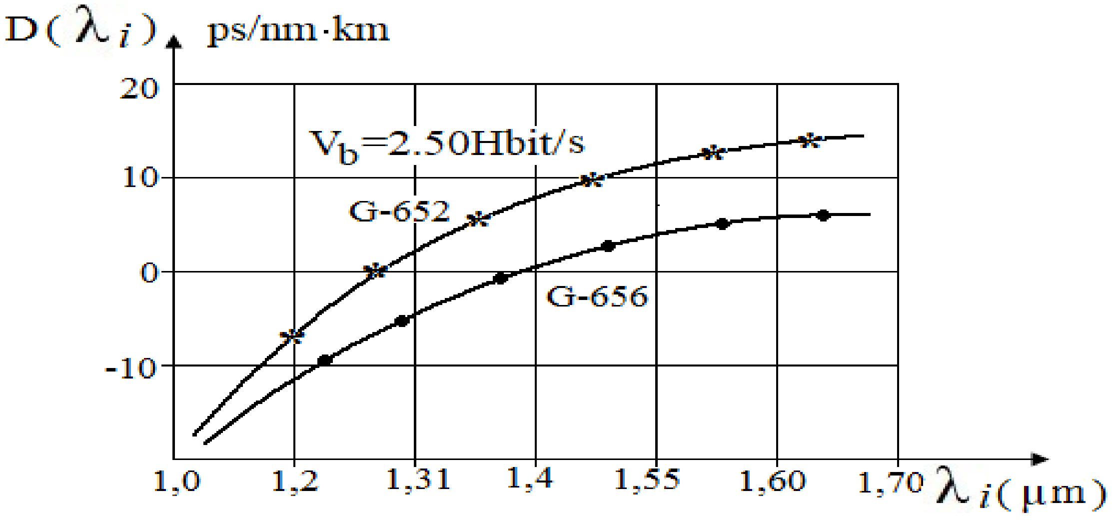

Figure 1. Graph dependence chromatic dispersion on wavelength at given bit rate transmission optical signals

Analysis of the graphical dependence $D_{хр}(\lambda_i) = \varphi[L_p, \lambda_i, V_b]$ shows that with increasing wavelength for a given parameter FOCL, the chromatic dispersion increases. Its noticeable change begins with the wavelength values $\lambda_i \geq 1{,}25\mu m$.

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The relationship between the broad-band coefficient and the variance for a Gaussian pulse is described by the expression: $\Delta F(\lambda) = 0{,}44 / T_b$, $T_b = 1/V_b$, T_b – where the optical transmission signal bit period, $V_b \le 2{,}50$ Hbit/s.

In figure 2 the spectral dependence of the attenuation coefficient and dispersion on the wavelength for single-mode FOCL is presented.

It follows from the graphical dependence that when the wavelength is increased, the spectral dependence of the parameters decreases with the average bit rate of transmission of the optical signals. In addition, it can be seen from the graphical dependence that in order to match the lowest losses in the FOCL with the wavelength λ_i, dispersion FOC with a shifted dispersion are necessary.

Taking into account the duration of the optical radiation pulse $\tau(L_p, \lambda_i)$ in its propagation through the FOC and the relationship between the magnitude of the pulse broadening and the bandwidth of the FOC, it is approximately determined by the relation:

$$\Delta F_{foc}(\lambda_i) = 1/\tau(\lambda_i, L_p), \text{ MHz}$$

So, if $\lambda_i \le 1{,}55$ µm, $\tau(\lambda_i) = 20$ ns, then $\Delta F_{foc}(\lambda_i) = (1/20ns) = 50 \cdot 10^6$ MHz.

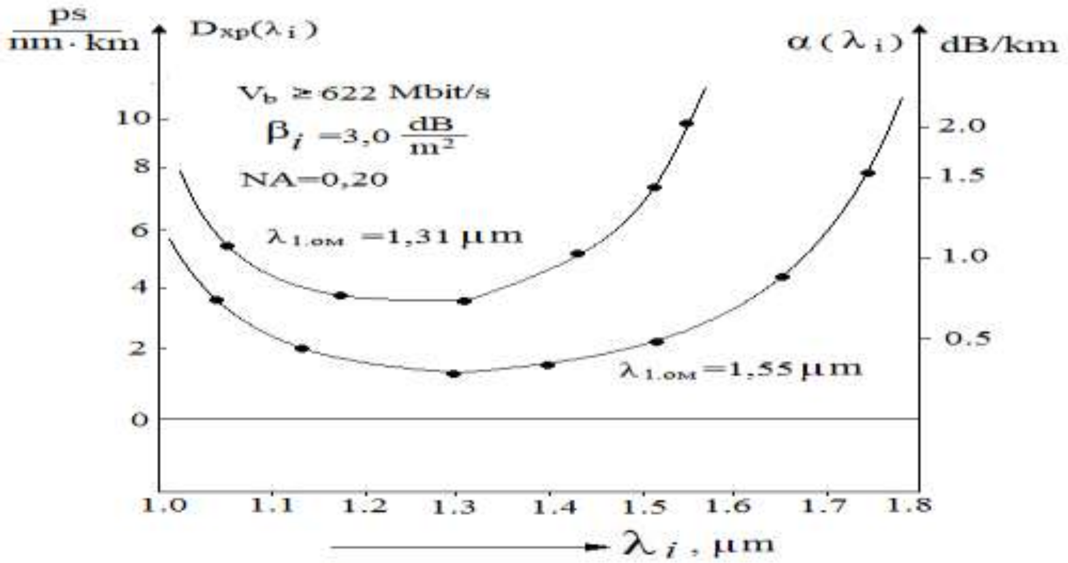

Figure2. The spectral dependence of the damping and dispersion coefficients from the wavelength for single-mode FOCL

Thus, based on the proposed calculation method, analytical expressions and graphical dependencies FOCL using ROM, FOC and TOM are obtained, which allow to estimate their possible transfer characteristics.

VI. CONCLUSIONS

As a result of the FOCT study, a method for calculating FOCL transfer characteristics using the ROM, FOC and TOM indicators was proposed, to ensure the efficiency optical signals transmission and reception. It was found that low attenuation, a small dispersion of signals on the FOCL and a wide bandwidth allow the maximum permissible length of the FOC hopper with increased bandwidth.

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