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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 circuits on one side 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 dependences of the inverse losses S11 of the model were calculated. *Results.* 1. The identification of modes in a homogeneous static magnetic field $\vec{H}$, directed parallel to the plane of a rectangular YIG film along its width (z-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 (y-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 (z-axis) and length (y-axis). *Conclusion.* In this paper short-circuited transducer with a thin linear jumper, circuited on one side 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 $\vec{H}$: 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 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 (z-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 (y-axis). At the same time, excitation of these modes in the case of the vector $\vec{H}$, directed along the length of YIG film (y axis) is effective in the band 4.4...4.6 GHz.

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

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Introduction

In the microwave spin wave electronics devices under development, 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 its most complete form was experimentally investigated in [1]. In this work, extensive experimental results are presented with the excitation of various series of MSM by a microstrip line in a rectangular sample with a YIG film placed in various ways relative to the conductor of the microstrip line.

The experimental structure [1] was used to excite MSM in a rectangular film of a YIG by a microstrip line with an external constant magnetic field that is either 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 YIG film is an urgent applied task.

In the works [2–5], the main goal was to visualize the distribution of high frequencies of the magnetic field of these modes and their identification. These works are devoted to the electrodynamic modeling of the distribution of a high-frequency magnetic field in rectangular thin films of YIG, the calculation of frequency dependencies 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 YIG film is excited by a microstrip line.

When magnetostatic modes are excited in rectangular ferrite films, the properties of these film samples are determined by the ferromagnetic resonance method using coaxial probes of various types. A short-circuited coaxial probe can be used as an exciter of magnetostatic modes, the design of which is presented in the work [3].

In the works [6, 7], this probe design with a single linear jumper between the central conductor and the grounded coaxial cylinder was studied in detail by electrodynamic modeling.

In [8], the design of a short-circuited exciter is investigated, which differs from that described in [7] in that a thin linear jumper closes on both sides of a grounded coaxial cylinder. The electrodynamic method of [7] and [9] calculated the distributions of the high-frequency magnetic field of the excited magnetostatic modes and identified them with the orientation of an external permanent magnetic field in the plane of a rectangular YIG film along its width.

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

An experimental study of the excitation of magnetostatic modes in an iron-yttrium garnet film by a short-circuited coaxial microstrip transducer probe is presented 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 an external constant magnetic field.

In [14], the electrodynamic method investigated the excitation of magnetostatic modes in a rectangular YIG film 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 YIG film along its length and parallel to the bridge between the conductors of the coaxial exciter, the identification of the excited modes was carried out and the effect of the gap between the film and the exciter on the reverse 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 YIG film along its width (z axis)

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 YIG film, the frequency dependences of the inverse losses of the S11 model were calculated.

Saturation magnetization of the YIG film is $4\pi M = 1750$ Gs, the width of the ferromagnetic resonance line is ΔH = 0.1 E. A homogeneous static magnetic field H = 1000 E is oriented along the y axis parallel to a thin linear jumper closed to one side of a grounded coaxial cylinder.

The rectangular sample of the YIG film had a length of 18 mm, a width of 2 mm, and a thickness of 24 microns. Dimensions of the linear jumper: length 1.3275 mm, width 0.1 mm, thickness 0.0005 mm. The segment of the coaxial line contained a copper inner conductor with a radius of 0.1525 mm and an external grounded cylinder with a radius of 1.3275 mm, the space between which was filled with a dielectric with a permittivity of 13.

Calculation of the model shown in Fig. 1, carried out for gaps d between a thin linear bridge and a film surface from 0.1 to 0.8 mm. At each resonant frequency of the inverse loss dependence S11, the distribution of the high frequency module of the magnetic field was calculated and visualized inside the YIG film, according to which the magnetostatic mode was identified.

The frequency dependence of the reverse losses S11, shown in Fig. 2, when the surface of the YIG film is removed from the short-circuited conductor of the exciter jumper at a distance of $d = 0.1$ mm, the distribution of the RF magnetic field module was analyzed at each of the numbered resonant frequencies. The distributions of the high frequency module of the magnetic field, according to which the identification of excited modes was carried out by the number of standing half-waves along the sides of the YIG film, are shown in Fig. 3.

At each distribution of high frequencies of the magnetic field inside the YIG film, sections of the central conductor, the grounded conducting cylinder and the linear jumper connecting them are also visible.

Next to each resonance in Fig. 3 the integers ny and nz are indicated, denoting the indices of the excited mode. The dependence of the number of effectively excited modes on the distance of a rectangular sample of a YIG film to a short-circuited exciter is investigated. The frequency characteristics of the reverse losses S11 calculated for distances $d = 0.1$ mm, 0.4 mm and 0.8 mm are shown in Fig. 4, 5 and 6. At the level of -10 dB, fourteen magnetostatic modes are excited at $d = 0.1$ mm, two at $d = 0.4$ mm, and none at $d = 0.8$ mm.

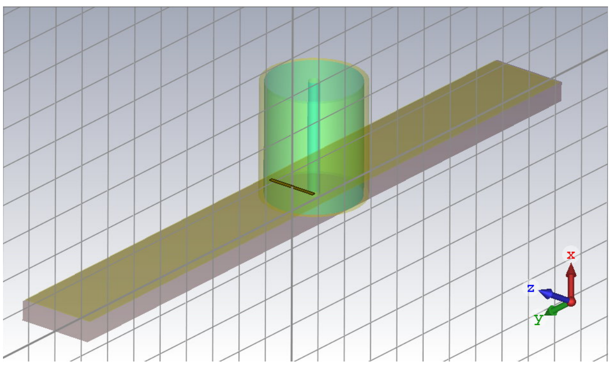

Fig 1. The studied model of the coaxial transducer with YIG film (color online)

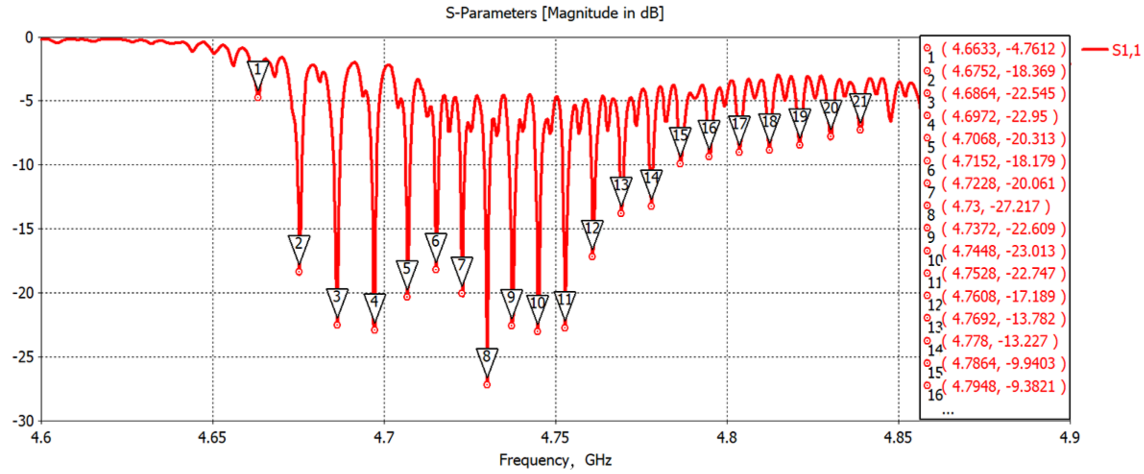

Fig 2. Frequency dependence S11 for vector $\vec{H}$, directed along YIG film width (z axis), when YIG film surface is removed from short-circuited conductor of jumper on $d = 0.1$ mm

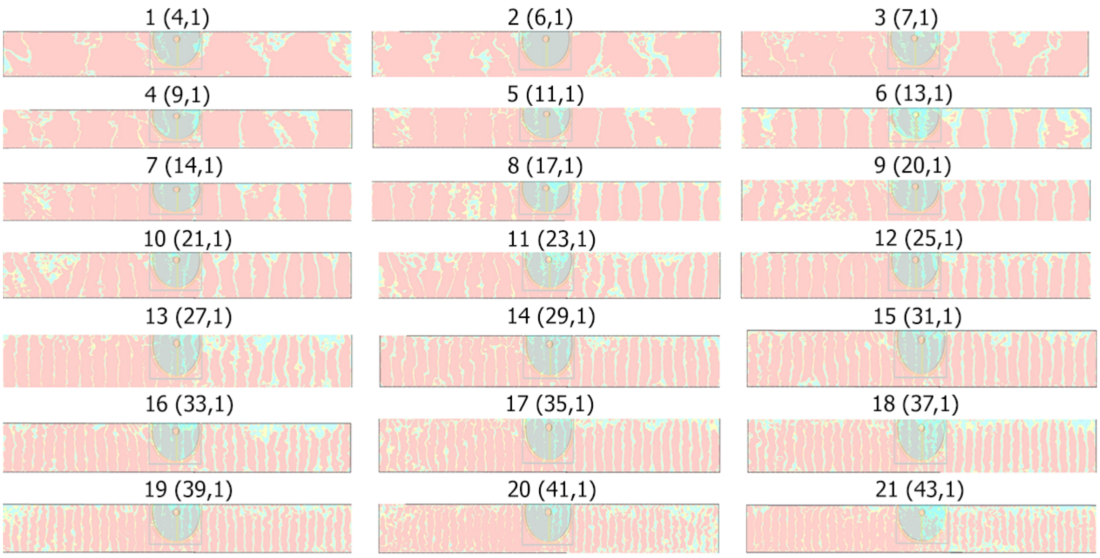

Fig 3. Distribution of the module of the radio frequency (RF) magnetic field mode for vector $\vec{H}$, directed along YIG film width (z axis), according to the numbering in Fig. 2 and their identification (color online)

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

The model was analyzed at distances d between the exciter and the ferrite surface from 0.1 mm to 0.8 mm. For each resonance on the frequency response of the reverse losses of 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's 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 corona-enclosed conductor of the exciter jumper. The frequency dependence of the reverse losses S11 for this case is shown in Fig. 7. For this

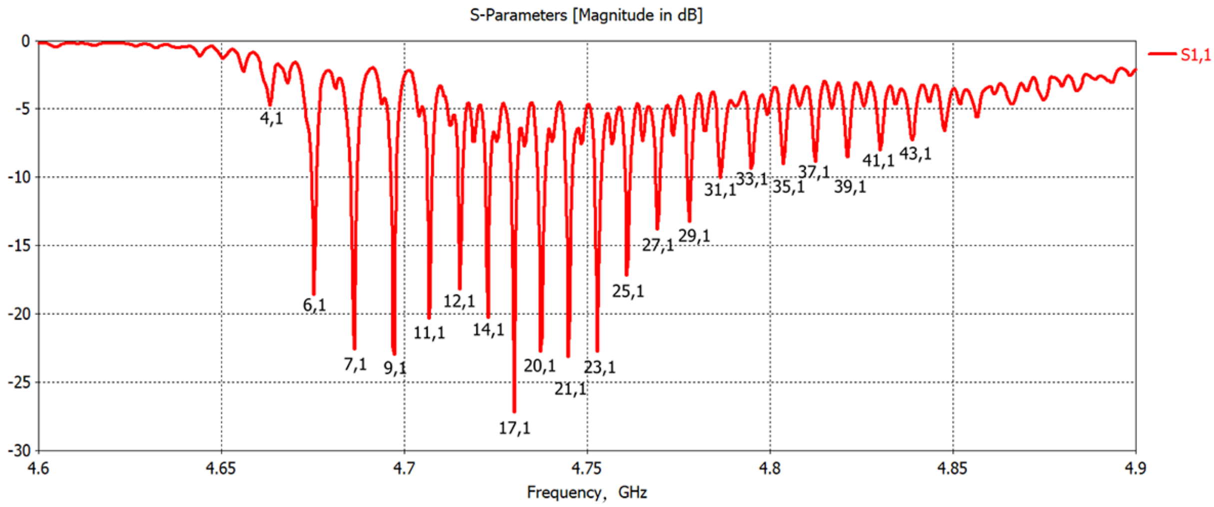

Fig 4. Frequency dependence S11 for vector $\vec{H}$, directed along YIG film width (z axis), model with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.1$ mm

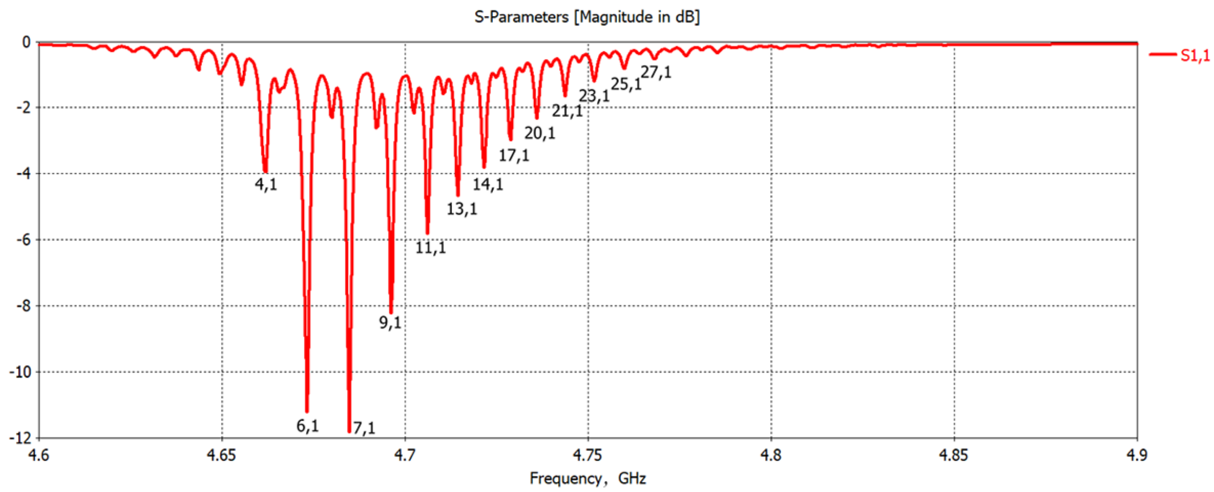

Fig 5. Frequency dependence of S11 model for vector $\vec{H}$, directed along YIG film width (z axis), with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.4$ mm

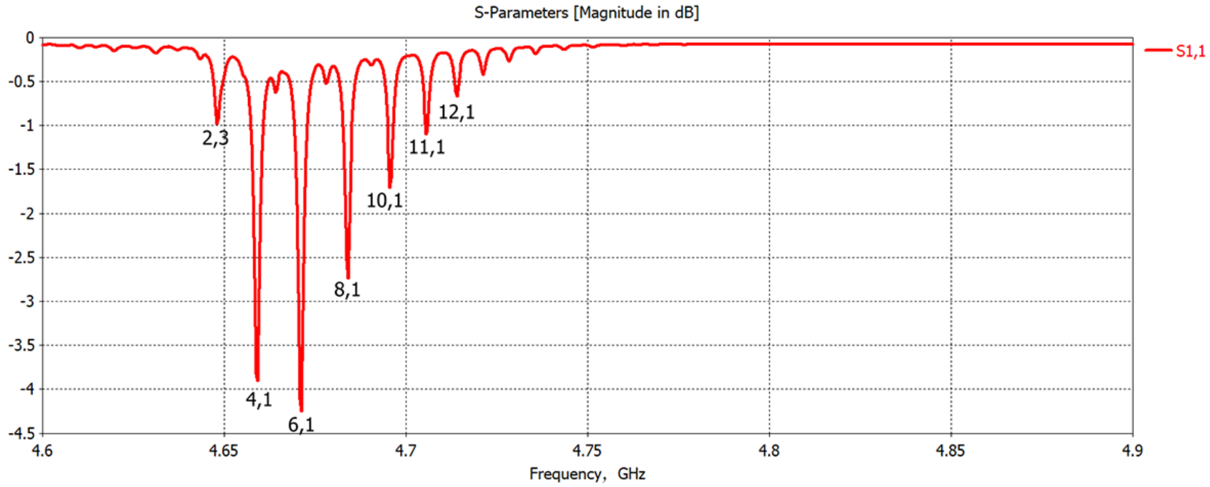

Fig 6. Frequency dependence of S11 model for vector $\vec{H}$, directed along YIG film width (z axis), with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.8$ mm

purpose, the distributions of the absolute value of the high-frequency magnetic field at numbered resonant frequencies were analyzed. The distributions of the high-frequency magnetic field module at resonant frequencies are shown in Fig. 8.

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 investigated. In Fig. 9, 10 and 11 show the calculated frequency characteristics of the reverse losses of S11 for several distances d. If 9 different magnetostatic modes are effectively excited in the 4.5... 4.9 GHz frequency band at $d = 0.1$ mm at the level of -5 dB, then at $d = 0.4$ mm and $d = 0.8$ mm — none. At the same time, for a distance of $d = 0.1$ mm, the most efficiently excited mode is 20.2 with maximum reverse losses S11 of about -9.7 dB, for $d = 0.4$ mm— modes 12.1 and 10.1 with maximum reverse losses S11 of the order of -2.1 dB, and for $d = 0.8$ mm — modes 10.1 and 8.1, but with maximum reverse losses of S11 about -0.45 dB.

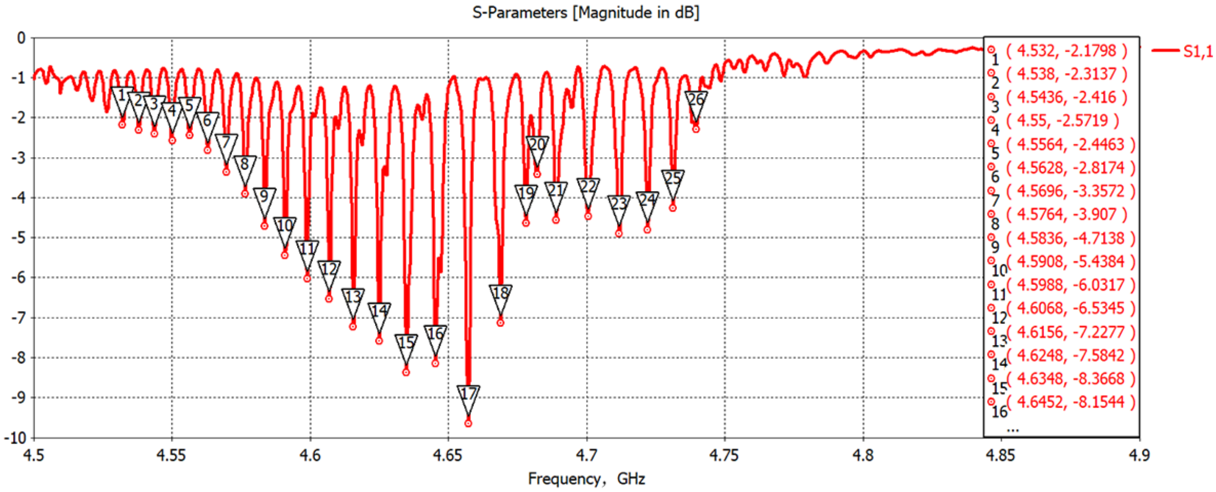

Fig 7. Frequency dependence of S11 model for vector $\vec{\mathrm{H}}$, directed along YIG film length (y axis), when the surface of YIG film is removed from conductor of jumper on $d = 0.1$ mm

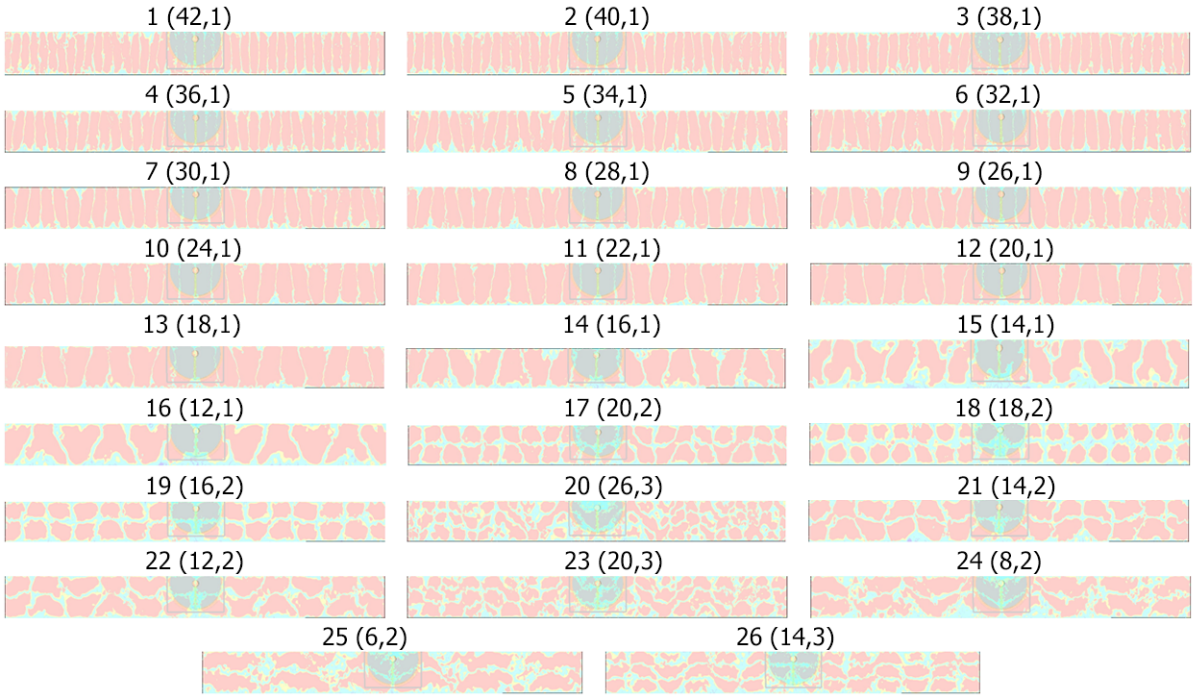

Fig 8. Distribution of the module of the RF magnetic field mode for vector $\vec{\mathrm{H}}$, directed along YIG film length (y axis), according to the numbering in Fig. 7 and their identification (color online)

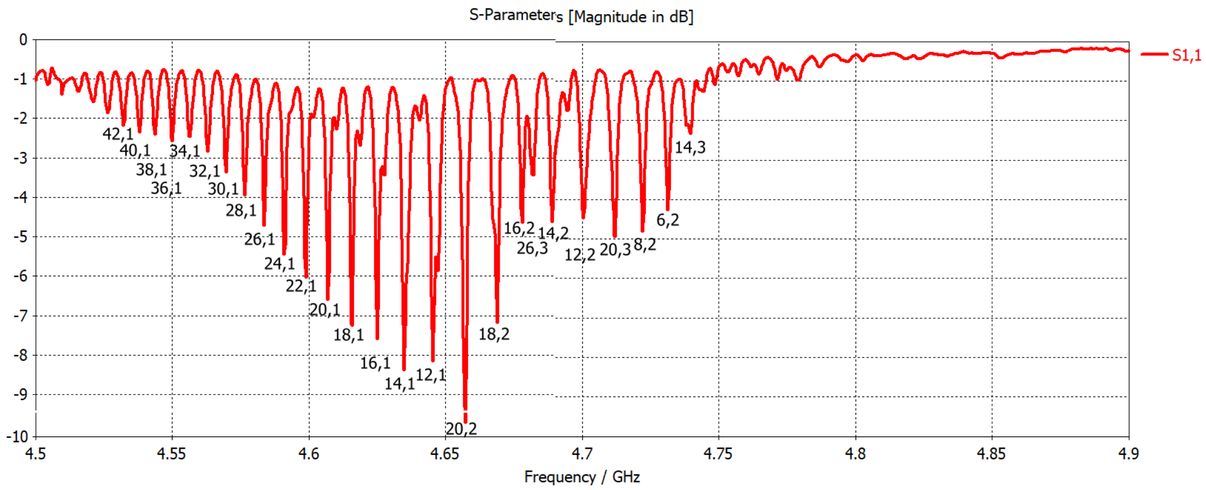

Fig 9. Frequency dependence of S11 model for vector $\vec{H}$, directed along YIG film length (y axis), with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.1$ mm

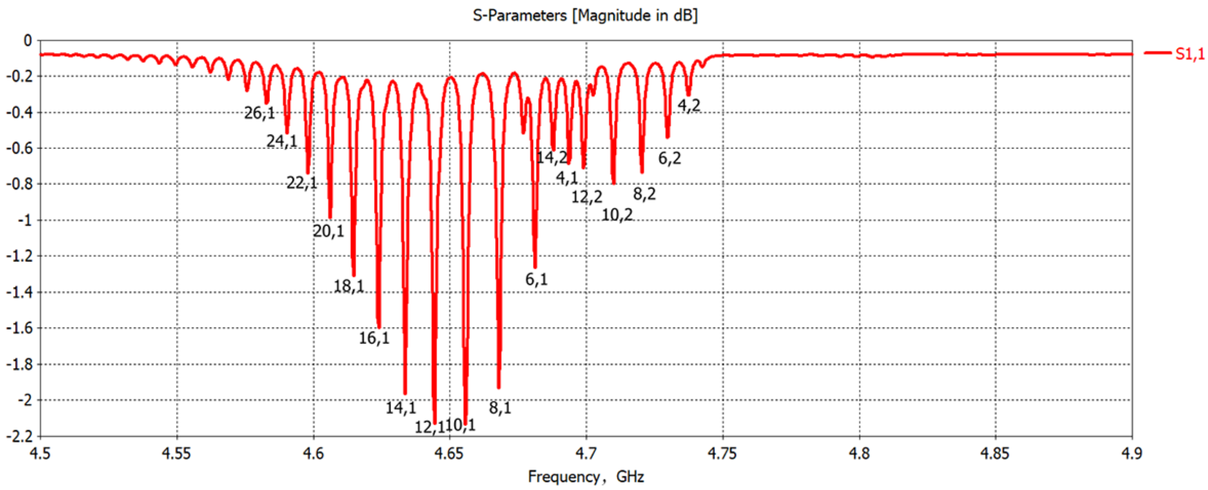

Fig 10. Frequency dependence of S11 model for vector $\vec{H}$, directed along YIG film length (y axis), with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.4$ mm

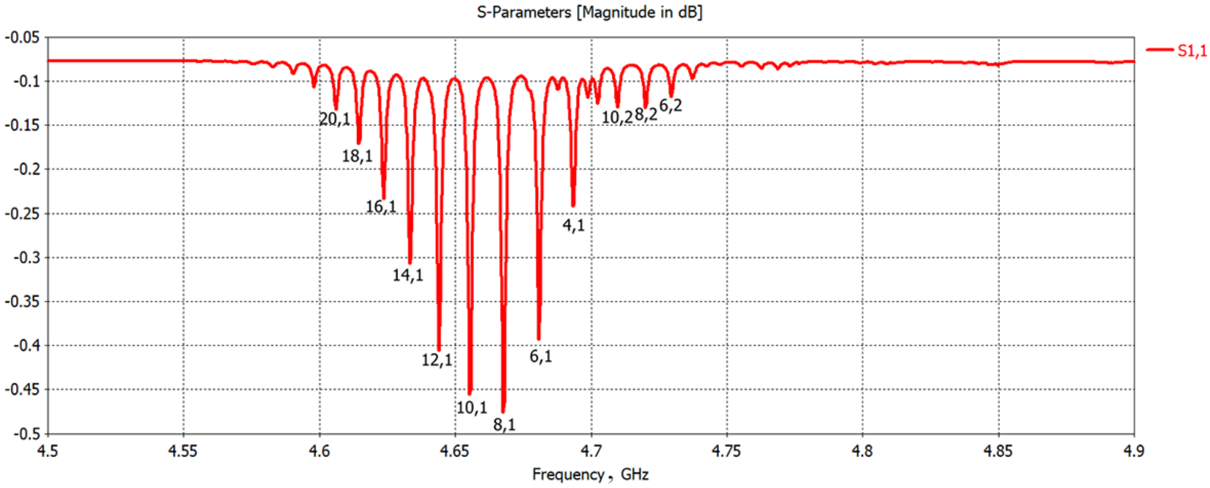

Fig 11. Frequency dependence of S11 model for vector $\vec{\mathrm{H}}$, directed along YIG film length (y axis), with identified modes when the surface of YIG film is removed from conductor of jumper on $d = 0.8$ mm

3. Comparison of the spectra of modes at H directed parallel to the plane of the YIG film along its width (z axis) and length (y axis)

Now let us compare, for a minimum distance of $d = 0.1$ mm with an external constant magnetic field of $H = 1000$ E, the mode spectrum shown in Fig. 4 for the direction H along the z axis, with the mode spectrum shown in Fig. 9 for the direction of H along the y axis. For the direction of H along the z axis, as seen in Fig. 4, 8 modes are excited in the frequency band 4.6...4.9 GHz at the level of −20 db: 7,1; 9,1; 11,1; 14,1; 17,1; 20,1; 21,1; 23,1. For the direction of H along the y axis, as seen in Fig. 9, 8 modes are excited in the frequency band 4.5...4.9 GHz at the level of −6 db: 22,1; 20,1; 18,1; 16,1; 14,1; 12,1; 20,2; 18,2.

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