4. The enhancement of the therapeutic effect of certain drugs at doping alkaloid in the presence of water-soluble fullerenes was registered.

5. The methods of template modification of physical-chemical and medical–biological parameters were proposed.

6. The influence of surface electric charge on the surface tension of some polymeric liquids was determined. The conditions of surface instability were established.

7. Based on the case study the perspective using of polysaccharides, doxorubicin alkaloids and some compounds of stilbene series for the creation of an effective anticancer drugs was proven.

These results show potential implementation of the above program.

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Submitted on 04.11.14

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ОСНОВНІ ПРОБЛЕМИ МОДИФІКАЦІЇ ПРОТИРАКОВИХ ПРЕПАРАТІВ

Обмежені можливості та низька ефективність у лікуванні місцево поширених та дисимінованих форм раку показує, що протиракові препарати потребують модифікації. Цей процес вимагає від лікарів та медичних фізиків вирішення деяких особливих задач. Тому було створено і запроваджено програму реалізації їх розв'язку. В цій статті представлено основні її завдання та результати отримані на даний момент.

Ключові слова: *рак, онкопрепарати, модифікація, радіація, бабстони.*

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ОСНОВНЫЕ ПРОБЛЕМЫ МОДИФИКАЦИИ ПРОТИВОРАКОВЫХ ПРЕПАРАТОВ

Ограниченые возмоности и низкая эффективность в лечении местных и дисиминированных форм рака показывает, что противораковые препараты нуждаються в модификации. Этот процес требует от врачей и медицинских физиков разрешения некоторых специальных задач. Для этого была разработана програма реализации их решения. В этой статье представлены ее основные задания и результаты, полученые на сегодняшний день.

Ключевые слова: *рак, онкопрепараты, модификация, радиация, бабстоны.*

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PASSIVE FERRITE RESONATOR-BASED MILLIMETER WAVE BAND COMPONENTS

The review of magnetodynamic resonances in ferrite resonators and their mm-wave band applications was given. Ferrite resonator eigenexcitations classification has been presented. The analytical theory for modes resonant frequencies calculations is stated and a number of prototype electronically tunable mm-wave devices, utilizing the "above" and "below FMR" magnetodynamic resonances, including isolator, phase shifter, band-pass and band-stop filters have been demonstrated.

Keywords: *magnetodynamic modes; mm-wave devices; barium hexaferrite; nickel ferite; yttrium-iron garnet.*

Introduction. The mm-wave band of the electromagnetic spectrum is of particular importance for applications related to security systems, radars, radio astronomy, and satellite communication [14]. There is a need for device components such as isolators and phase shifters, and others for signal-processing devices working at these frequencies. Such low-loss components can be constructed using ferrites. Since ferrites are magnetic dielectrics, eigenoscillations of ferrite resonators, in general case, belong to magnetodynamic type. Magnetic nature of ferrites influences such oscillations most prominently in resonance region near ferromagnetic resonance (FMR) frequency, where dipole-exchange spin oscillations and waves can exist. Most known oscillations of such kind are the Walker modes. Their main peculiarities are wide-range magnetic field tuning of frequency and fast spatial variations of rf-fields, which, in turn, makes retardation effects insignificant and allows miniaturizing resonator dimensions, which can be important for low-power microwave microelectronics. Theoretical analysis of Walker modes, at frequencies well below that of ferrite resonator main electromagnetic mode (assuming resonator is nonmagnetic dielectric), can be done in magnetostatic approximation.

Meanwhile, in such wide spread ferrite devices like circulators and isolators, ferrite resonator operates at frequencies far from FMR and its magnetic properties influence magnetodynamic modes [1, 3] due to, basically, Faraday effect. Such resonators have much larger dimensions, although can operate at higher power. A lot of research on ferrites resonators, mostly fabricated from garnets and spinels, in the L – to Ka-bands has been performed [11, 2].

Some important properties of widely used ferrite materials are given in Table 1. The ferrites of choice for mm-wave FMR devices is M-type hexagonal ferrites which are characterized by a large uniaxial magneto-crystalline anisotropy field and FMR at 50 GHz or more with zero external magnetic field [6].

***Table* 1**

Magnetic properties of some common ferrite

Material	**Magnetic parameters**			
	***4πM*₀, Gs**	**ΔH, Oe**	**H$_a$, Oe**	***Minimum FMR frequency, GHz***
$Y_3Fe_5O_{12}$	1800	≈1	50	≈1
$Ni_x Zn_{1-x}Fe_2O_4$	3500–5000	≈5	100–250	≈3
$BaFe_{12}O_{19}$	4800	≈20	16800	47
$SrFe_{12}O_{19}$	4700	≈20	18700	51

We will divide frequency region of electromagnetic excitations in magnetized ferromagnetic media into three regions (see Fig. 1): 1) FMR region; 2) above FMR region – magnetodynamic resonances (MDR) with frequencies higher the approximately $\gamma\ (H_a + H_0 + 4\pi M_0)$ (here γ is gyromagnetic ratio, H_a – uniaxial anisotropy field, H_0 – bias magnetic field, $4\pi M_0$ – saturation magnetization); 3) below resonance region, MDR with frequencies smaller than $\gamma\ (H_a + H_0 - 4\pi M_0)$. From above mentioned ferrite materials, only hexaferrites, magnetized along easy axis can be explored in mm-wave band in all three regions, whereas spinels and garnets can operate only in "above FMR" region.

1. Mode splitting effect in disc ferrite resonators. Let's consider resonator as a section of an open gyromagnetic rod waveguide with the tensor magnetic permeability in the demagnetized state.

$$\hat{\mu} = \begin{pmatrix} \mu & -i\mu_a & 0 \\ i\mu_a & \mu & 0 \\ 0 & 0 & \mu_z \end{pmatrix}. \qquad (1)$$

where $\mu_z = 1$, $\mu_a = \gamma 4\pi M_0/\omega$ for garnets and spinels and $\mu = 1 - \frac{\gamma H_a(\gamma 4\pi M_0)}{\omega^2 - (\gamma H_a)^2}$, $\mu_a = \frac{\omega(\gamma 4\pi M)}{\omega^2 - (\gamma H_a)^2}$ in the case of hexaferrites, (M – is net magnetization).

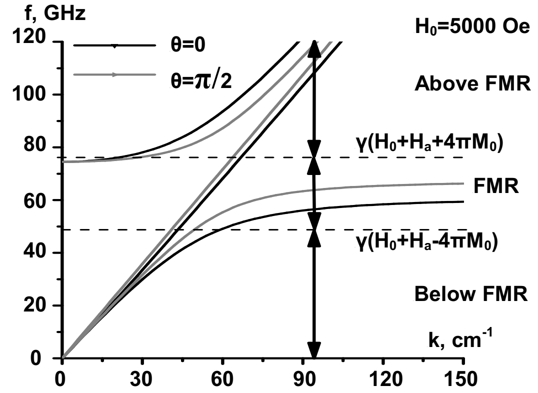

Fig. 1. Electromagnetic waves dispersion in magnetized ferrite media (barium hexaferrite, BaM), for waves propagating perpendicularly and parallel to the bias field direction

Expressions for electromagnetic field in such waveguides with tensor susceptibility in the form (1) in cylindrical coordinates are known [12]. After applying electromagnetic boundary conditions at the rod surface, the explicit dispersion equation (2) for guided electromagnetic waves can be found [4].

$$\begin{vmatrix} 1 & 0 & 1 & 1 \\ 0 & 1 & \theta_1 & \theta_2 \\ in\left(\frac{q_3}{ha_1}\right)^2 \frac{\mu_a}{\mu} & \frac{K_n'(ha_1)}{ha_1 K_n(ha_1)}\frac{1}{\mu_z} & -\frac{\theta_{m1}J_n'(q_1a_1)}{q_1a_1J_n(q_1a_1)} - \frac{\mu_a}{\mu}\frac{nq_3^2}{(q_1a_1)^2} & -\frac{\theta_{m2}J_n'(q_2a_1)}{q_2a_1J_n(q_2a_1)} - \frac{\mu_a}{\mu}\frac{nq_3^2}{(q_2a_1)^2} \\ -\frac{1}{\varepsilon}\frac{K_n'(ha_1)}{ha_1K_n(ha_1)}\frac{\mu_a}{\mu} & -i\frac{n}{(ha_1)^2}\frac{1}{\mu_z} & \frac{J_n'(q_1a_1)}{q_1a_1J_n(q_1a_1)}\frac{\mu_a}{\mu} + \frac{n\sigma_{m1}}{(q_1a_1)^2} & \frac{J_n'(q_2a_1)}{q_2a_1J_n(q_2a_1)}\frac{\mu_a}{\mu} + \frac{n\sigma_{m2}}{(q_2a_1)^2} \end{vmatrix} = 0, \qquad (2)$$

where $q_3 = \frac{\beta}{k_0\sqrt{\varepsilon}}$, $q_{1,2} = \frac{\chi_{1,2}}{k_0\sqrt{\varepsilon}}$, $h = \frac{\tau}{k_0\sqrt{\varepsilon}}$, $\theta_{m1,2} = \mu_\perp - \left(\frac{\varepsilon}{\varepsilon_z}q_{1,2}^2 + q_3^2\right)$, $\tau = \sqrt{\beta^2 - k_0^2}$, $a_1 = ak_0\sqrt{\varepsilon}$, $\sigma_{m1,2} = \frac{\theta_{m1,2}}{\mu} + \left(\frac{\mu_a}{\mu}\right)^2$,

$|n| = 0,1,2\ldots$ $\chi_{1,2}^2 = \frac{1}{2}\left(k_0^2\varepsilon(\mu_\perp + \mu_z) - \left(1 + \frac{\mu_z}{\mu}\right)\beta^2\right) \pm \sqrt{\frac{1}{4}\left(k_0^2\varepsilon(\mu_\perp - \mu_z) - \left(1 - \frac{\mu_z}{\mu}\right)\beta^2\right)^2 + \beta^2 k_0^2 \varepsilon\mu_z\left(\frac{\mu_a}{\mu}\right)^2}$, $\mu_\perp = \frac{\mu^2 - \mu_a^2}{\mu}$, $k_0 = \omega\sqrt{\varepsilon_0\mu_0}$.

In order to define the longitudinal wave number β we replaced real experimental setup – sample of thickness S lying on the metal surface of rectangular waveguide – with simplified theoretical model, where perfect electric wall is substituted instead of lower metal wall and far lying upper metal wall is replaced with perfect magnetic wall, while sidewalls are completely removed. This led to the following discrete wave numbers $\beta_p = (2p-1)\pi/(2S)$, p=1,2…

Experimental and theoretical frequency vs. bias field dependence for the two lowest MDR modes in before FMR region for BaM disc-shaped resonator with radius a=1.2 mm and S=0.36 mm is shown on Fig. 2 [5]. Comparison between experimental results and theoretical calculations in above FMR region for BaM magnetodynamic resonator with radius a=0.62 mm and S=0.28 mm is shown on Fig. 3 [4].

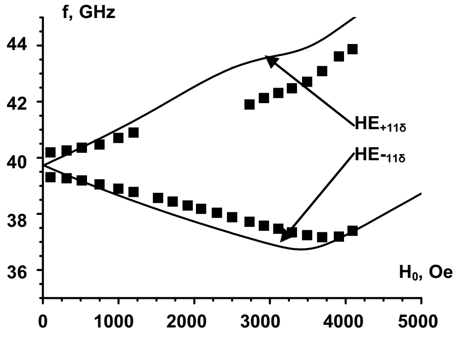

Fig. 2. Frequency vs. bias field dependence for the lowest MDR modes of the BaM disk located on the metal wall for magnetic field applied perpendicular to the disk: theoretical calculations (solid lines) and experiment (dots)

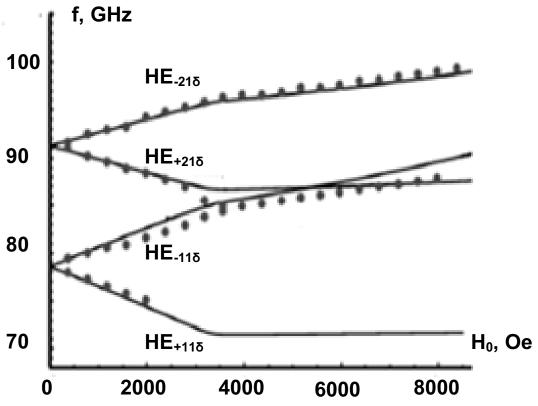

Fig. 3. Freuqency vs bias field dependence for lowest MDR in barium hexaferrite disk resonator: theory (solid lines) and experiment (dots)

Since MDR frequencies depend on dielectric constant and resonator dimensions, magnetic field tunable devices utilizing MDR can operate in subteraherz band, at frequencies much higher, than attainable for FMR devices.

2. Hexaferrite, nickel ferrite and yttrium-iron garnet resonators utilizing $HE_{\pm11\delta}$ modes.

2.1. Millimeter wave waveguide isolator using single-crystal BaM disk. Typical waveguide-based prototype device setup is shown on Fig. 4. Disk sample (D=1.2 mm, S=0.17 mm) was situated inside a waveguide flange, with lateral position varied if necessary, fixed with foam and (possibly) with polyethylene layer, that allows for eigenfrequencies mechanical tuning and decrease losses due to eddy currents in metal wall. Magnetic field is perpendicular to the disk flat surface.

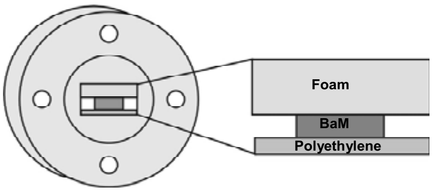

Fig. 4. Diagram showing a disc of single crystal BaM mounted inside a waveguide flange and sandwiched between a dielectric polyethylene layer and a foam slab

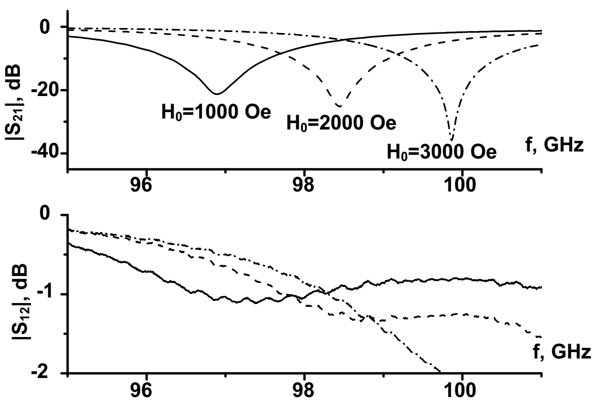

Fig. 5. Direct and reverse transmission characterictics of BaM isolator

Comparison between direct and reverse losses for BaM disk, shifted from the center of waveguide, approximately into the point, where waveguide H_{10} mode have circular polarization, is shown on Fig. 5. An isolator effect is clearly visible; with isolation frequency is tunable with magnetic field in over 5 GHz range.

2.2. Single-crystal yttrium-iron garnet (YIG) disk waveguide band-stop filters. This device is based on D=1 mm, S=0.2 mm YIG disk, positioned on the center of flange. Its transmission characteristic, showing more than 2 GHz tunability with 100 GHz central frequency is presented on Fig. 6 [7].

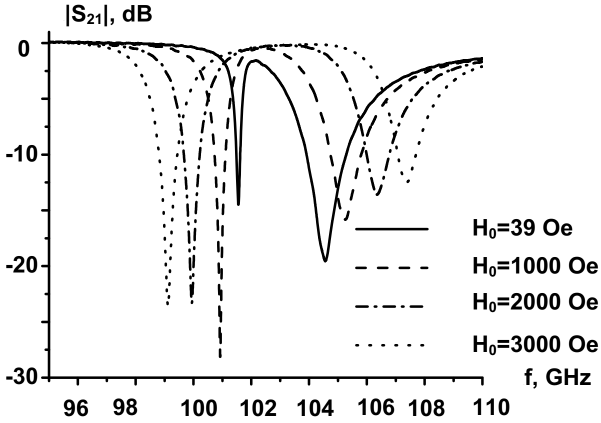

Fig. 6. Transmission characterictics of YIG disk band stop filter

2.3. Waveguide nickel ferrite-based tunable phase shifter. Phase vs. bias field characteristic of mm-wave poly-crystalline nickel ferrite oxide (NFO) disk-based tunable phase shifter (D=1 mm, S=0.25 mm) is shown on Fig. 7.

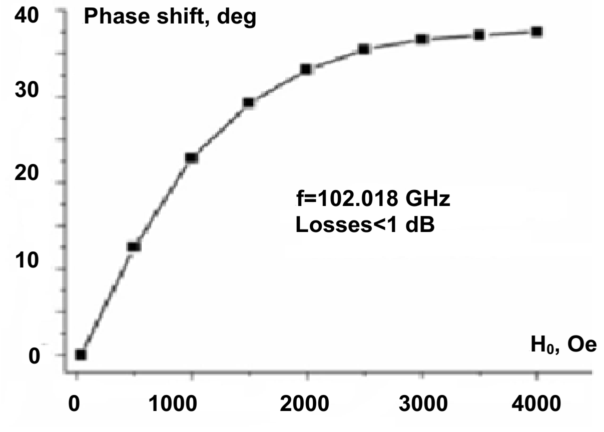

Fig. 7. Tunable insertion phase shift of NFO phase shiter

2.4. Stripline nickel ferrite-based tunable band-pass filter. A filter based on the magnetodynamic mode in NFO was designed and characterized. The microstripline filter shown on inset on Fig.8 was made from a 0.25 mm thick RT Duroid 5880 substrate and had a gap in the central strip. Power is transferred from input to output due to excitation of magnetodynamic resonance in the NFO disk. The scattering parameter S_{21} vs. f measured for a series of H_0 are shown in Fig. 8 [8].

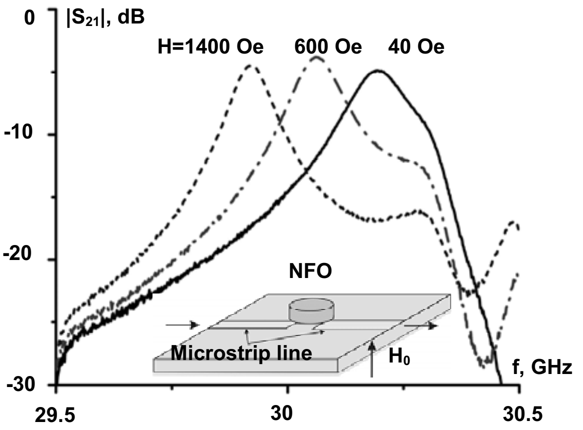

Fig. 8. Schematic diagram showing NFO dielectric resonator bandpass filter and profiles of scattering parameter S_{21} for different H_0

2.5. BaM nonreciprocal phase shifter with bistability effect. It was found, that when H_0 decreases from large values, sample stays saturated up to some critical field $H_{cr}\approx 2500$ Oe [9]. But then single-domain state becomes metastable, whereas multidomain state becomes energetically favorable, and at some point jump-type transition to unsaturated state is observed. This bistability leads to noticeable phase shift $\delta\varphi$ of transmitted electromagnetic wave in frequency region between resonance frequencies, when ferrite resonator is switched amongst a two states on the hysteresys curve (see Fig. 9).

From Fig. 9 one can see, that $\delta\varphi$ increase from 22° at 2700 Oe to 77° at 3700 Oe at middle frequency, but losses at the very same frequency also monotonically increase. Theoretical calculations, using HFSS and analytical theory (2) for frequency determination and equivalent circuit model for phase shift derivation, demonstrate rather satisfactory coincidence with experimental data.

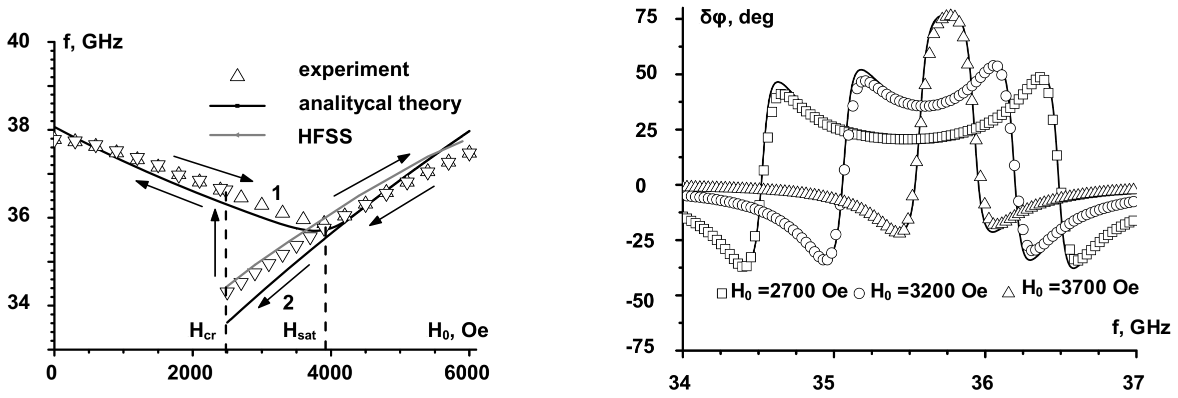

Fig. 9. Experimental (dots) and theoretical (lines) frequency vs. field dependence of main MDR, demonstrating high-frequency hysteresys and corresponding differential phase shift for different bias fields

2.6. BaM tunable devices in "below FMR" region. MDR modes properties in the below-FMR region mostly remain unexplored. Also, when operating in the below-FMR region, the spin-wave manifold is inevitably lying above the MDR frequency, hence 1) no spin wave modes would ever appear inside device bandwidth for any value of bias magnetic field and 2) any possible nonlinear interactions between MDR and spin waves are also excluded.

An examples of phase shifter and isolator in the below-FMR region [10] made from BaM disks with radius a=1.2 mm, and thicknesses S=0.36 mm (№1) and S=0.44 mm (№2) are shown on Fig. 10.

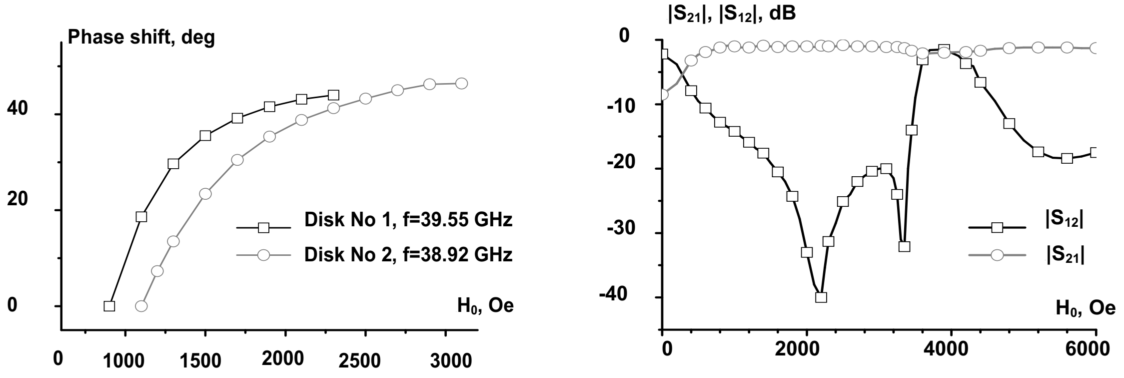

Fig. 10. Tunable differential phase shift for №1 and № 2 BaM disk resonators; direct loss and isolation of resonance isolator (resonator №2), operating frequency 39.9–41.2 GHz, in the "below FMR" region

3. Hexaferrite magnetostatic resonators with dual magnetic and electric field tuning. The bilayer made from substituted barium hexaferrite bonded to piezoelectric lead zirconate titanate (PZT) was used for studies on millimeter-wave electric field tunable magnetostatic resonator. For an electric field E applied to bilayer, the piezoelectric deformation leads to an internal magnetic field, proportional to mechanical strain. Thus, the condition for FMR, for H_0 perpendicular to the plane is

$$f_0 = \gamma (H_a + H_0 - 4\pi M_0) + AE \qquad (3)$$

Figure 11 shows data on the *E* dependence of δ*f* obtained for a bilayer with a ferrite thickness of 95 μm [13].

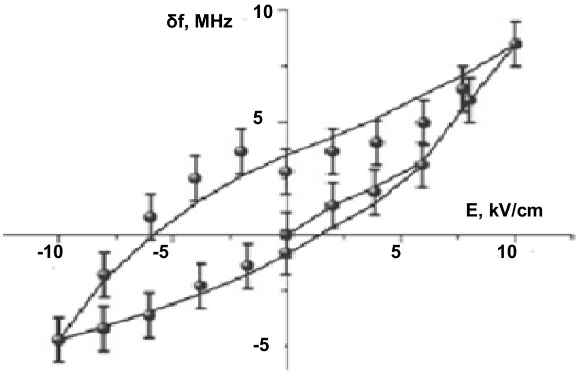

Fig. 11. Electric field induced frequency shift δ*f* vs *E* for Ba*M*/PZT bilayer for H_0=6020 Oe

A maximum frequency shift of 8 MHz was measured for E=±10 kV/cm using vector network analyzer. Thus the magnetodielectric coupling constant *A*=0.8 MHz cm/kV.

Conclusions. In the frequency range 30–110 GHz tunable ferrite devices can be manufactured using any type of considered above excitations, however at higher frequencies, magnetic field tunable devices on the basis of magnetodynamic resonances in ferrite resonator seems to be the most promising option.

A number of prototype magnetic field tunable resonance millimeter wave devices (phase shifters, isolators and band-pass filter) utilizing magnetodielectric resonances were presented and their principal characteristics have been measured. With proper choice of ferrite resonator dimensions one can vary the device operating frequency in the below-FMR region as well as in the above-FMR frequency domain. Moreover, maximum operating frequency in the above-FMR region does not depend on magnetic parameters of the ferrite and, in theory, can easily reach THz frequencies.

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Submitted on 28.10.14

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ПРИСТРОЇ МІЛІМЕТРОВОГО ДІАПАЗОНУ НА ОСНОВІ ПАСИВНИХ ФЕРИТОВИХ РЕЗОНАТОРІВ

В огляді розглянуто магнітодинамічні коливання в феритових резонаторах та їх застосування в міліметровому діапазоні довжин хвиль. Дано класифікацію власних коливань феритових резонаторів. Запропонована аналітична теорія для розрахунку резонансних частот та продемонстровано ряд електрично перестроюваних пристроїв міліметрового діапазону, що використовують магнітодинамічні коливання в зарезонансній та дорезонансній областях, наприклад вентилі, фазообертачі, смугопропускаючі фільтри.

Ключові слова: *магнітодинамічні моди, прилади міліметрового дапазону, гексаферит барію, нікелевий ферит, залізо-ітрієвий гранат.*

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ПРИБОРЫ МИЛЛИМЕТРОВОГО ДИАПАЗОНА НА ОСНОВЕ ПАССИВНЫХ ФЕРРИТОВЫХ РЕЗОНАТОРОВ

В обзоре рассмотрено магнитодинамические колебания в ферритовых резонаторах и их использование в миллиметровом диапазоне длин волн. Дана классификация собственных колебаний ферритовых резонаторов. Предложена аналитическая теория для расчета резонансных частот и продемонстрировано ряд электрически перестраиваемых приборов миллиметрового диапазона, которые используют магнитодинамические колебания в зарезонансной и дорезонансной областях, например вентили, фазовращатели, полосопропускающие фильтры.

Ключевые слова: *магнитодинамические моды, приборы миллиметрового диапазона, гексаферрит бария, никелевый феррит, железо-иттриевый гранат.*