The Diplexer on Cylindrical Waveguide with Anisotropic Crystal

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***Abstract*-A diplexer that is able to separate microwave signals (specifically in C band) on frequencies, polarizations and on different waveguide channels simultaneously has been worked out. The worked out device is based on an anisotropic crystal. Its advantage is the uniquely small size, weight and losses of signal in the pass band.**

***Keywords*- Diplexer; Resonant Frequency; Waveguide; Uniaxial Crystal**

I. INTRODUCTION

Microwave diplexers are important components in mobile communication systems. They are typically applied to transmit and receive signals by a single antenna. A diplexer can also be used to separate a composite signal coming from a common port into two channel signals to permit each signal to be transmitted separately. Since the interaction of the two filters composes the diplexer, the characteristics of a diplexer are different from the responses of the individual two filters. The complexity of the interaction makes the design of a diplexer complicated. For the design of microwave diplexers, the traditional approach is to design the *TX* and *RX* filters individually, and then to design a distribution network. The most employed distribution network used today may be the T-junction (as in [1-5]) connecting the *TX* and *RX* filters. The drawbacks of diplexer with the T-junction configuration are that it has large volume and is time-consuming. Some interesting diplexers design without distribution networks have appeared in the recent literatures [6-12]. If we compare the well-known microwave filters by the loss minimum (at identical pass band or stop band width), the waveguide filters possess the best indexes. It is explained by the fact that the waveguide and waveguide-dielectric resonators have the highest Q-factor in the centimeter range of wavelengths. Waveguide filters are proved to be good in a stationary apparatus, where the requirements of minimum signal losses have greater significances than weight and size parameters. However, for a compact radioelectronic apparatus (that is used, for example, in aviation and satellite communication and television systems), weight and size parameters are the most determining factors. At the same time, accumulated experience on the miniaturization of microwave filters allows to conclude that power and weight /size parameters are in contradiction [13]. In the process of searching a tradeoff between these indexes, the filters on anisotropic dielectrics are offered. The anisotropy of permittivity acquired by a crystal in the process of growth is undesirable in a number of cases (complication of mathematical modeling; reduction of Q-factor of the resonators, filled with the anisotropic environment etc.). In this work, a diplexer built of cylindrical waveguide section with an anisotropic dielectric insert has been offered.

II. THE DEVICE

Frequency separating devices based on anisotropic dielectrics are developed and implemented for the first time. In particular, a diplexer that is able to separate microwave signals on frequencies, polarizations and on different waveguide channels simultaneously, and with the uniquely small size and weight is proposed [14]. The problem has been approached by using a dielectric disk of anisotropic material in a waveguide or coaxial section. Due to this, the resonator has an amplitude-frequency characteristic with two pass bands, resonant frequencies of which are determined by dimensions of the waveguide and the disk, and by tensor components of disk permittivity in the corresponding directions. A certain type of dielectric should be chosen depending on the design requirements (broadbandness, operating range, minimum of transmission losses in the pass band or stop band etc.). The majority of synthetic single-crystal materials have low electric loss angle (for example, leucosapphire has $tg\delta$ $\tan\delta \le 5\cdot 10^{-6}$ at room temperature), so the frequency-separating devices using it have low transmission losses in the pass band.

The diplexer (Fig. 1) consists of a section of circular waveguide, which is evanescent for asymmetrical type of oscillation, (1) with an anisotropic disk in the transvers plane (2) and coupling elements (4) - (7). It can be implemented both with coaxial and hollow waveguide ports (in the waveguide variant the coaxial waveguides (3), (8), (9) should be substituted by rectangular waveguides which will be connected to the device by means of the standard waveguide-coaxial adapters with the coupling elements (4) - (7)). The diplexer works in the following way: the input signal with frequencies f_1, f_2 enters into the cylindrical waveguide (1) and excites the oscillations HE^{c}_{111} (with frequency f_1) and oscillations HE^{s}_{111} (with frequency f_2)

in the anisotropic dielectric disk (2) by means of the coupling elements (4), (5) (c is the direction of $\varepsilon_1 = \varepsilon_{\|}$ permittivity; s is the direction of $\varepsilon_2 = \varepsilon_{\perp}$ permittivity). As far as these oscillations are linearly polarized, the oscillations with a single frequency f_1 or f_2 can be excited in the output coupling element 6 (7). The output signal with frequency f_1 is fed into the coaxial (waveguide) line (8) by means of the coupling element (6), and the signal with frequency f_2 – into the line (9) by means of the coupling element (7).

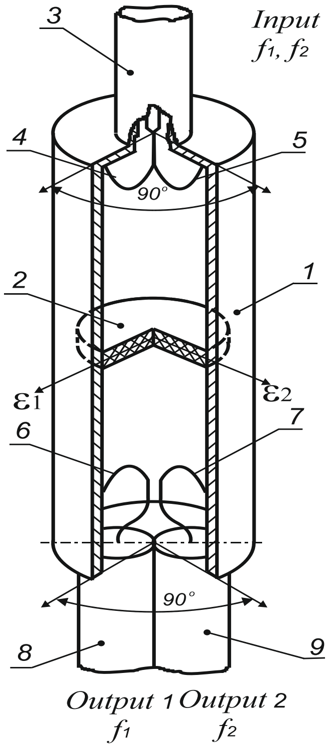

Fig. 1 The diplexer

Theoretical and experimental studies showed that for dielectrics with comparatively small degree of anisotropy ($(\varepsilon_{\|} - \varepsilon_{\perp})/(\varepsilon_{\|} + \varepsilon_{\perp}) \le 0.2$), it is possible to neglect coupling of oscillations with orthogonal polarization HE_{111}^{c} and HE_{111}^{s}.

The unidirectional approximation has been used for determining frequencies of HE_{111}^{c}- and HE_{111}^{s}- oscillation types for given dimensions of cylindrical waveguide that is fully filled in a cross section by an anisotropic disk with permittivity tensor aligned along the waveguide axis:

$$\beta_i / \Gamma_i = tg(\Gamma_i l/2) \quad \text{– for even oscillations number } i; \tag{1}$$

$$\beta_i / \Gamma_i = -ctg(\Gamma_i l/2) \quad \text{– for odd oscillations;} \tag{2}$$

where β_i are propagation constants in the waveguide without dielectric: $\beta = [(\frac{1.841}{a})^2 - k_i^2]^{\frac{1}{2}}$; $\varepsilon_i = \varepsilon_{\|}$ or $\varepsilon_{\perp}$; $k_i = \frac{2 \cdot \pi}{\lambda_i}$; $i = c, s$; λ_i is the cut off wavelength; a , l are the radius and the thickness of the disk correspondingly; Γ_i are propagation constants in the waveguide for polarization along c-axis of the disk permittivity tensor (Γ_c) and for the orthogonal polarization (Γ_s). The dispersion equations for Γ_i are:

a) polarization along the c-axis of the disk (Γ_c):

$$N_2^c \cdot \chi_2^{c\cdot} \cdot z_1^c \cdot J_1^{/}(\chi_2) - N_1^c \cdot \chi_1^{c\cdot} \cdot z_2^c \cdot J_1^{/}(\chi_1) = \frac{\omega_c^2 \cdot \varepsilon_\delta}{2 \cdot a}[z_1^c - z_2^c] \cdot J_1(\chi_2) \cdot J_1(\chi_1); \tag{3}$$

where $\chi_1 = \chi_1^c \cdot a$; $\chi_2 = \chi_2^c \cdot a$; $N_{1,2} = [\omega_c^2 \cdot \varepsilon_{||} - \Gamma_c^2 - \frac{1}{2}\omega_c \cdot \varepsilon_\delta \cdot (\omega_c + \Gamma_c \cdot z_{1,2}^c)]$;

b) polarization orthogonal to the c-axis of the disk (Γ_s):

$$N_2^s \cdot \chi_2^s \cdot z_1^s \cdot J_1^{/}(\chi_2) - N_1^s \cdot \chi_1^s \cdot z_2^s \cdot J_1^{/}(\chi_1) = \frac{\omega_s^2 \cdot \varepsilon_\delta}{2 \cdot a}[z_1^s - z_2^s] \cdot J_1(\chi_2) \cdot J_1(\chi_1); \tag{4}$$

where $\chi_1 = \chi_1^c \cdot a$; $\chi_2 = \chi_2^s \cdot a$; $N_{1,2} = [\omega_s^2 \cdot \varepsilon_\perp - \Gamma_s^2 - \frac{1}{2}\omega_s \cdot \varepsilon_\delta \cdot (\omega_s + \Gamma_s \cdot z_{1,2}^s)]$;

$$\varepsilon = \frac{\varepsilon_{||} + \varepsilon_\perp}{2}; \varepsilon_\delta = \frac{\varepsilon_{||} - \varepsilon_\perp}{2} \quad ; \chi_{1,2}^c = \chi_{||} \cdot \left(\frac{3 \cdot \varepsilon \cdot \chi_\perp^2 + \varepsilon_\perp \chi_{||}^2 \pm \varepsilon_\delta \sqrt{9\chi_\perp^4 + 4k_c^2 \cdot \varepsilon_\perp \Gamma_c^2}}{2 \cdot (\varepsilon \cdot \chi_{||}^2 + \varepsilon_{||} \cdot \chi_\perp^2)}\right)^{\frac{1}{2}};$$

$$\chi_1^s = \sqrt{\frac{2 \cdot \varepsilon_\perp \chi_{||}^2 \cdot \chi_\perp^2}{\varepsilon \cdot \chi_\perp^2 + \chi_\perp^2 \varepsilon_\perp \chi_{||}^2}}; \ \chi_\perp^2 = k_s^2 \varepsilon_\perp - \Gamma_s^2; \ \chi^2 = \frac{\varepsilon_{||}\chi_\perp^2 + \varepsilon_\perp \chi_{||}^2}{2 \cdot \varepsilon};$$

$$Z_{1,2}^c = \frac{2}{3} \cdot \Gamma_c \cdot \omega_c \cdot \mu_0 \cdot \chi_\perp^2 \pm \sqrt{9\chi_\perp^4 + 4k_c^2 \cdot \varepsilon_\perp \Gamma_c^2}; Z_1^s = \frac{\Gamma_s}{\omega_s \cdot \varepsilon_0 \varepsilon_\perp}; Z_2^s = -\frac{\omega_s \cdot \mu_0}{\Gamma_s}; \omega_i = k_i C; \ \varepsilon_0, \mu_0 -$$

are electric and magnetic constants; C is the light speed in vacuum; $J_1(\chi_1), J_1^{/}(\chi_1)$ are the Bessel function of the first order and its derivative. Joint solution of equations (1) or (2) and dispersion equations (3) - (4) for propagation constants at given values of $\varepsilon_{||}$ and $\varepsilon_\perp$ allows one to determine resonant frequencies and dimensions of the dielectric disk.

Calculated dependences of resonant wavelengths (λ) of waveguide-dielectric resonator as a function of ε for several values of (l) and radius (a) are presented in Fig. 2. The disk permittivity tensor was measured using the device described in [15].

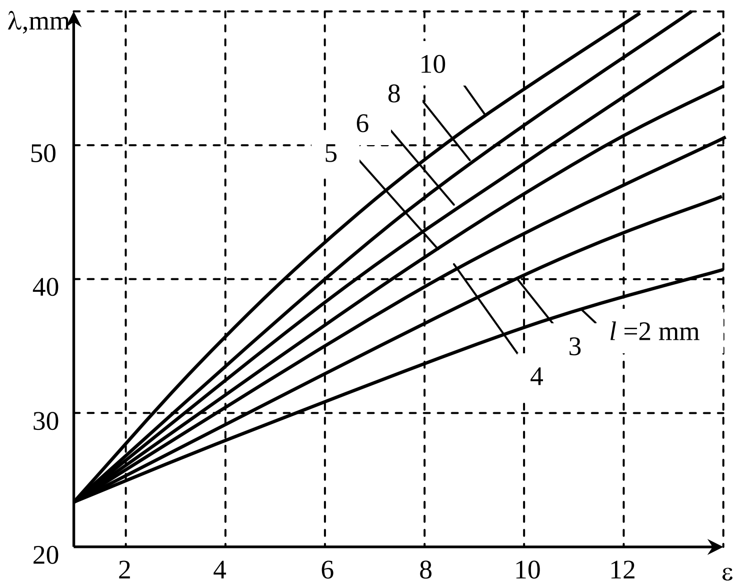

Fig. 2 The calculated relation between the resonance wavelength λ of the waveguide-dielectric resonator and disk permittivity ε for several dielectric disk thickness values (l) for even type of oscillations (a = 6 mm)

The calculated (f_{calc}) and measured ($f_{meas.}$) resonant frequencies of the diplexer are given in Table 1.

TABLE 1 COMPARISON OF EXPERIMENTALLY MEASURED ($f_{meas.}$) AND CALCULATED (F_{CALC}) RESONANCE FREQUENCIES

ε	f_{calc}, MHz	$f_{meas.}$, MHz	Error: $(f_{calc} - f_{meas.})/f_{calc} \cdot 100\%$
11.66	6288	6198	1.43%
9.30	6949	6853	1.38%

Based on these calculations, the diplexer has been designed. Its basic technical features are:

- resonant frequencies f_1 (f_2), MHz 6198 (6853)

- permittivity of material: $\varepsilon_1 = \varepsilon_{\|}$ 11.66

$\varepsilon_2 = \varepsilon_{\perp}$ 9.30

- minimum of transmission losses in the pass band, dB < 0,5

- signal suppression of one of the channels out of the pass band,

dB, not less than 40

- pass band width (at 1 dB level):

for single-link diplexer 2.2 MHz

for double-link diplexer 10 MHz

- diameter of cylindrical waveguide and disk ($2a$), mm $12 \pm 0{,}02$

- device length, mm 40

- material of dielectric leucosapphire

III. CONCLUSIONS

For solving the problems of electromagnetic compatibility, compression of receiving and transmitting channels of satellite communication networks in a microwave range, a new device based on anisotropic dielectrics is developed and implemented: the diplexer that is able to separate microwave signals on frequencies, polarizations and on different waveguide channels simultaneously. Its advantage consists of the uniquely small size and weight. Synthetic crystals have uniquely low electric loss angle; additionally, such frequency-separating devices also possess low transmission losses in pass bands.

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