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Scattering of Optical Pulses by Add-Drop Filters on Dielectric Microresonators

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We consider a system of ring microresonators with whispering gallery oscillations of ultrahigh-Q, which are widely used to construct various integrated filters of the optical wavelength range. Using the perturbation theory, an electrodynamic model has been developed that describes a complex system of coupled microresonators with doubly degenerate types of natural oscillations, as well as located between two different transmission lines. General analytical expressions are obtained for describing the non-mutual characteristics of the scattering of the eigenwaves of a line on a system of optical microresonators that form a channel splitter. The frequency dependences of the scattering matrix of optical filter couplers with several communication channels are calculated. Based on the constructed analytical model, the time Green's functions are calculated for filters with serial coupling between microresonators, filters with microresonators coupled along the side wall and two transmission lines, as well as filters built on a double lattice of microresonators coupled along two transmission lines. The envelopes of optical pulses scattered by filters into various channels are considered. The envelopes of a rectangular and Gaussian single pulses scattered by 10-cavity filters of various designs are studied. The mutual influence of several rectangular as well as Gaussian pulses during their scattering by multilink optical splitters is investigated. Based on a comparison of the data obtained for the three types of structures, it is concluded that filters with laterally coupled microresonators are preferred. The obtained practical simulation results can significantly reduce the computation time and optimize complex multi-resonator structures of optical communication systems that simultaneously perform the functions of separation, or combination of channels.

Key words: dielectric microresonator; scattering; pulse; Add-Drop filter; Double-channel SCISSOR; Twisted Double-channel SCISSOR

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Introduction

Optical filters built on the basis of microresonators are widely used in various devices of the optical and infrared wavelength ranges [1–14]. The most promising is the use of dielectric microresonators in optical communication systems for the separation and combination of channels in WDM technologies. To solve this problem, it is proposed to use the so-called Add-Drop filters. Of greatest interest are filters built using planar structures of microresonators. The better part studied Add-Drop filters are divided into filters with sequential arrangement of microresonators and filters with lateral connection with optical transmission lines. Each of these types of filters has its own advantages and disadvantages. However, no comparative analysis of the filters was carried out. To compare the characteristics of the filters, it is desirable to study the scattering of optical pulses. Currently, only frequency response of scattering matrices of Add-Drop filters is considered. The scattering of optical pulses by such filters has not been fully investigated.

1 Statement of the problem

The purpose of this article is analysis of envelopes of optical pulses scattered by different Add-Drop filters; research of the best type of filters for transmitting optical pulses with minimal distortion. An analytical solution to the pulse scattering problem can be obtained by calculating and applying the temporal Green's functions [10]. In this case, we will only be interested in the pulse envelopes in the input and output transmission lines of the filter. As a result, the solution to the problem is obtained in a simplified form of an integral of the time Green's function and the envelope of the incident pulse.

2 Calculation Green' functions of the Add-Drop filters

Suppose we have a complex system of the N coupled microresonators, which is located in open space and a part of it also coupled with two different transmission lines (Fig. 1-3, a). Suppose that each of the microresonators has a doubly degenerate type of natural oscillations on the frequency $\omega_0 = 2\pi f_0$, each of which is characterized by a given symmetry with respect to the selected plane: even $(\vec{e}_n^{\,e}, \vec{h}_n^{e})$, or odd $(\vec{e}_n^{\,o}, \vec{h}_n^{o})$ [15]. Let a wave $\left(\vec{E}^+, \vec{H}^+\right)$ falls on 1 port of the system via regular transmission line (Fig. 1-3, a).

The eigenoscillation field of the system of N dielectric resonators we represented as a superposition of isolated fields of the resonators of even and odd types:

$$\vec{e}^{\,s} = \sum_{n=1}^{N} b_n^{es} \vec{e}_n^{\,e} + \sum_{n=1}^{N} b_n^{os} \vec{e}_n^{\,o}\,; \qquad \vec{h}^{s} = \sum_{n=1}^{N} b_n^{es} \vec{h}_n^{e} + \sum_{n=1}^{N} b_n^{os} \vec{h}_n^{o}\,. \tag{1}$$

The matrix B

$$B = \begin{bmatrix} b_1^{e1} & b_1^{e2} & \ldots & b_1^{e2N} \\ b_1^{o1} & b_2^{o2} & \ldots & b_2^{o2N} \\ . & . & . \\ b_N^{o1} & b_N^{o2} & \ldots & b_N^{o2N} \end{bmatrix} \tag{2}$$

of the amplitudes of coupled microresonator oscillations $b_t^{e,o,s}$ should satisfy the equation system as an eigenvector of coupling operator K [12]. The found eigenvalue $\lambda = 2(\delta\omega + i\omega'')/\omega_0$; ($\delta\omega = \mathrm{Re}(\omega - \omega_0)$; $\omega'' = \mathrm{Im}(\omega)$) and eigenvectors of the matrix K we used for solving the scattering problem of the wave $(\vec{E}^+, \vec{H}^+)$ on a system of coupled microresonators of the filter. For the solution of the problem we represented decomposition:

$$\vec{E} \approx \vec{E}^+ + \sum_{s=1}^{2N} a^s \vec{e}^{\,s}\,; \qquad \vec{H} \approx \vec{H}^+ + \sum_{s=1}^{2N} a^s \vec{h}^{s}\,, \tag{3}$$

where a^s are the unknown amplitudes ($s = 1, 2, ..., 2N$) and $(\vec{e}^{\,s}, \vec{h}^{s})$ are the s-th eigenoscillation field of the coupled microresonator system (1) with complex frequency ω_s.

As a result, the transfer coefficient between the 1 and v ports is determined from the expression [15]:

$$T_{1v}(\omega) = \delta_{v2} - \frac{Q^D}{\det B} \cdot \sum_{s=1}^{2N} \frac{\det B_v^s}{Q_s(\omega)}\,, \tag{4}$$

where $Q_s(\omega) = \omega/\omega_0 + 2iQ^D(\omega/\omega_0 - 1 - \lambda_s/2)$; Q^D – is the dielectric Q-factor of the microresonators ($v = 1, \ldots, 4$). An expression of the matrix B_v^s is presented below ((9), (11), (13)) for a specific kind of filter topology.

The time-domain Green's function of the Add-Drop filter, as follow from [10], can be obtain from (4) taking into account the principle of causality:

$$g_v(\tau) = \begin{cases} \delta(\tau)\delta_{v2} + \frac{i\omega_0}{1+2iQ^D} \sum\limits_{s=1}^{N} A_s^v e^{i\omega_s \tau}, & \tau \geq 0 \\ 0, & \tau < 0 \end{cases}, \tag{5}$$

where

$$A_s^v = -Q^D \frac{\det B_s^v}{\det B}\,. \tag{6}$$

The field $E_v^{out}(t)$ in the plane of "first" microresonator center of the v-th port of the filter at the moment t is a integral on falling pulse $E_1^{in}(t)$:

$$E_v^{out}(t) = \int_{-\infty}^{t} g_v(t - t') E_1^{in}(t') dt'\,. \tag{7}$$

3 Calculating pulses scattering by Add-Drop filters

The design of the simplest Add-Drop filter is shown in Fig. 1, a. In this case, the coupling matrix of the microresonators we represented in the form:

$$K = \|i(\tilde{k}_1^e \delta_{s1} + \tilde{k}_1^o \delta_{s2} + \tilde{k}_N^e \delta_{s(2N-1)} + \tilde{k}_N^o \delta_{s(2N)} + \tilde{k}_{OS})\delta_{sn} + \kappa_{sn}(1 - \delta_{sn})\|, \tag{8}$$

where $\tilde{k}_1^{eo}$ – is the coupling coefficient of the 1st microresonator with the transmission line 1-2 (Fig. 1, a) on an even (or odd) mode oscillation; $\tilde{k}_N^{eo}$ – is the coupling coefficient of the N-th microresonator with the transmission line 3-4 also on an even (odd) oscillation; $\tilde{k}_{OS}$ – is the coupling coefficient of the microresonator with open space; $\kappa_{sn} = k_{12}^{e,o} = k_{21}^{e,o}$ – is the mutual coupling coefficient between microresonators, if $|s - n| = 1$ and $\kappa_{sn} = 0$ in other cases; δ_{st} – is the Kronecker δ-function.

The matrix, defining a scattering on the Add-Drop filter:

$$B_1^s = \begin{bmatrix} b_1^{e1} & \ldots & b_1^{es}\tilde{k}_{11}^{ee-+} + b_1^{os}\tilde{k}_{11}^{oe-+} & \ldots & b_1^{e2N} \\ b_1^{o1} & \ldots & b_1^{es}\tilde{k}_{11}^{eo-+} + b_1^{os}\tilde{k}_{11}^{oo-+} & \ldots & b_1^{o2N} \\ . & \ldots & . & \ldots & . \\ b_N^{o1} & \ldots & 0 & \ldots & b_N^{o2N} \end{bmatrix}; \quad B_2^s = \begin{bmatrix} b_1^{e1} & \ldots & b_1^{es}\tilde{k}_{21}^{ee++} + b_1^{os}\tilde{k}_{21}^{oe++} & \ldots & b_1^{e2N} \\ b_1^{o1} & \ldots & b_1^{es}\tilde{k}_{21}^{eo++} + b_1^{os}\tilde{k}_{21}^{oo++} & \ldots & b_1^{o2N} \\ . & \ldots & . & \ldots & . \\ b_N^{o1} & \ldots & 0 & \ldots & b_N^{o2N} \end{bmatrix}; \tag{9}$$

$$B_3^s = \begin{bmatrix} b_1^{e1} & \ldots & b_{N-1}^{es}\tilde{k}_{31}^{ee++} + b_N^{os}\tilde{k}_{31}^{oe++} & \ldots & b_1^{e2N} \\ b_1^{o1} & \ldots & b_{N-1}^{es}\tilde{k}_{31}^{eo++} + b_N^{os}\tilde{k}_{31}^{oo++} & \ldots & b_1^{o2N} \\ . & \ldots & . & \ldots & . \\ b_N^{o1} & \ldots & 0 & \ldots & b_N^{o2N} \end{bmatrix}; \quad B_4^s = \begin{bmatrix} b_1^{e1} & \ldots & b_{N-1}^{es}\tilde{k}_{41}^{ee-+} + b_N^{os}\tilde{k}_{41}^{oe-+} & \ldots & b_1^{e2N} \\ b_1^{o1} & \ldots & b_{N-1}^{es}\tilde{k}_{41}^{eo-+} + b_N^{os}\tilde{k}_{41}^{oo-+} & \ldots & b_1^{o2N} \\ . & \ldots & . & \ldots & . \\ b_N^{o1} & \ldots & 0 & \ldots & b_N^{o2N} \end{bmatrix}.$$

In this case, index s is determined by the column number in matrix B. Here

$$\tilde{k}^{ab++}_{mn} = \left(c^{a+}_m c^{b+^*}_n\right)/(\omega_0 w_n) = (\tilde{k}^{ab}_{mn})_0 e^{-i\Gamma(z_m - z_n)};$$

$$\tilde{k}^{ab-+}_{mn} = \left(c^{a-}_m c^{b+^*}_n\right)/(\omega_0 w_n) = (\tilde{k}^{ab}_{mn})_0 e^{-i\Gamma(z_m + z_n)},$$

$c^{a\pm}_n$ – is the expansion coefficient of the n-th microresonator field with a – mode on the propagating wave of the transmission line [12]; w_n – is the energy stored in the dielectric of microresonator; Γ – is the longitudinal wave number of the transmission line; z_n – is the longitudinal coordinate of the n-th microresonator center.

In Fig. 1, b - e shows the results, based on (2–9), of the dependences on the frequency of the S-matrix ($S_{v1} = 20\lg|T_{1v}|$) of a 10-section Add-Drop filter. As can be seen from the above data, the filter has minimal attenuation between ports 1-4.

The calculation results of the envelopes of rectangular and Gaussian pulses reflected and transmitted through the filter, calculated using (5–9), are shown in Fig. 1, f - i. As follows from the data obtained, the passage of pulses through a chain of microresonators is accompanied by a noticeable delay in time. The magnitude of the delay increases with increasing number of resonators. The envelopes of the transmitted pulses with not wide enough filter pass bands tend to a Gaussian-like distribution. With the simultaneous scattering of several pulses (Fig. 1, h, i), their distinguishability is determined by the passband of the filter, the width and the relative distance between them. It should also be noted that the relative amplitudes of the initially identical pulses change as they pass through the filter.

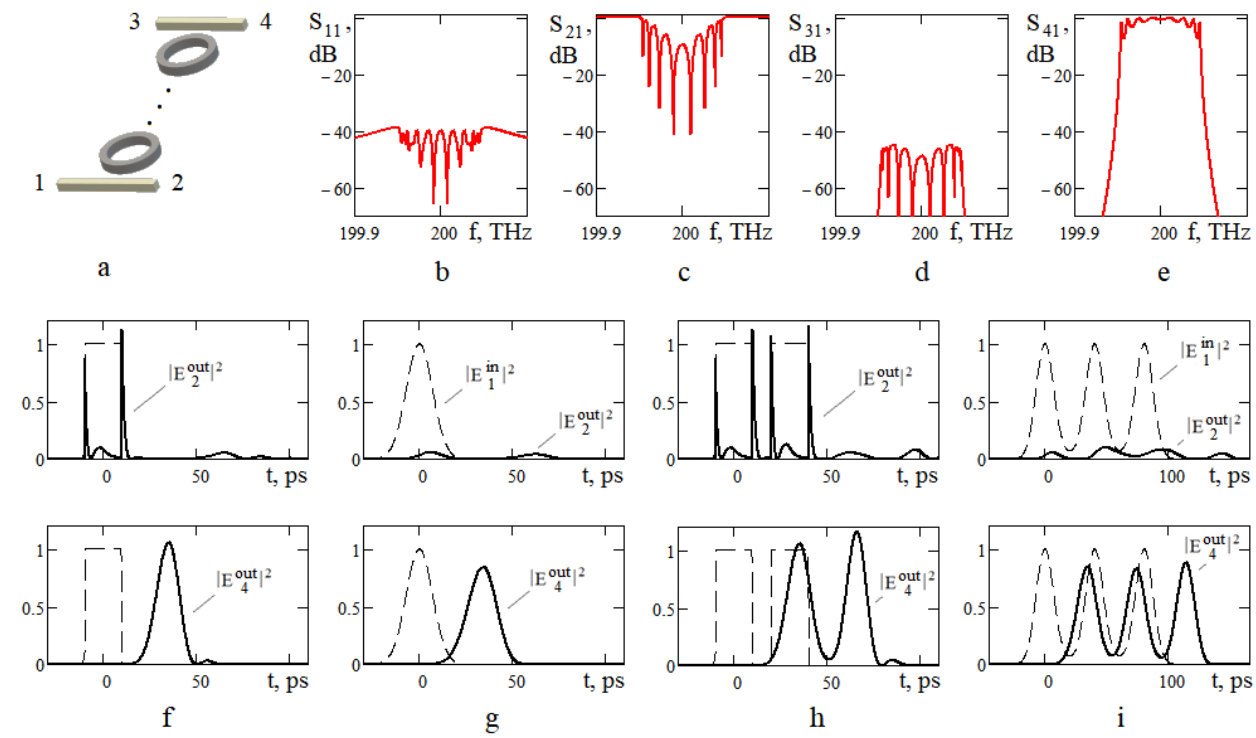

Fig. 1. A - laterally coupled microresonator filter. S-matrix responses of the 10-section bandpass filter as functions of frequency (b - e). Coupling coefficients of the first and last microresonators with transmission lines: $\tilde{k}^e_{nm} = 3,4 \cdot 10^{-4}$ for even oscillations; $\tilde{k}^o_{nm} = 3,48 \cdot 10^{-4}$ for odd oscillations. Open Space microresonator coupling coefficients: $\tilde{k}_{OS} = 1 \cdot 10^{-7}$. Mutual coupling coefficients of the microresonators for even oscillations: $k^e_{12} = k^e_{21} = 2,4 \cdot 10^{-4}$; for odd oscillations $k^o_{12} = k^o_{21} = -2,4 \cdot 10^{-4}$. Frequency of free microresonators oscillations $f_0 = 200\,\text{THz}$; $Q^D = 10^6$. The envelops of the rectangular (f, h); Gaussian (g, i) pulses, scattered by 10-section bandpass filter.

4 Calculating pulses scattering by Double-channel SCISSORs

The sketch of parallel coupled microresonator Add-Drop filter is shown in Fig. 2, a. In this case, each microresonator is coupled simultaneously with two transmission lines.

The K-matrix of SCISSOR (side-coupled integrated spaced sequence of resonators) has the form:

$$K = \left\| i(\tilde{k}^a_{(12)s} + \tilde{k}^a_{(34)s} + \tilde{k}_{OS})\delta_{sn} + \kappa_{sn}(1 - \delta_{sn}) \right\|. \quad (10)$$

Formally, the filter transfer coefficient is also (4), but for the SCISSOR structure shown on Fig. 2, a:

$$B_1^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ae-+} & \dots & b_1^{e2N} \\ b_1^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ao-+} & \dots & b_1^{o2N} \\ . & \dots & . & \dots & . \\ b_N^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{uN}^{ao-+} & \dots & b_N^{o2N} \end{bmatrix}; \quad B_2^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ae++} & \dots & b_1^{e2N} \\ b_1^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ao++} & \dots & b_1^{o2N} \\ . & \dots & . & \dots & . \\ b_N^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{uN}^{ao++} & \dots & b_N^{o2N} \end{bmatrix}; \qquad (11)$$

$$B_3^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ae++} & \dots & b_1^{e2N} \\ b_1^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ao++} & \dots & b_1^{o2N} \\ . & \dots & . & \dots & . \\ b_N^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{uN}^{ao++} & \dots & b_N^{o2N} \end{bmatrix}; \quad B_4^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u1}^{ae-+} & \dots & b_1^{e2N} \\ b_1^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{u2}^{ao-+} & \dots & b_1^{o2N} \\ . & \dots & . & \dots & . \\ b_N^{o1} & \dots & \sum_{u=1}^{2N} b_u^s \tilde{k}_{uN}^{ao-+} & \dots & b_N^{o2N} \end{bmatrix}.$$

Here $\tilde{k}^a_{(v)s} = \tilde{k}^{e,o}_{(v)s}$ is the coupling coefficient of the s-th microresonator with the v-th transmission line; $\kappa_{sn} = k_{sn} + i\tilde{k}^{ab\pm\pm}_{sn}$ is the complex mutual coupling coefficient of the microresonators [12]. Here a, b takes values even or odd depending on the type of u-th microresonator oscillations.

As known, Double-channel SCISSOR is characterized by a transfer function with minimal attenuation to the port 3 (Fig. 2, b, c). The delay in the pulses during transmission through a filter is minimal, but is characterized by their visible distortions (Fig. 2, d - g) as well as uneven frequency response (Fig. 2, b, c). Apparently this is due to beats that occur between the microresonators of this structure due to the mutual connection along the propagating waves of both lines.

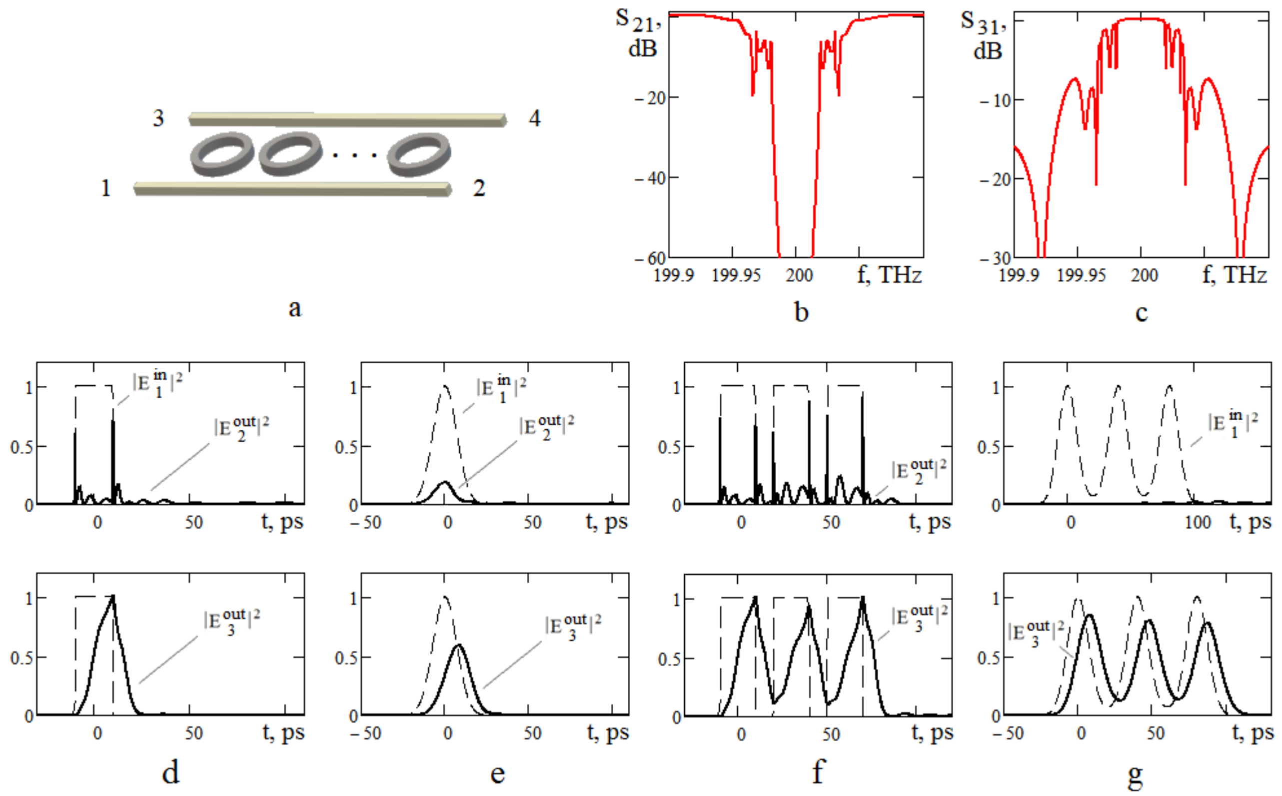

Fig. 2. Parallel coupled microresonator Add-Drop filter on Double-channel SCISSOR (a). S-matrix responses of the 10-section Add-Drop filter as functions of frequency (b, c). Coupling coefficients of the microresonators with transmission lines: $\tilde{k}^e_{nm} = \tilde{k}^o_{nm} = 1{,}2 \cdot 10^{-4}$. Open Space microresonator coupling coefficients: $\tilde{k}_{OS} = 1 \cdot 10^{-7}$. Mutual coupling coefficients of the microresonators for even oscillations: $k^e_{12} = k^e_{21} = 3 \cdot 10^{-5}$; for odd oscillations $k^o_{12} = k^o_{21} = -3 \cdot 10^{-5}$. The envelops of the rectangular (d, f); Gaussian (e, g) pulses, scattered by 10-section Add-Drop filter.

5 Calculating pulses scattering by Twisted Double-channel SCISSORs

To increase out-of-band attenuation, the use of so-called Twisted Double-channel SCISSORs is proposed. The sketch of Twisted Double-channel SCISSOR is shown in Fig. 3, a.

The coupling and B_n^s matrices of the Double-channel SCISSOR has the form:

$$K = \left\| i(\tilde{k}_s^a + \tilde{k}_{OS})\delta_{sn} + \kappa_{sn}(1-\delta_{sn}) \right\|, \qquad (12)$$

where $\tilde{k}_s^a = \tilde{k}_{(12)s}^a$ if $s \le N$ and $\tilde{k}_s^a = \tilde{k}_{(34)s}^a$ if $s > N$.

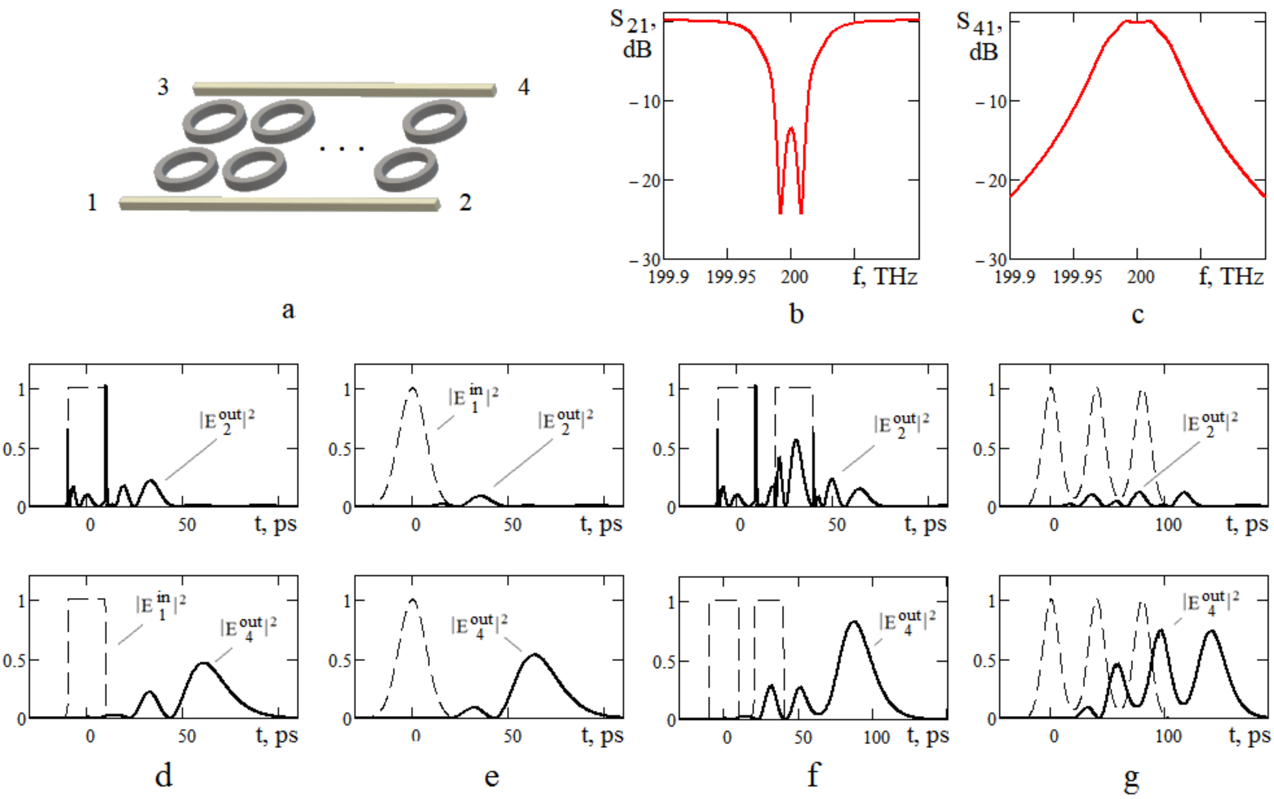

Fig. 3. Optical Add-Drop filter on a Twisted double-channel SCISSOR (a). S-matrix responses of the 10-section Add-Drop filter as functions of frequency (b, c). Coupling coefficients of the microresonators with transmission lines: $\tilde{k}_{nm}^e = \tilde{k}_{nm}^o = 2\cdot 10^{-4}$. Open Space microresonator coupling coefficients: $\tilde{k}_{OS} = 1\cdot 10^{-7}$. Mutual coupling coefficients of the microresonators for even oscillations: $k_{12}^e = k_{21}^e = 2\cdot 10^{-6}$; for odd oscillations $k_{12}^o = k_{21}^o = -2\cdot 10^{-6}$; $k_V^e = 4\cdot 10^{-5}$; $k_V^o = -4\cdot 10^{-5}$; $f_0 = 200\,\text{THz}$; $Q^D = 10^9$. The envelops of the rectangular (d, f); Gaussian (e, g) pulses, scattered by 10-section filter.

$$B_1^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ae-+} & \dots & b_1^{e4N} \\ b_1^{o1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ao-+} & \dots & b_1^{o4N} \\ . & \dots & . & \dots & . \\ b_{2N}^{o1} & \dots & 0 & \dots & b_{2N}^{o4N} \end{bmatrix}; \quad B_2^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ae++} & \dots & b_1^{e4N} \\ b_1^{o1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ao++} & \dots & b_1^{o4N} \\ . & \dots & . & \dots & . \\ b_{2N}^{o1} & \dots & 0 & \dots & b_{2N}^{o4N} \end{bmatrix}; \qquad (13)$$

$$B_3^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ae++} & \dots & b_1^{e4N} \\ b_1^{o1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ao++} & \dots & b_1^{o4N} \\ . & \dots & . & \dots & . \\ b_{2N}^{o1} & \dots & 0 & \dots & b_{2N}^{o4N} \end{bmatrix}; \quad B_4^s = \begin{bmatrix} b_1^{e1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u1}^{ae-+} & \dots & b_1^{e4N} \\ b_1^{o1} & \dots & \sum_{u=1}^{4N} b_u^s \tilde{k}_{u2}^{ao-+} & \dots & b_1^{o4N} \\ . & \dots & . & \dots & . \\ b_{2N}^{o1} & \dots & 0 & \dots & b_{2N}^{o4N} \end{bmatrix}.$$

Here also $\kappa_{sn} = k_{sn} + i\tilde{k}_{sn}^{ab}$ the complex coupling coefficient [12]. For different microresonators with the same longitudinal coordinates $\kappa_{sn} = k_{sn} = k_V^a$, where k_V^a is the mutual coupling coefficient of "vertically coupled" microcavities (Fig. 3, a).

Twisted Double-channel SCISSOR is characterized by a minimal attenuation to port 4 (Fig. 3, b, c).

The transmission of pulses through such a filter is characterized by their large distortions (Fig. 3, d, e), and in addition, by the phenomena of elevated mutual interference (Fig. 3, f, g).

6 Discussion and Conclusion

As follows from our calculations, the use of parallel structures of microresonators, such as Double-channel SCISSOR and Twisted Double-channel SCISSOR, leads to an increase in out-of-band attenuation, but is accompanied by processes of destructive interference of pulses which is unacceptable for use in separation of communication channels with increased speeds. The best scattering parameters are possessed by filters with laterally coupled microresonators.

In this paper, we have extended the scattering theory of the electromagnetic pulses on Add-Drop filters of receiving and transmitting optical communication systems. The proposed theory can be used to model and optimizing wide class of multiplexers, of the optical communication systems.

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Розсіювання оптичних імпульсів фільтрами-розгалужувачами на діелектричних мікрорезонаторах

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Розглядається система кільцевих мікрорезонаторів з коливаннями шепочучей галереї надвисокої добротності, які широко використовуються для побудови різноманітних інтегральних фільтрів оптичного діапазону довжин хвиль. За допомогою теорії збурень розроблена електродинамічна модель, яка описує складну систему зв'язаних між собою мікрорезонаторів з двократно виродженими типами власних коливань, а також розташованих між двома різними лініями передачи. Отримані загальні аналітичні вирази для опису не взаємних характеристик розсіювання власних хвиль лінії на системі оптичних мікрорезонаторів, які утворюють фільтр-розгалужувач. Розраховані частотні залежності матриці розсіювання оптичних фільтрів-розгалужувачів з декількома каналами зв'язку. На основі побудованої аналітичної моделі, розраховані часові функції Гріна для фільтрів з послідовним зв'язком між мікрорезонаторами, фільтрів з мікрорезонаторами зв'язаними по боковій стінці, та двом лініям передачи, а також фільтрів, побудованих на подвійній решітці мікрорезонаторів, зв'язаних з двома лініями передачи. За допомогою використання знайдених часових функцій Гріна, розраховані огинаючі оптичних імпульсів, розсіюваних фільтрами-розгалужувачами в різні канали зв'язку. Розглянуті огинаючі прямокутного та Гауссовского одиночних імпульсів, розсіюваних на 10-резонаторних фільтрах різних конструкцій. Досліджено взаємний вплив декількох прямокутних, а також Гауссовских імпульсів при їх розсіюванні на багатоланкових оптичних фільтрах-розгалужувачах. На основі порівняння отриманих даних для трьох найбільш поширених видів конструкцій, зроблено висновок про перевагу застосування фільтрів з послідовно зв'язаними мікрорезонаторами. Отримані практичні результати моделювання дозволяють суттєво скоротити час розрахунків та оптимізувати складні багаторезонаторні структури оптичних систем зв'язку, одночасно виконуючих функції розподілу, або об'єднання каналів.

Ключові слова: діелектричний мікрорезонатор; розсіювання; імпульс; фільтр-розгалужувач; двоканальний фільтр на оптичних мікрорезонаторах, зв'язаних по боковій стінці

Рассеяние оптических импульсов фильтрами-разветвителями на диэлектрических микрорезонаторах

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Рассматривается система кольцевых микрорезонаторов с колебаниями шепчущей галереи сверхвысокой добротности, широко применяемых для построения различных интегральных фильтров оптического диапазона длин волн. С помощью теории возмущений разработана электродинамическая модель, описывающая сложную систему связанных между собой микрорезонаторов с двукратно вырожденными типами собственных колебаний, а также расположенных между двумя разными линиями передачи. Получены общие аналитические выражения для описания не взаимных характеристик рассеяния собственных волн линии на системе оптических микрорезонаторов, которые образуют фильтр-разветвитель каналов. Рассчитаны частотные зависимости матрицы рассеяния оптических фильтров-разветвителей с несколькими каналами связи. На основе построенной аналитической модели, рассчитаны временные функции Грина для фильтров с последовательной связью между микрорезонаторами, фильтров с микрорезонаторами, связанными по боковой стенке и двум линиям передачи, а также фильтров, построенных на двойной решетке микрорезонаторов, связанных по двум линиям передачи. Рассмотрены огибающие оптических импульсов, рассеиваемых фильтрами-разветвителями в различные каналы. Рассмотрены огибающие прямоугольного и Гауссовского одиночного импульсов, рассеиваемых на 10-резонаторных фильтрах различной конструкции. Исследовано взаимное влияние нескольких прямоугольных, а также Гауссовских импульсов при их рассеянии на многозвенных оптических фильтрах-разветвителях. На основе сравнения полученных данных для трех видов конструкций, сделан вывод о предпочтительности применения фильтров с последовательно связанными микрорезонаторами. Полученные практические результаты моделирования позволяют значительно сократить время вычислений и оптимизировать сложные многорезонаторные структуры оптических систем связи, одновременно выполняющие функции разделения, или объединения каналов.

Ключевые слова: диэлектрический микрорезонатор; рассеяние; импульс; фильтр-разветвитель; двухканальный фильтр на оптических микрорезонаторах, связанных по боковой стенке