[7] Antenna radiators connection method for RoF using the optical device and its parameters calculation method

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Abstract

It's proposed to connect radio antenna array in Radio-over-Fiber light guide line through the special optical device, which provides splitting the optical signals in accordance with defined frequency bandwidths. The field calculation inside the device working body is done.

Keywords: *broadband signal, Radio-over-Fiber, fiber optic mixer interference pattern, 3D-refractive index distribution.*

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Introduction

Wideband transmission technology(WBT) "fiber optic radio" (RoF – Radio-over-Fiber, a radio path in the range of ~ 3 ÷ 11 GHz [1]) seems to be one of promising technologies for customer access segments, and is of interest in construction of special applications, for example, creation of GLONASS radio extension, etc. Besides wide bandwidth RoF basic advantages are: small size hardware components, due to the use of analog signal transmission, and therefore a lack of conversion and digital signal processing schemes. An also a considerable secrecy in view of very low-power radio signals (~ -50 ... 55 dBm), which is caused by need to comply with installed spectral mask [1] for WBT radio lines. However, this same quality is also a RoF drawback : the range of the radio transmission remains small (some tens of meters), which greatly limits the applicability of such systems.

WBT-radio RoF length can be increased with the use of antenna array (AA) of directed radio emission [2] instead of separate non– directed antenna radiators It also will allow to increase the adaptability of RoF segments, that has great actuality and is one of coordinating directions in construction of category 5G networks.

However, the question arises of supplying signals and managing antenna array: the use of electronic components is undesirable because of their complexity and considerable size (compared with optical), given the specificity of the considered radio spectrum. Moreover, RoF systems are classically built with a primary optical control: electronic microwave components are only a photodiode, an amplifier, and an antenna itself. One of the main difficulties in construction of directed radio line with AA in the range of frequencies RoF is to provide a predetermined shape of directional diagram (DD), taking into account the broadband emission. The latter is determined not only by wide gain bandwidth of a separate radiator, such as represented in [3], but the method of constructing AA itself, in particular, by selecting the distance between the transmitters *d*, which significantly affects the DD [4]. Thus, in particular, if the parameter *d* is selected from the condition $d \le \Lambda_1/2$ [4], where Λ_1 is the wavelength of radio emission, corresponding to $f_1 = 4$ GHz, then for $f_2 = 8$ GHz and corresponding decrease of Λ_2, the specified condition will no longer be fulfilled, and this will significantly change DD form, making it "colored" in individual spatial segments, Fig.1. The above is highly undesirable as from the point of view of transmission, as for ensuring electromagnetic compatibility and emission stealth.

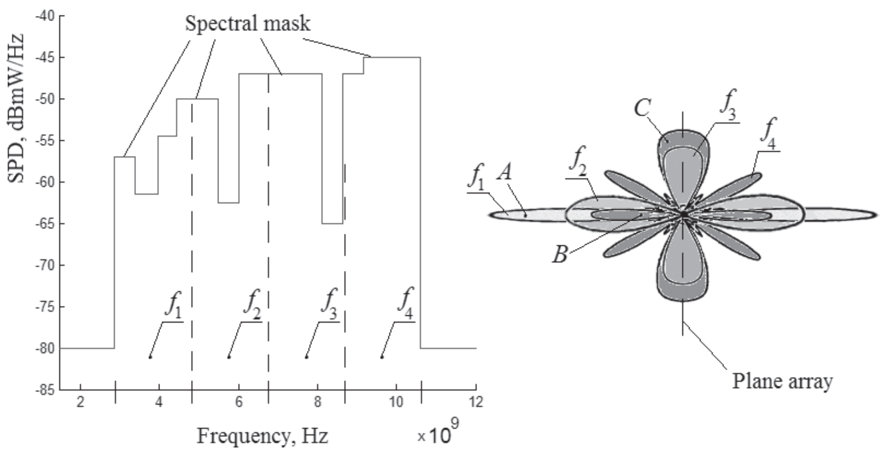


Fig. 1. Example of DD in WBT ; emission at point A is present only on the frequency f1, at point B – on all frequencies, at point C – parasitic radiation at frequency f3, which should not be there.

In the well-known works, such as [5 – 7 and others], aimed at studying the possibility of building the AA for RoF, the problem of eliminating "color" DD is not examined, but it is proposed to use only a narrow part of the range for which the indicated problem yet does not arise. This, of course, improves the DD properties, but significantly reduces the information signal capacity and data transfer speed, virtually nullifying the advantages of WBT RoF. Compensation of these factors in published works is achieved through the use of multiple optical carriers, each of which is assigned a separate radio band, which inevitably requires allocation of additional λ-resource of optical line and, accordingly, is problematic for the majority of access networks, as well as it does not allow a single transmitter to work at a RoF segment, limiting the use of these solutions for the problems of special communication applications.

The aim of this the work is to find the connection method of broadband antenna radiators into the antenna array, which allows to reduce the effect of frequency-spatial dependence of the directional diagram, implemented using optical line device, and assessing technical parameters of the device.

It is proposed to achieve this with the use of interference fiber optic splitter comprising profiled optical mixer as the working body. It seems appropriate also to explore methods for calculating the spatial interference picture in the mixer and to develop acceptable from a technical point of view methodology of calculation. It will allow to specify technical parameters of the latter and to propose an approach to its implementation.

1. Method of connecting antenn a radiators using an optical device

To align the spatial frequency characteristic of AA it is proposed to use as part of an array a larger number of radiators, than is required to produce a given directed properties radioline, and energize them not identically, but with division into frequency subbands (along the y, Fig. 2). At the same time radiators of each subband should be placed with implementation of the condition :

$$d_k \cong \frac{\Lambda_k}{2}\ , \qquad (1)$$

where Λ_k corresponds to the central radio frequency of a subband f_k.

This way of connecting AA elements provides DD pointedness for all WBT signal, and to perform the task of petal deflection the array shall be made not linear but flat, Fig. 2.This provides a settlement of signals on each series of radiators, connected on the basis of the condition (1), with a consistent phase shift (along direction x), from which the location of DD petal will depend [4].

The presented method of connecting the AA radiators involves the use of complex optical component in RoF fiber line. The latter must provide "cutting" frequency bands from the optical WBT signal , branching the received optical signals with a separation coefficient at least 50 (and in practice – much more) to format an effective AA and, if necessary (if the RoF fiber optic line is about some tens of kilometers), compensation of acquired in-line signal distortion. For this purpose it is proposed to use a fiber optic interference splitter with profiled mixer [8], characterized by [8] using an alloy (with, for example, Erbium, for amplification of emission in the range 1550 nm) of a material for manufacturing the mixer, Fig. 3, and the presence of the piezoelectric matrix (PM) in the additional waveguides.

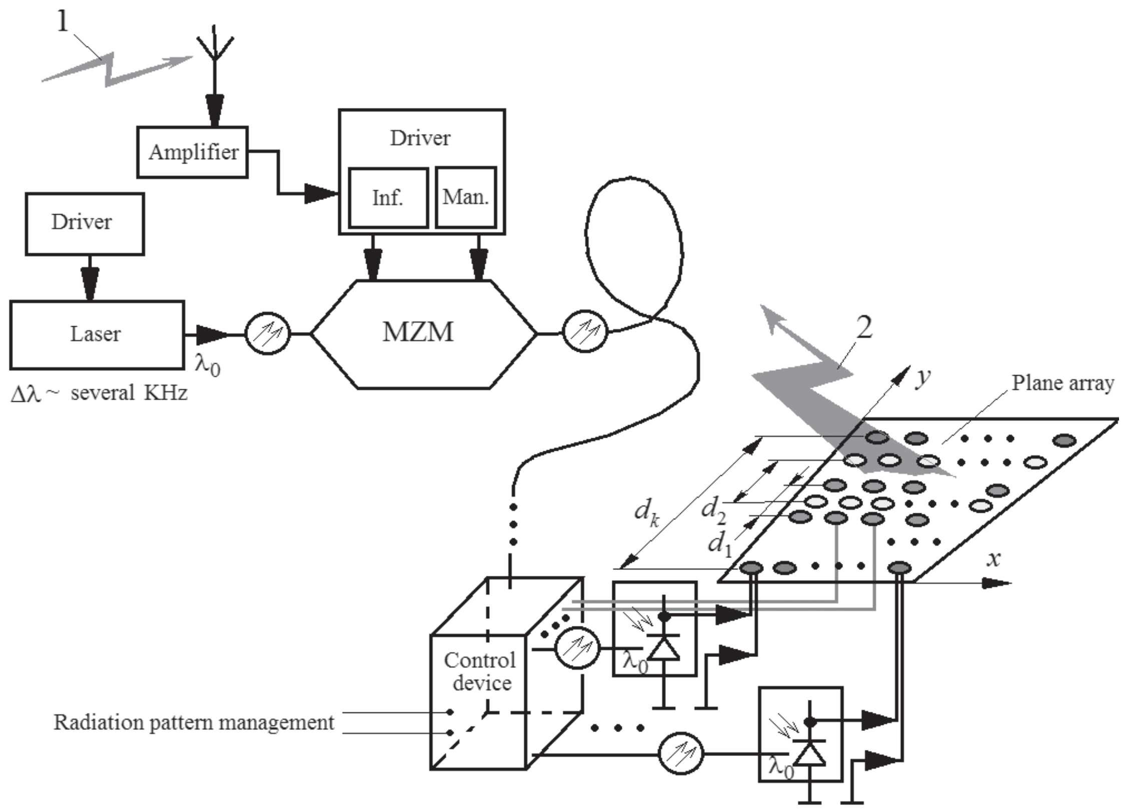


Fig. 2. Scheme of the transmission line for the WBT-RoF with radiating AA; 1 – emission at the line input, received by transmission system; 2 – directed emission generated by the AA; LNA – low noise amplifier; MZM – Mach-Zehnder modulator; OCD – optical control device

Device according to Fig. 3 enables connection of a large number (up to ~ 200) of the output waveguides through the use of a mixer with widening end portions [8], amplification of the signal when applying pump emission through the optical fiber 2 due to application of doped material, as well as interference selection (cut) of spectral bands $\Delta\lambda_k$ of WBT signal with the width, determined by the quality of Fabry-Perot resonator formed by the ends 6 and 7.

It should be noted that the ends 6 and 7 are composed of the end faces of optical fibers, which are offset in an axial direction relative to each other and are set under the following conditions by distances [8] Fig.3:

$$l_{0,k} = m\frac{\lambda_k}{n_0} \qquad (2)$$

where λ_k are central optical lengths of spectral bands waves $\Delta\lambda_k$, n_0 is an averaged over volume value of the refractive coefficient of the material of the mixer, m is the order of the interference pattern determined by the same ratio $l_0 = m\frac{e_0}{n_0}$, in which λ_0 is the central wavelength of signal transmission, and l_0 is the distance between the ends 6 and 7 along the axis line of the mixer.

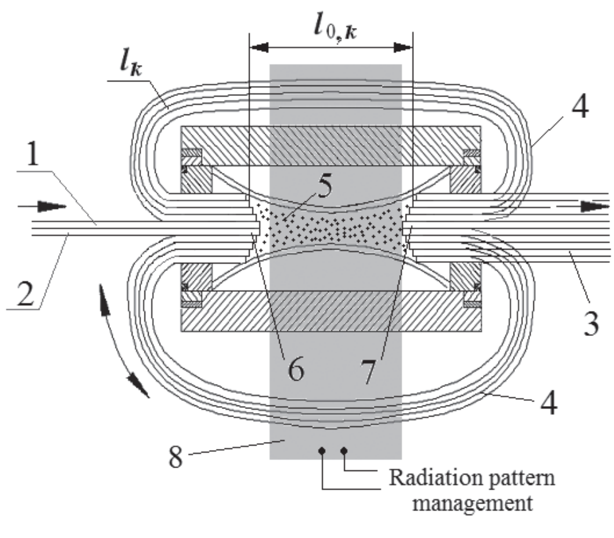


Fig. 3. The design of the optical control device for optical signal for AA in RoF; 1 – input lightguide; 2 – lightguide for supplying pump emission into the mixer; 3 – output and 4 – additional lightguides; 5 – mixer; 6 and 7 – the input and output ends of the mixer, one of which can be made flat, and 8 – piezoelectric matrix

Using the PM, at whose piezoelectric elements additional OCD lightguides are selectively attached, Fig. 3, allows to change the length of sections of additional lightguides, respectively changing the signals phase shift, propagating in them. This provides the delay of signals submitted to AA, which leads to a deviation of DD petal.

To make the ends of the mixer 6 and 7 ensure interference of the Fabry-Perot type, and homogeneity of the reflection was achieved, they are first covered with a reflective material, and then polished lightguides end faces (input, output, and additional) are glued to such ends of a mixer. The coating thickness must be less than half the emission wavelength. To ensure an acceptable illumination of the mixer, the emission is not served by a single lightguide, but along the lightguide wiring with a dense deployment of lightguides. To increase the percentage of "radiating" area of the wiring end before its assembly the optical hull of each of used lightguides is partially grinded. In order to increase the dimensional stability of the mixer reverse optical communication can be used (for example, with involvement of one of the additional lightguides) that will allow real-time control of devices. Furthermore, the mixer should be placed on an electronic temperature stabilizer, based on the Peltier element, and its external protective shells must have damping properties.

2. Setting the modeling task

For effective calculation of optical interference managing device for AA – RoF it is necessary to perform a simulation of electromagnetic field structure in the mixer, Fig. 4, which is the most difficult element of the OCD, which will allow to specify its design parameters with respect to the estimates presented in [8].

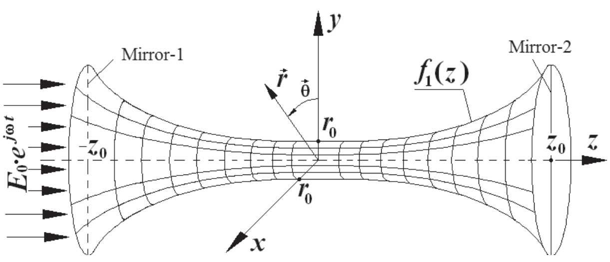


Fig. 4. Illustration of the mixer, which is a OCD work area ; the mirror 1 corresponds to end 6, and the mirror 2 – to end 7 in Fig. 3, respectively

The task is set to find the intensity of electric component of the light wave field $E(r,z,t)$, or its Fourier image $\widetilde{E}(r,z,\omega)$ for $r^2 < f_1(z)$, $z \in [-z_0, z_0]$ with a relative error $\varepsilon \le 10\%$. Effects on the mirrors and on the profile surface of the mixer may be non-regarded. Consider that the profile is a body of rotation, ie, $x^2 + y^2 = r^2 = f_1(z)$ and does not depend on θ, $f_1(z)$ is smooth, monotonic. The refractive index inside the mixer may be not uniform, i.e. defined as: $n(r,z) = f_2(r)$, or $n(r,z) = f_3(r,z)$ for $r^2 < f_1(z)$ for the given value ω. The refractive index out of the mixer is $n(r,z) = n_{\hat{i}\acute{a}}$ for $r^2 > f_1(z)$. The reflection coefficient from the ends ρ_T can be represented by the so-called effective index of refraction at the ends $n(r,-z_0) = n(r,z_0) = n_0^*$ and may be calculated from the ratio [9]:

$$n_0^* = \frac{1+\rho_T}{1-\rho_T} \text{ для } r^2 < f_1(-z_0) \text{ и } r^2 < f_1(z_0) \qquad (3)$$

which is physically due to the difference in refractive indexes of material of the mixer and the medium in the vicinity of its ends.

Let the geometrical parameters be assumed on the basis of estimates presented in [8]: $z_0 \in [20, 200]$ micron, $r_0 \in [2, 15]$ micron. Suppose that the mixer input receives continuous wave $E_0 \cdot \exp(j\omega t)$ with $\omega \in [10 \cdot 10^{14}, 15 \cdot 10^{14}]$ rad/s, which corresponds to wavelengths about $\lambda_0 = 1550$ nm.

As part of the task set the sub-problem is being presented of finding $E(r,z,t)$ or $\tilde{E}(r,z,\omega)$ in case if the profile has a reflection with a reflection coefficient:

$$\tilde{n}_{\ddot{I}} = \frac{f_2 - 1}{f_2 + 1} \text{ or } \tilde{n}_{\ddot{I}} = \frac{f_3 - 1}{f_3 + 1} \text{ for } r^2 = f_1(z).$$

Besides, at least one of the mixer mirrors, for example, the second is "difficult", for which $r = f_4(z)$, $z \in [z_0 - \frac{\hat{i}\ddot{e}_0}{2}, z_0 + \frac{\hat{i}\ddot{e}_0}{2}]$; ν is a coefficient of 3.depth of the end (of the mirror), Fig.5. The end can be coated with a reflective coating, then $n(r,z) = f_5(z)$ for $r^2 < f_1(z)$ and $r = f_4(z)$.

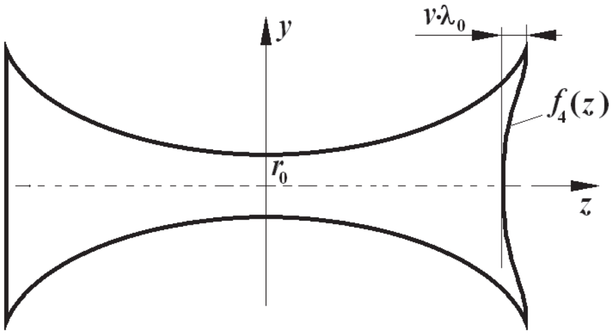


Fig. 5. Illustration of the mixer with a "difficult" second mirror.

3. Modeling methods and results

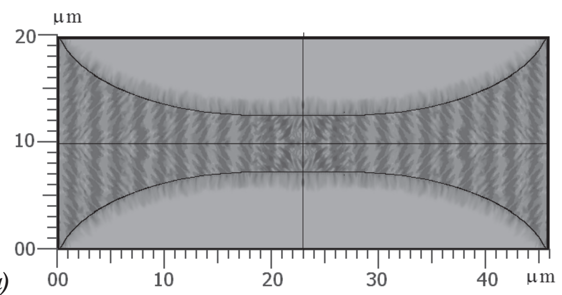
«Direct» approach to obtaining spatial interference pattern in profile mixer, based on the finite difference numerical solution of the Helmholtz equation, presented in the form of:

$$\frac{\tilde{E}(r_{i+1},z,\omega)-2\tilde{E}(r_i,z,\omega)+\tilde{E}(r_{i-1},z,\omega)}{h_r^2}+$$
$$+\frac{\tilde{E}(r,z_{i+1},\omega)-2\tilde{E}(r,z_i,\omega)+\tilde{E}(r,z_{i-1},\omega)}{h_z^2}+ \qquad (4)$$
$$+n^2(r,z,\omega)\cdot\frac{\omega^2}{c^2}\cdot\tilde{E}(r,z,\omega)=0$$

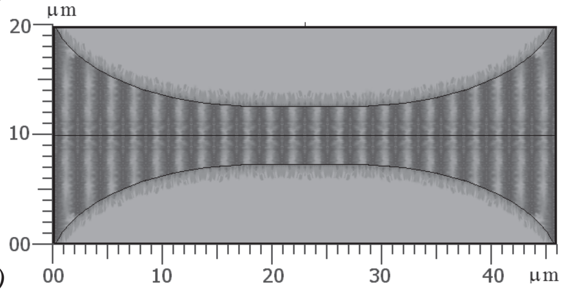
gives the result shown in Fig. 6a. Calculation of optical emission power $M(r, z, \omega)$ was conducted for the following parameters of mixer and emission: $f_1(z)=\chi_1 z^2+\chi_2 r_0^2$, $r_0 = 7$ мкм, $\omega=\omega_0=12{,}2\times10^{14}$ rad/s ($\lambda_0 = 1{,}55$ micron); $E_0 = 2{,}1\times10^5$ V / m (corresponding to 10 mW in the light guide of SMF-28 type); mixer material was accepted homogenous: $f_2(r) = 1{,}52 = n_{сер}$ и $n_0^* = 9$ ($\rho_т = 0{,}8$), $n_{об} = 1{,}48$, that corresponds to refractive medium $n_{сер}$ and $n_{об}$ for SMF-28; $f_4(z) = 1$. Coefficients χ_1 and χ_2, which in this case define f_1 and actually the depth of the profile, have been taken: $\chi_1 = 7{,}1\times10^{-3}$ and $\chi_2 = 1$. Their values were determined by choice on the basis of the resulting structure of the field: a single-mode propagation regime in a mixer had to be maintained. M parameter was calculated basing on the following ratio:

$$M(r,z,T)=\frac{\dot{E}(r,z,T)\cdot\dot{E}^*(r,z,T)}{2Z_B},$$

where $\dot{E}(r,z,T)$ is a complex-value function that characterizes the electric field intensity of the light wave, determined from $\tilde{E}(r,z,\omega)$ by Fourier inverse transform method using a change of variables $T=\frac{t-z\cdot\alpha_1}{T_0}$ in order to move to the timeline associated with the signal; T_0 is the effective duration of the input signal; $\dot{E}^*(r,z,T)$ is complex conjugate function for $\dot{E}(r,z,T)$; Z_B is the wave medium impedance, in the calculations taken as $Z_B = 120\pi$ Ohm.



a)



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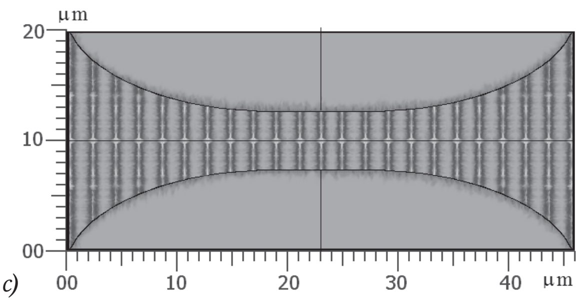


c)

Fig. 6. The results of calculation of electromagnetic field structure in a short symmetrical mixer with the step of Δz = 10 nm; a) method A or "direct" method; b) method B, and c) method C.1

An error estimation of counting was held by comparison with the same values in the center of the mixer (along the z-axis), obtained for classical Fabry-Perot interferometer (IFP) with parameters $f_1(z)=r_0=7$ and $z_0 = 46$ micron:

$$E(0,z_0,T)=\frac{1-\rho_T}{1-\rho_T\cdot\exp\left(j\frac{8\pi n_{cep}z_0}{\lambda}\right)}E_0\cdot\exp(j\omega T) \qquad (5)$$

In the central area of the mixer due to the parallelism of mirrors the difference of the interference pattern of the profile and the classic of IFP should not occur. The greatest error of calculations was as follows: $\varepsilon \le 6{,}4\%$.

The method of calculation in accordance with (4) is useful for analyzing the structure of the field in the short (up to ~ 50 micron) mixers. But with an increase in the length of the latter decision diverges, Fig. 7.

Therefore, for calculation of the field in practically significant mixers with length of the order of 200 micron the equation (4) should be simplified. By analogy with [10] it is proposed to simplify the Helmholtz equation by neglecting the second derivatives of the wave amplitudes by the coordinate z, representation of refractive index n by the phase coefficient β: $\beta = n\frac{\omega}{c}$, where c is the speed of light in vacuum.

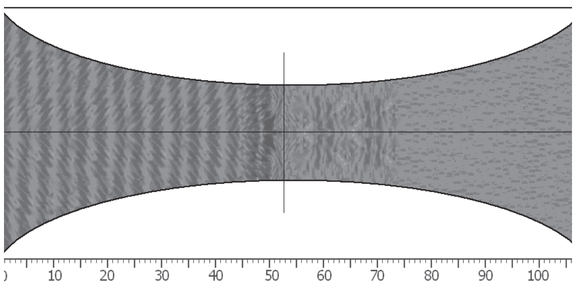


Fig. 7. Illustration of divergent solution, based on the finite-difference integration of differential equation of 2nd order (4)

As well as decomposition of β function in a power series in powers (ω − ω_0) and considering only the first two terms β_0 (characterizing the input radiation and approximately equal to $2\pi/\lambda_0$) and β_1 (characterizing value of the group speed of the signal in the mixer [10]), and a further algebraic simplification of type $n^2 = (n_0 + \Delta n)^2 \approx n_0^{\,2} + 2n_0\Delta n$. Also a solution for $\tilde{E}(\omega, r, z)$ is proposed to search as a product of "longitudinal" $\tilde{A}(\omega, z)$ and "transverse" $\tilde{F}(\omega, \mathbf{r})$ components, while with the presence of the interference pattern it should be represented $\tilde{E}(\grave{u}, r, z)$, or rather, its component $\tilde{A}(\omega, z)$ as the sum of counterpropagating waves. For the case where the profile can be considered non-reflective ($\rho_\Pi \le 0{,}2$), solution search was carried out in the form of flat opposing waves, and that was what constituted the B method:

$$\tilde{E}^q(r, z, \omega) = \tilde{F}^q(\mathbf{r}, \omega) \cdot \exp(-j\beta_r^q r) \times$$
$$\times \left[\tilde{A}_f(z, \omega) \cdot \exp(j\beta z) + \tilde{A}_b(z, \omega) \cdot \exp(-j\beta z)\right] \quad (6)$$

where $\tilde{A}_f$ and $\tilde{A}_b$ are Fourier transforms of the longitudinal amplitude components of the waves, going back and forth in a mixer; $\tilde{F}^q(\mathbf{r}\grave{u})$ is the effective radial distribution of the amplitude field component at each step Δz for (Fig. 8*a*); *q* is the number of the "short" resonator, $q \in [1, Q]$;

$$\hat{a}_r^q = \frac{\eth \cdot n(r, \Delta z \cdot q)}{2\sqrt{f_1(\Delta z \cdot q)}}$$

are phases coefficients of the corresponding waves. Effective radial field distribution was determined by a modified method of Gauss [11], where:

$$\tilde{F}^q(r, \omega) = \tilde{F}(r, z_q, \omega) =$$
$$= \frac{1}{J_0(U(\omega))} \cdot J_0\left(U(\omega) \cdot \frac{r}{\sqrt{f_1(\Delta z \cdot q)}}\right) \quad (7)$$

for $r^2 < f_1(\Delta z \cdot q)$, where $U(\omega)$ is a generalized parameter characterizing propagation of emission in view of the refractive index of the medium of resonator mixer, in this case was calculated as:

$$U(\omega) = \frac{\omega}{c} r \cdot n(r, z, \omega)$$

J_0 is Bessel function of the first kind. Equation (7) is not represented as vector, but as scalar, for it is possible to view a flat picture because of a circular (azimuth) mixer symmetry and feasibility of consideration of only such decisions in which there is a single-mode propagation of the field in a mixer.

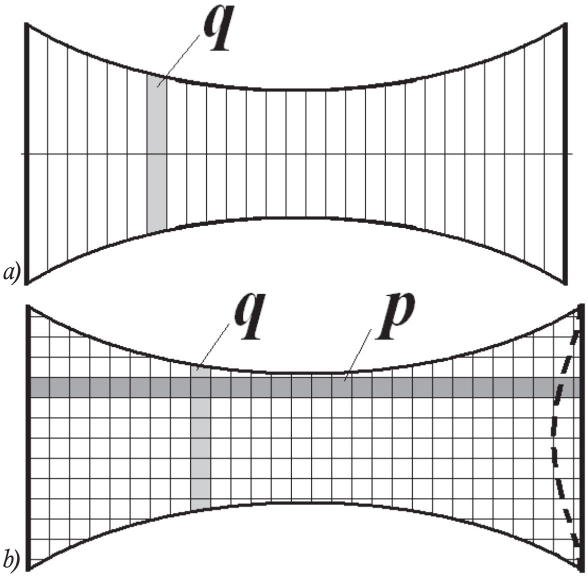


Fig. 8. Illustration of the principle of partition: a– on the "short" resonators, b – on the "short and narrow" resonators

Ratios for longitudinally propagating field in a mixer, resulting from simplification of the Helmholtz equation, have the form:

$$\frac{d\tilde{A}_f(z, \omega)}{dz} = j(\beta - \beta_q) \cdot \tilde{A}_f(z, \omega) + \Re_q \cdot \left|\tilde{A}_b(z, \omega)\right| \text{ и}$$
$$-\frac{d\tilde{A}_b(z, \omega)}{dz} = j(\beta - \beta_q) \cdot \tilde{A}_b(z, \omega) + \Re_q \cdot \left|\tilde{A}_f(z, \omega)\right| \quad (8)$$

At each step Δz, where $\beta_q = \frac{\pi}{|z_{q+1} - z_q|} \cdot \left[\frac{f_1(z_q)}{f_1(z_0)}\right]^2 \cdot n(r, z_q)$

and the coupling coefficient $\Re_q$ was defined as:

$$\Re_q = \frac{\pi}{\lambda_0} \cdot \frac{\int_{-\infty}^{\infty} \left|n^2(r, z_q) - \langle n^2(r, z_q)\rangle\right| \cdot \left|F^q(r, T)\right|^2 dr}{\int_{-\infty}^{\infty} \left|F^q(r, T)\right|^2 dr},$$

$F^q(r, T)$ was found from (7) by inverse Fourier transform. Equations (8) were solved by finite difference method using a computer.

Fig. 6b shows the result of calculation of the standing waves in a mixer-resonator by method B for Q = 10 and $T_0 = 10^{-6}$ c (other parameters were taken the same) for the constant refractive index of material of the mixer.

In order to explore the importance of reflection from the profile it was suggested to seek solution in the form of conical counter– propagating waves:

$$\tilde{E}^q(r, z, \omega) = \left[\tilde{F}_+^q(r, \omega) \cdot \exp(j\beta_r^q r) + \right.$$
$$\left. + \tilde{F}_-^q(r, \omega) \cdot \exp(-j\beta_r^q r)\right] \times \quad (9)$$
$$\times \left[\tilde{A}_f(z, \omega) \cdot \exp(j\beta z) + \tilde{A}_b(z, \omega) \cdot \exp(-j\beta z)\right]$$

and to add the system of equations (8) with equations composed by analogy with the procedure set forth in [10], which was a method of C.1:

$$\frac{d^2\tilde{F}_+(r,\omega)}{dr^2} = j\left(\beta-\beta_r^q\right)\tilde{F}_+(r,\omega)+\Re_q\cdot\left|\tilde{F}_-(r,\omega)\right| \text{ и}$$

$$-\frac{d^2\tilde{F}_-(r,\omega)}{dr^2} = j\left(\beta-\beta_r^q\right)\tilde{F}_-(r,\omega)+\Re_q\cdot\left|\tilde{F}_+(r,\omega)\right| \qquad (10)$$

Splitting the transparent area of the mixer during the calculations was still carried out in accordance with Fig. 8a.

As a result of calculation of the M value by method C.1 for a short mixer (with a length of 46 micron) with the parameters given above, the following was established: ridges of the standing wave significantly skew with an increase in the reflection coefficient of the profile $\rho_П$. Already at $\rho_П \geq 0,18$ deviation of the ridges of the standing wave from a straight line (as measured by standard deviation) exceeded 7%, and only with $\rho_П < 0,08$ were obtained substantially straight (with a deviation of less than 2%) ridges, Fig. 6c. Furthermore, the method of computing C.1, unlike calculations by "direct" method and by B method showed that the tops of the ridges have many peaks, Fig. 9, that, generally speaking, is in good agreement with the results obtained by "beam" method in the analysis of the spatial interference picture in the profiled Fabry-Perot interferometer with a view of reflection of the profile [12, 13].

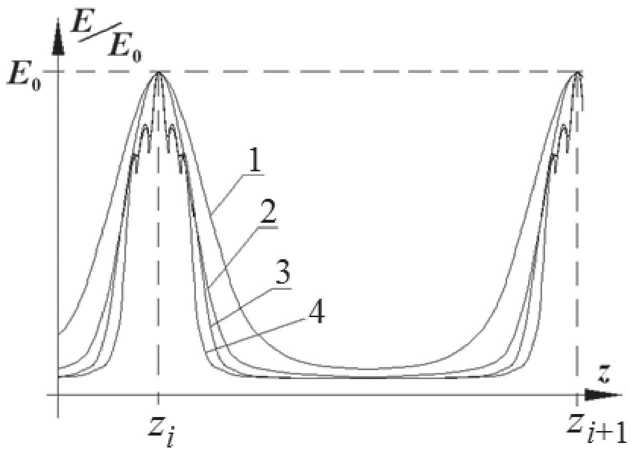


Fig. 9. Illustration of the results of field power calculation by the axis of the mixer by methods presented above: 1 – "direct method"; 2 – method B; 3 – "beam" method [12, 13], and 4 – method C.1

Basing on these calculations the conclusion was made that for research of the field in long mixers C.1 method should be used. Further, since for practical applications it is desired to obtain flat crests of a standing wave in a mixer– resonator, located perpendicular to the axis of the last, the mixer index n must not be uniform. Also taking into account the complex nature of construction of resonator mirrors, Fig. 3, n ratio is likely to have to change not only by r, but also by z. Function $n(r,z)$ can be determined by solving the inverse problem: when the location of the standing wave crests and the mixer parameters are given, including the desired $\rho_П$.

For calculating the capacity of the field in the long mixer with a difficult second mirror it was proposed to present equations (9) in the form of:

$$\begin{aligned}\tilde{E}^{q,p}(r,z,\omega) &= \Big[\tilde{F}_+^{q,p}(r,\omega)\cdot\exp\left(j\beta_r^{q,p}r\right)+\\ &+\tilde{F}_-^{q,p}(r,\omega)\cdot\exp\left(-j\beta_r^{q,p}r\right)\Big]\times\\ &\times\Big[\tilde{A}_f(z,\omega)\cdot\exp(j\beta z)+\\ &+\tilde{A}_b(z,\omega)\cdot\exp\left(-j\left(\beta-B\left(z_{q,p}\right)\right)z\right)\Big]\end{aligned} \qquad (11)$$

and consider the process of spreading of counter-propagating waves in the "short and narrow" resonators, Fig. 8b, which was the C.2 method. In (11) is indicated:

$$\beta^{q\ p} = \frac{\pi\cdot n\left(r_p\ z_q\right)}{\sqrt{f(z)}},\ B\left(z_{q,p}\right)=\frac{\pi n\left(r_p,z_q\right)}{2z_0+z_p},$$

$\nu = 1$, $\Delta r = 10$ nm, $z_p = f_4^{-1}(\Delta r\cdot p)$, $p\in[1,P]$.

Equations (8) were used for calculation with coefficients

$$\beta_{q,p} = \frac{\pi}{\left|z_{q+1}-z_q\right|}\cdot\left[\frac{f_1\left(z_q\right)}{f_1\left(z_0\right)}\right]^2\cdot n\left(r_p,z_q\right)$$

and equations (10). To simplify calculations the same $\Re_q$ coefficients were used.

Fig. 10 shows the results of calculation by methods C.1 and C.2, conducted with the assistance of program modules [14]. The values were used in the calculations: $\rho_т = 0,8$; $Q = 80$; $f_1(z) = \div_1 z^{1,6}+r_0^2$. When receiving the forms shown in Fig. 10, a and b, the profile reflection was established $\rho_П = 0,08$, which allowed to determine the value r_0 and χ_1 for the case of uniform refraction in the mixer. The highest value r_0 was received, at which the field in the area of the second mirror of the mixer practically is still not formed as a series of some concentric shapes, which equaled ~ 39,8 mkm; while the coefficient χ_1 turned out to be 8,4×10-

[2] (coefficient χ_2 = 1). When calculating a field pattern in a long mixer with a complex second mirror with the function $f_4(z)=|r|=1,43\left(z-z_0^*\right)^{3,31}$, selected on the basis of geometric parameters of light guiding wiring, and parameters z_0^* = 200 mkm, z_0 = 205 mkm, P = 30 it was found out that even for weakly reflecting profile the ridges of standing wave skew greatly already starting almost from the middle of the mixer (along the z axis), and in the area of the second mirror everything is mixed and chaos begins . Selection of parameters of the system, in which the refractive index of the material of the mixer remained unchanged, did not allow to receive any pronounced interference pattern in which separately located and not intersecting ridges could be observed. This led to the need to perform the selection of function $n(r,z)$, which provides achieving such spaced apart ridges. Thus, Fig. 10B shows the result of field calculation by method C.2, obtained from a pre-selection of the volumetric nature of the change in the refractive index, Fig. 11, provided significant (ρP = 0.3) reflection from the profile.

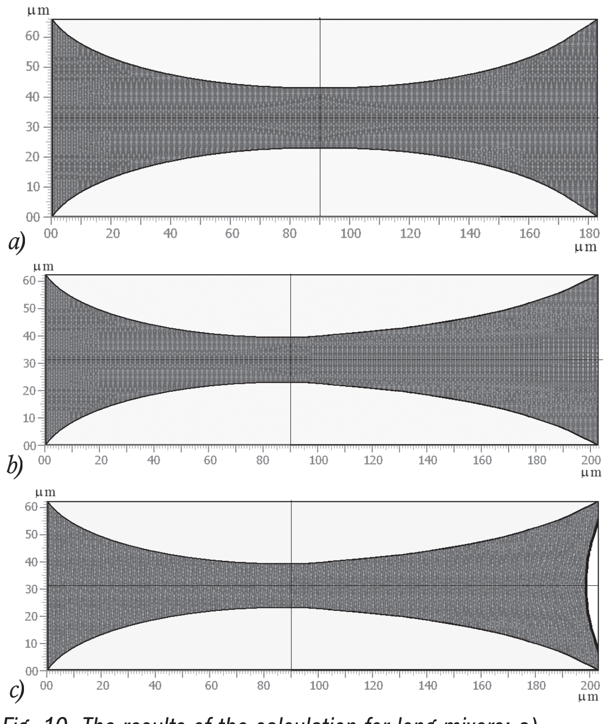
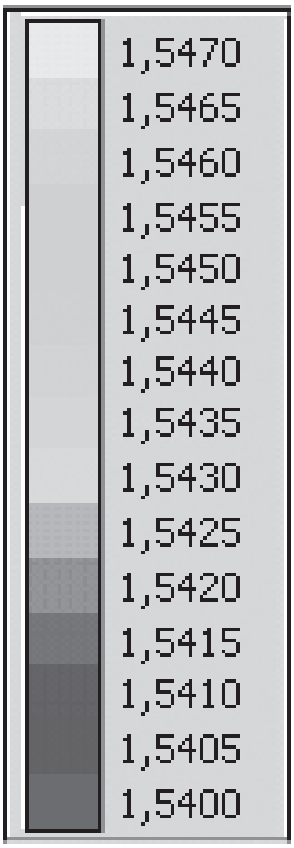
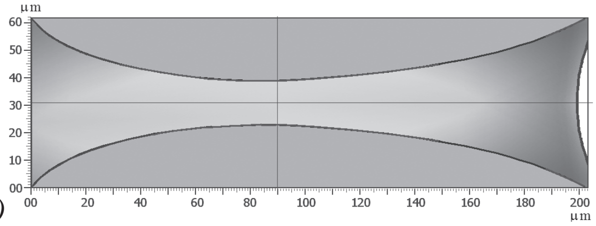


Fig. 10. The results of the calculation for long mixers: a) – method C.1 and χ_1 = 2,5×10^{-2}; b) method C.1; calculating the results shows that there is a predominance of single concentric beam, χ_1 = 8,4×10^{-2}; c) method C.2, applied to the material of the mixer with a volumetric nature of change of the refractive index, shown in Fig. 11.

It is evident that in order to get a virtually significant optical element for antenna array controller in the RoF it is required to ensure the implementation of complex volumetric 3D-distribution of refractive index of the mixer in view of the profile of the latter. Modern technologies of producing optical elements with gradient index, based on the use of a complex alloying material, allow, as a rule, to solve the problem of 2D-distribution, which means the need to bring a new approach to production of such optical media. For this purpose it seems appropriate to explore the possibility of using volumetric 3D nanocrystal optical material made with volumetric non-uniformity of nanostructure processing. It is possible that such processing in relation to the workpiece with an appropriately chosen original 2D distribution of n due to alloying or mixing of similar material compounds will allow to get the desired optical element. In order to monitor parameters of the workpiece, for example, a mass spectrometer analyzing instrument base can be used.



a)



b)

Fig. 11. Illustration of refraction function n (r, z), obtained by numerical selection and provided in the color format: a) – the scale for values of the refractive index, and b) – the result of calculation of n (r, z)

Conclusion

In the work the task is designated to connect radio emitting elements into antenna array for broadband signals that are of interest in Radio-over-Fiber systems. To eliminate the effect of frequency-spatial dependence of direction diagram of the array it is proposed to use in RoF optical line an interferential fiber optic splitter, comprising a profiled optical mixer as a working device body. Eliminating the effect is achieved by separating optical signals of given spectral bands and their corresponding summing to radio-emitting elements. The last should be located at distances from each other which are determined from the conditions of high gain DD for each of the frequency bands.

To clarify the parameters of the most complex element of the considered optical device, an optical mixer, the methods are investigated of calculating the spatial interference pattern which is established between its ends. The comparison was made of simulation results obtained by numerical integration of the equation of order 2 (Helmholtz, method A), and also the system of equations, derived from simplifying the latter and from presentation of the desired solution in the form of a product of the longitudinal and transverse components (methods B and C). It was established that by the A method interference pattern in the small length mixers can be obtained (up to about 50 microns). To investigate the mixers of practical significance with the order of 200 microns in length, one should use the methods B and C.

It was also established that in mixers with a "complex" (curved) end (the mirror) and constant refractive index throughout its volume, the interference pattern in the area of output end is irreversibly broken. To restore the structure of the latter is possible by using volumetric 3D-distribution of refraction of the mixer, obtained by numerical solution of the inverse problem, finding the said distribution, in which there are separately located ridges of a stationary electromagnetic wave in a mixer– resonator with nonintersecting orders of interference. For manufacture of this optical body it is suggested to explore the possibility of volumetric nanostructural processing to obtained by alloying 2D– billet.

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