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Excitation by shot circuited coaxial transducer of magnetostatic modes in rectangular yttrium iron garnet film

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Abstract. The *purpose* of this work is the study of design of new short-circuited coaxial transducer with thin linear jumper, that circuites on both sides of the grounded coaxial cylinder, located above the rectangular iron-yttrium garnet (YIG) film, in homogeneous constant magnetic field with rectangular film along its length or width. The thin linear jumper is directed parallel to the width of the YIG film. *Methods.* In the CST Microwave Studio environment, an electrodynamic analysis of the model was carried out using the finite element method. To study the efficiency of modes excitation in a ferrite film at different distances between the coaxial transducer and the surface of the YIG film, the frequency dependencies of the inverse losses S11 of the model were calculated. *Results.* 1. The identification of modes in a homogeneous static magnetic field H, directed parallel to the plane of a rectangular YIG film along its width (y-axis) was carried out. 2. The identification of modes in a homogeneous static magnetic field H directed parallel to the plane of the rectangular YIG film along its length (z-axis) was carried out. 3. A comparison of modes spectra was made at $\vec{H}$, directed parallel to the plane of the YIG film along its width (y axis) and length (z axis). *Conclusion.* In this paper short-circuited transducer with a thin linear jumper, circuited on both sides of the grounded coaxial cylinder, is investigated. By the electrodynamic method distributions of high-frequency magnetic field of the excited magnetostatic modes were calculated and their identification was carried out for two directions of homogeneous static magnetic field: along width and along length of rectangular YIG film. The dependence of number of excited modes on the distance between a short-circuited transducer and rectangular YIG was also studied. A comparison of modes spectra is carried out at $\vec{H}$, directed parallel to the plane of the YIG film along its width and length. With this rotation of $\vec{H}$ vector, the band of effectively excitable modes shifts from 4.6...4.9 GHz to 4.5...4.75 GHz. However, the excitation of these modes in the case of the vector $\vec{H}$, directed along the width of YIG film (y-axis), is much more effective in the band 4.65...4.9 GHz than in the case when this vector is directed along the length of YIG film (z-axis). At the same time, excitation of these modes in the case of the vector $\vec{H}$, directed along the length of YIG film (z axis) is much more effective in the band 4.4...4.6 GHz.

Keywords: iron-yttrium garnet, magnetostatic modes, coaxial transducer.

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Introduction

In the developed devices of spin-wave microwave electronics, the excitation of magnetostatic waves can be carried out using segments of coplanar, microstrip, slit and other distributed transmission lines.

The excitation of magnetostatic modes (MSM) by a microstrip line in the most complete form was experimentally investigated in [1]. This paper presents experimental results of the excitation of various series of MSM by a microstrip line in a rectangular sample with a film of YIG placed in various ways relative to the conductor of the microstrip line.The experimental structure studied in [1]was used to excite MSM in a rectangular film of YIG by a microstrip line with an external constant magnetic field parallel or perpendicular to the plane of the film. The type of the observed spectrum in both cases was determined by the dispersion relations (equations), the relative position of the microstrip conductor and the sample, as well as the current distribution in the microstrip line.

The study of the relationship between an electromagnetic wave propagating in a microstrip transmission line and the excitation of MSM in films of YIG is an urgent applied task. The purpose of the works [**?**, 2, 4, 5] Visualization of the HF magnetic field distribution of these modes and their identification was performed. These works are devoted to the electrodynamic modeling of the distribution of a high-frequency magnetic field in rectangular thin films of YIG, calculation of the frequency dependences of insertion losses (parameter S21) and return losses (parameter S11) and their comparison with those obtained experimentally in [1] in the form of MSM spectra when a rectangular sample of a film of YIG is excited by a microstrip line.

A short-circuited coaxial probe can be used as an exciter of MSM, the design of which is proposed in the work [6]. In the works [7, 8], this probe design with a single linear jumper between the central conductor and the grounded coaxial cylinder was studied in detail by electrodynamic modeling. With an external magnetic field applied in the plane of the film (perpendicular to the bridge between the conductors of the coaxial exciter), the identification of the excited modes was carried out and the effect of the distance between the film and the exciter was considered. In the case of an external magnetic field perpendicular to the plane of the ferrite film, the identification of excited modes was also carried out at a distance of 0.2 mm from the probe. The results of the calculation of the frequencies of the spectra coincide with the experiment [6]. The peculiarities of the mode spectra for these two mutually orthogonal orientations of the magnetizing field can be explained by the difference in the dispersion and excitation frequencies in the resonances of surface and reverse volumetric magnetostatic waves in the film (in the first case) and direct volumetric magnetostatic waves (in the second case).

In [9], the design of a short-circuited exciter is investigated, which differs from the one described in [8] in that a thin linear jumper closes on both sides of a grounded coaxial cylinder. By the electrodynamic method of [5] and [8], the distributions of the high-frequency magnetic field of the excited magnetostatic modes were calculated and their identification was carried out with the orientation of the external constant magnetic field in the plane of a rectangular film of YIG along its width.

In the work [10], a study of excitation of magnetostatic modes by a short-circuited coaxial-loop converter in a rectangular film of iron-yttrium garnet.

An experimental study of the excitation of magnetostatic modes in a film of YIG by a short-circuited coaxial microstrip transducer probe is presented by in [11–13]. The frequency dependences of the reverse losses are measured for different orientation of the plane of the half-turn of the converter relative to the direction of the external constant magnetic field.

In [14], the electrodynamic method was used to study the excitation of magnetostatic modes in a rectangular film of YIG by a short-circuited coaxial exciter, in which a thin linear jumper closes on both sides of an external grounded coaxial cylinder. With a constant magnetic field applied in the plane of a rectangular film of YIG along its length and parallel to the jumper between the conductors of the coaxial exciter, the identification of the excited modes was carried out, the effect of the gap between the film and the exciter on the return losses S11 of the excited modes was considered.

1. Identification of modes in a homogeneous static magnetic field H directed parallel to the plane of a rectangular film of YIG along its width (y axis)

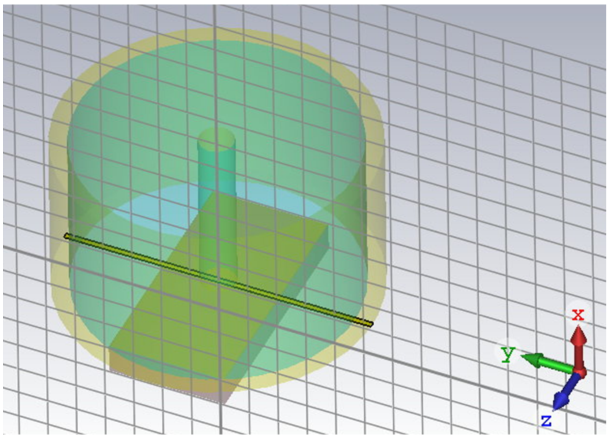

Fig. 1. The studied model of the coaxial transducer with YIG film

In the CST Microwave Studio environment, the electrodynamic analysis of the model presented in Fig. 1. To study the efficiency of excitation of modes in a ferrite film at different distances between the coaxial exciter and the surface of the film of YIG, the dependences of the inverse losses of the S11 model on the frequency were calculated.

Saturation magnetization of the YIG film $4\pi M = 1750$ Gs, ferromagnetic resonance line width $\Delta H = 0.1$ E. Uniform static magnetic field $H = 1000$ E is oriented along the y axis parallel to a thin linear jumper closed on both sides of a grounded coaxial cylinder. The rectangular sample of the YIG film had a length of 4 mm, a width of 2 mm, a thickness of 24 microns. Dimensions of the linear jumper: length 5.6 m, width 0.1 mm, thickness 0.0005 mm. The segment of the coaxial line contained a copper inner conductor with a radius of 0.3 mm and an external grounded cylinder with a radius of 2.655 mm, the space between which is filled with a dielectric with a permittivity of 7.

Calculation of the model shown in Fig. 1, is carried out for gaps d between a thin linear bridge and a film surface from 0.1 to 0.6 mm. At each resonant frequency of the dependence of the reverse losses S11, the distribution of the HF magnetic field module inside the YIG film was calculated and visualized, according to which the magnetostatic mode was identified. Consider the frequency dependence of the reverse losses S11, shown in Fig. 2 for the case when the surface of the YIG film is removed from the corked conductor of the exciter jumper by a distance of $d = 0.1$ mm.

In Fig. 3 the distributions of the HF magnetic field modulus are presented, with the help of

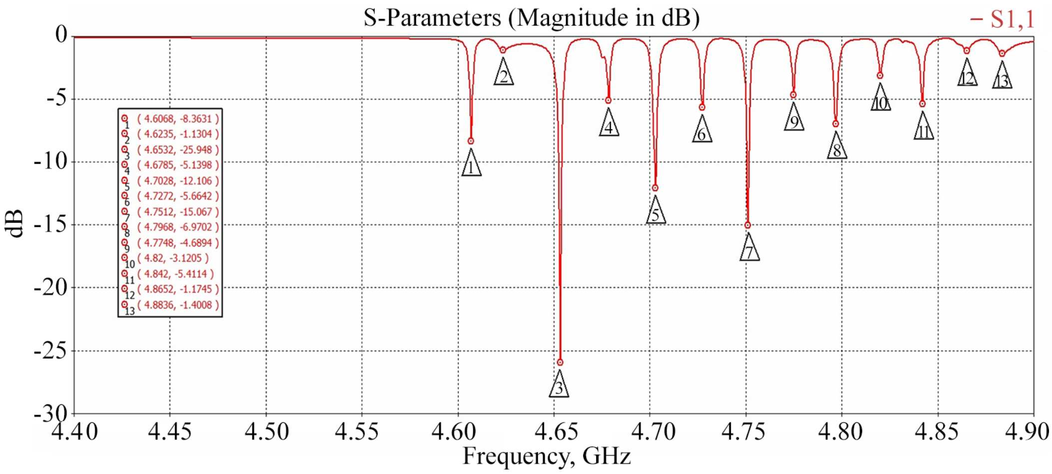

Fig. 2. Frequency dependence S11, when the surface of YIG film is removed from conductor of jumper on $d = 0.1$ mm

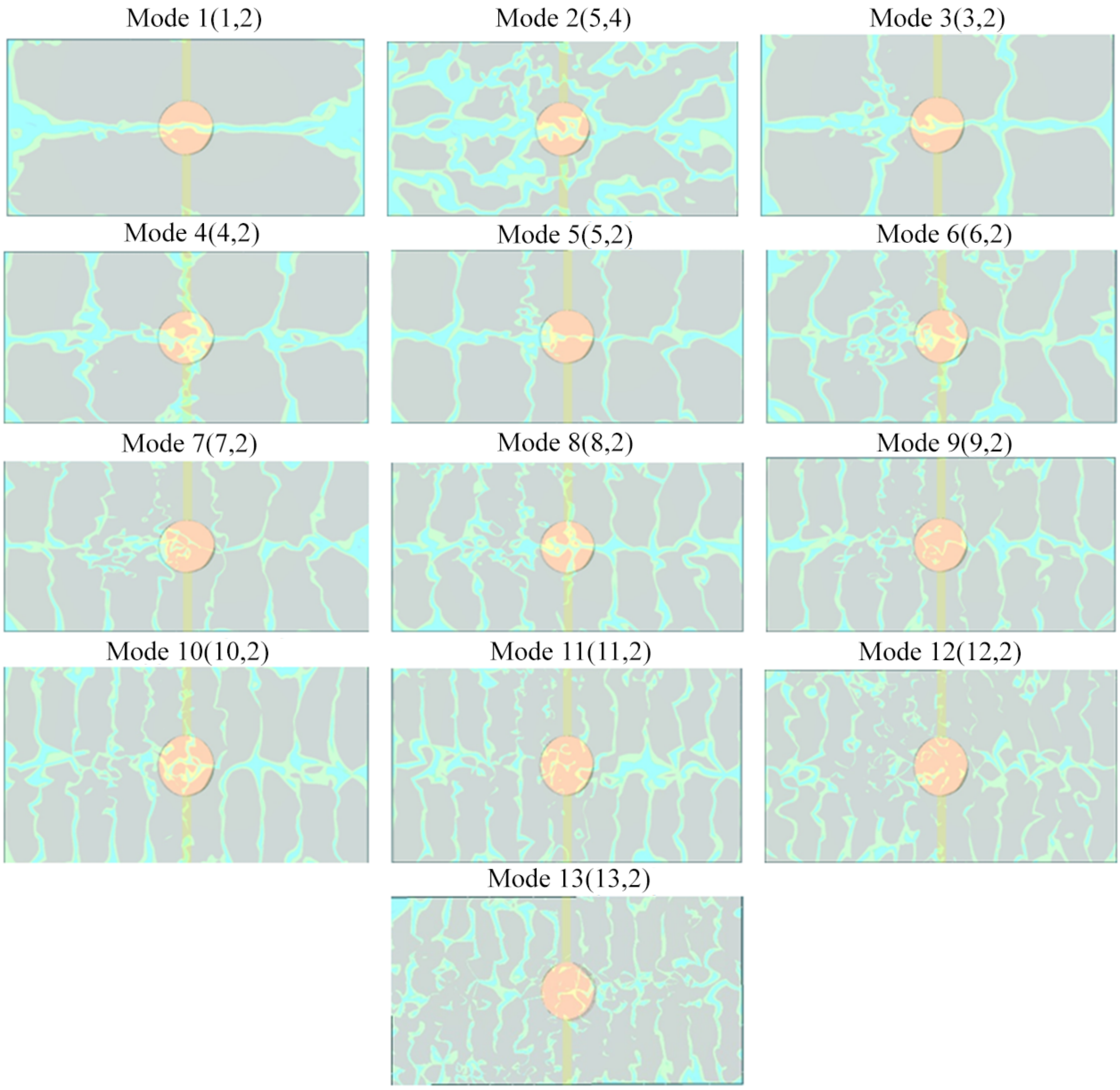

Fig. 3. Distribution of the module of the RF magnetic field mode according to the numbering in Fig. 2 and their identification

which the identification of excited modes was carried out by the number of standing half-waves along the sides of the YIG film.

Next to each resonance in Fig. 3 the integers n_z and n_y denoting the indices of the excited mode are specified. The dependence of the number of efficiently excited modes on the distance of a rectangular sample of YIG film to a short-circuited exciter is investigated. The frequency characteristics of the reverse losses S11 calculated for distances $d = 0.1$ mm (a), 0.2 mm (b), 0.4 mm (c) and 0.6 mm (d) are shown in Fig. 4.

It can be seen that at the level of -4 dB at $d = 0.1$ mm, nine magnetostatic modes are excited, and at $d = 0.6$ mm, only one is excited.

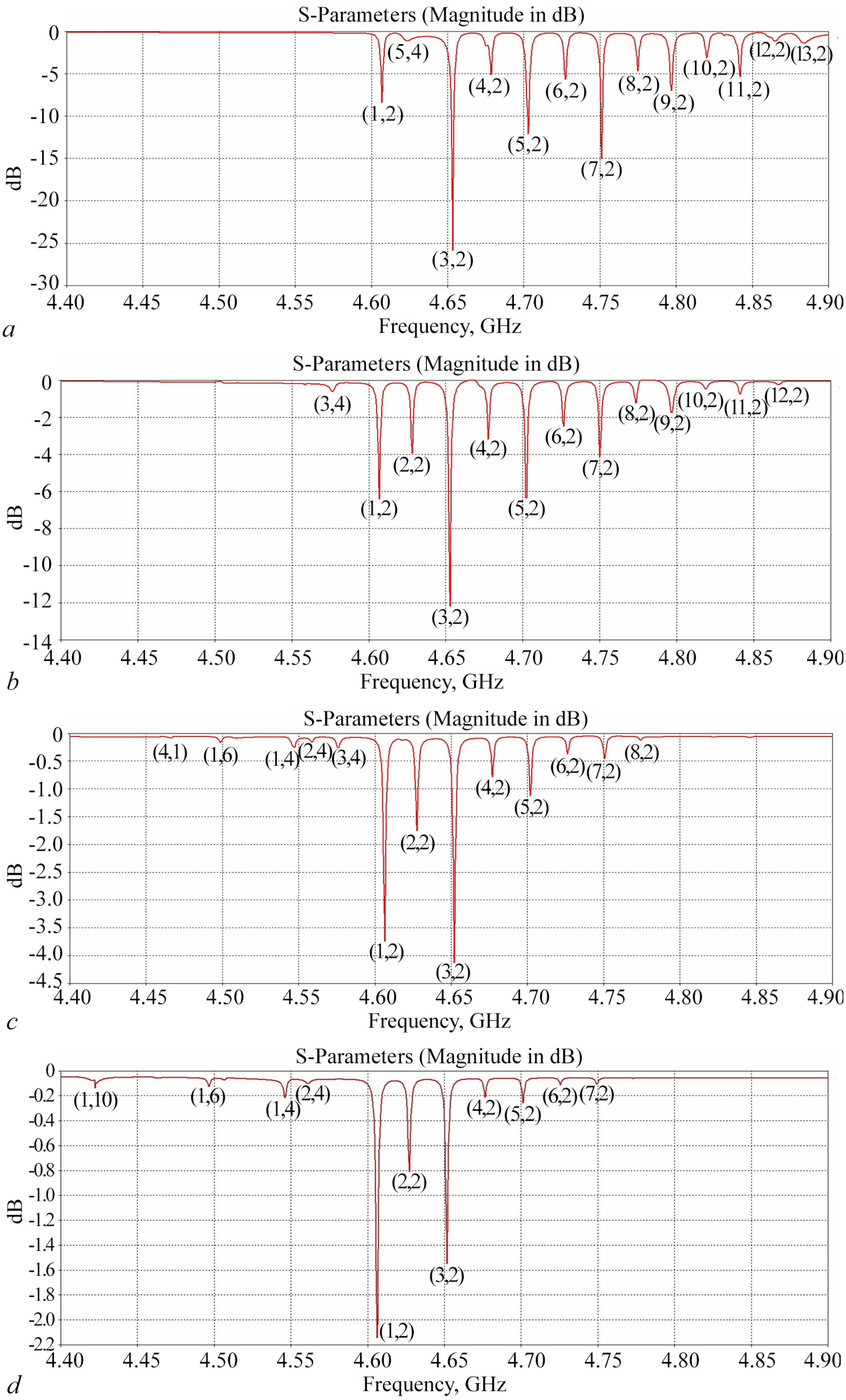

Fig. 4. Frequency dependences S11 for model with identified modes for distances 0.1 mm (a), 0.2 mm (b), 0.4 mm (c) and 0.6 mm (d)

2. Identification of modes in a homogeneous static magnetic field H directed parallel to the plane of a rectangular film of YIG along its length (z axis)

The model was analyzed at distances d between the exciter and the ferrite surface from 0.1 to 0.6 mm. For each resonance on the frequency response of the reverse losses S11, the distributions of the absolute value of the high-frequency magnetic field of the mode inside the YIG film were calculated and visualized. Magnetostatic modes were identified from these distributions.

Let us consider the spectrum of excited magnetostatic modes in a YIG film when its surface is located at a distance of $d = 0.1$ mm from the coro-closed conductor of the exciter jumper.

The frequency dependence of the reverse losses S11 for this case is shown in Fig. 5. For this purpose, the distributions of the absolute value of the high-frequency magnetic field at numbered resonant frequencies were analyzed, which are shown in Fig. 6. According to these distributions, the identification of the excited series of modes by the number of standing half-waves along the sides of the YIG film was carried out. Near each resonance in Fig. 7 a pair of numbers n_z and n_y denoting the indices of this mode is specified.

The dependence of the number of excited modes on the proximity of a rectangular sample of a YIG film to a short-circuited exciter is also investigated. In Fig. 7, *a–d* the calculated frequency characteristics of the reverse losses of S11 for several distances d are given. From Fig. 7 it follows that if three different magnetostatic modes are effectively excited in the frequency band 4.4...4.9 GHz at $d = 0.1$ mm at the level of -4 dB, then at $d = 0.6$ mm only one mode is excited.

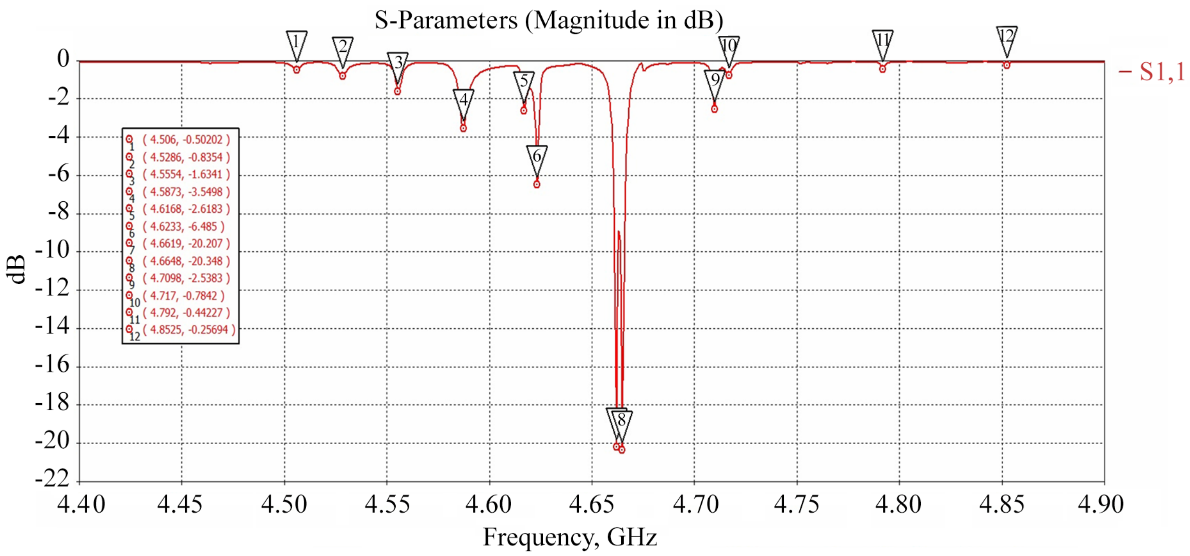

Fig. 5. Frequency dependence S11, when the surface of YIG film is removed from conductor of jumper on $d = 0.1$ mm

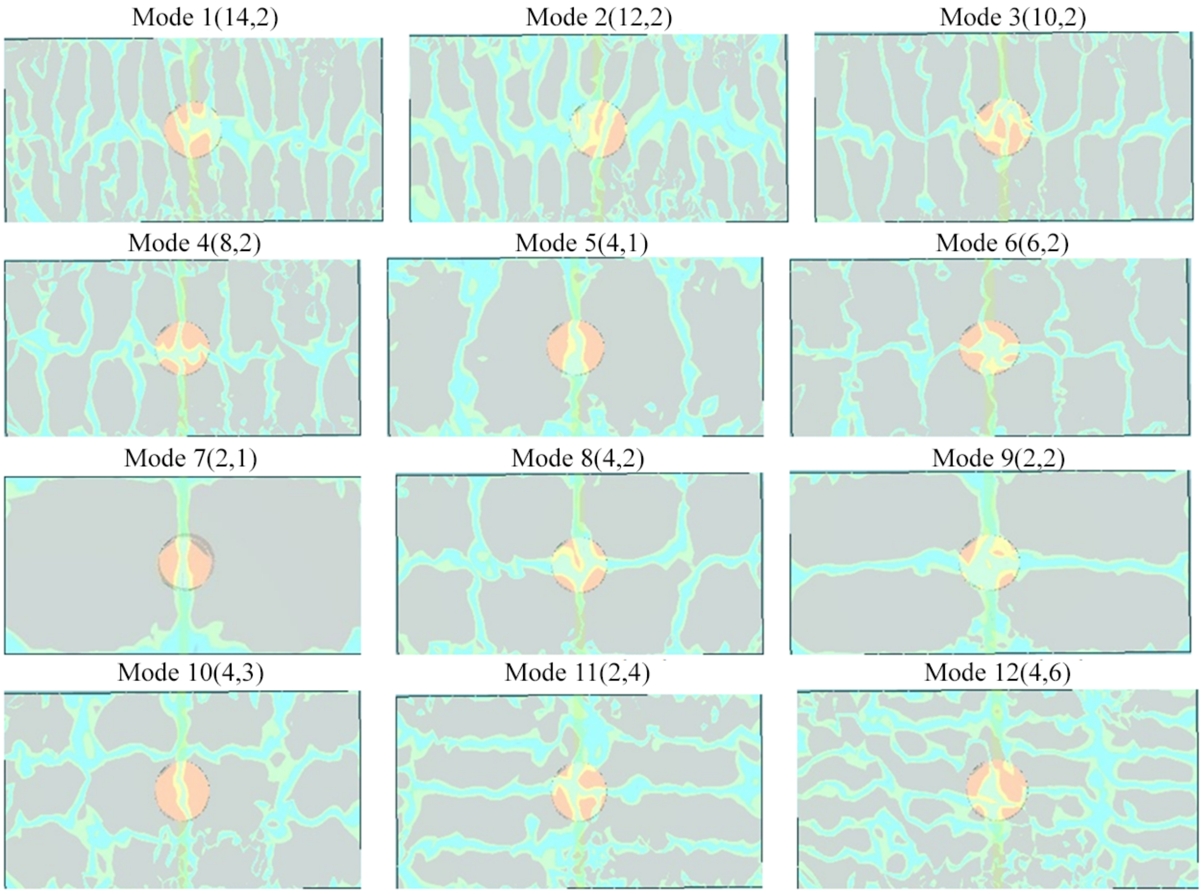

Fig. 6. Distribution of the module of the RF magnetic field mode according to the numbering in Fig. 5 and their identification

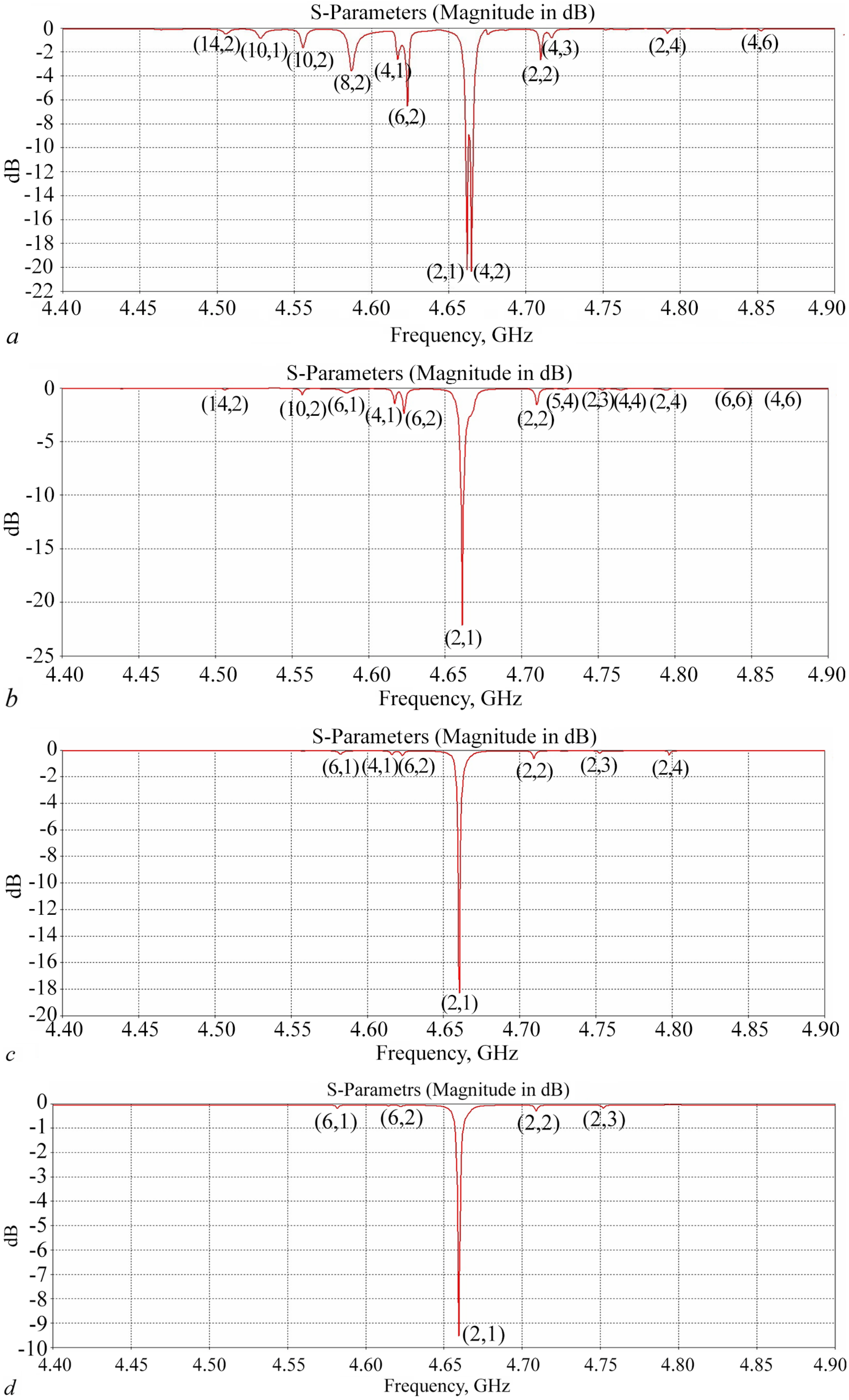

Fig. 7. Frequency dependences S11 model with identified modes for distances 0.1 mm (a), 0.2 mm (b), 0.4 mm (c) and (d) 0.6 mm

3. Comparison of the mode spectra at $\vec{H}$ directed parallel to the plane of the YIG film along its width (y axis) and length (z axis)

Now let's compare for the minimum distance $d = 0.1$ mm with an external constant magnetic field $H = 1000$ E the spectrum of modes shown in Fig. 4, *a* for the direction $\vec{H}$ along the axis y, with the spectrum of modes shown in Fig. 7, *a* for the direction $\vec{H}$ along the axis z. With such a rotation of the vector $\vec{H}$, as can be seen from Fig. 4, *a* and Fig. 7, *a*, the band of effectively excited modes shifts from 4.6...4.9 GHz to 4.5...4.75 GHz. However, the excitation of these modes in the case of the vector $\vec{H}$ directed along the width of the YIG film (axis y) is much more efficient in the band 4.65...4.9 GHz than when this vector is directed along the length of the YIG film (z axis). At the same time, the excitation of these modes in the case of the vector $\vec{H}$ directed along the length of the YIG film (axis z) is much more efficient in the band 4.4...4.6 GHz.

Conclusions

In this paper, the design of a short-circuited exciter is investigated. It differs from the one described in [1] by the fact that a thin linear jumper closes on both sides of a grounded coaxial cylinder. The electrodynamic method [2, 6] calculated the distributions of the high-frequency magnetic field of the excited magnetostatic modes and carried out their identification for two directions of the homogeneous field of magnetization: along the width and along the length of the rectangular YIG film.

The dependence of the number of excited modes on the proximity of a short-circuited exciter to a rectangular sample of a YIG film is also investigated.

The comparison of the spectra of modes at $\vec{H}$ directed parallel to the plane of the YIG film along its width and length is carried out. With such a rotation of the vector $\vec{H}$, the band of effectively excited modes shifts from 4.6...4.9 GHz to 4.5...4.75 GHz. However, the excitation of these modes in the case of the vector $\vec{H}$ directed along the width of the YIG film (axis y) is much more efficient in the band 4.65...4.9 GHz than when this vector is directed along the length of the YIG film (z axis). At the same time, the excitation of these modes in the case of the vector $\vec{H}$ directed along the length of the YIG film (z axis) is much more efficient in the band 4.4...4.6 GHz.

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