Magnetostatic-Magnon Sensors for Microwave Microscopy of Biological Structures

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Introduction: Direct detection of chiral biological structures in microwave frequencies is considered as a problem of a great importance. However, the near-field patterns of nowadays microwave sensors do not have symmetry breakings and so cannot be effectively used for microwave characterization of chemical and biological objects with chiral properties as well as chiral metamaterials[1].

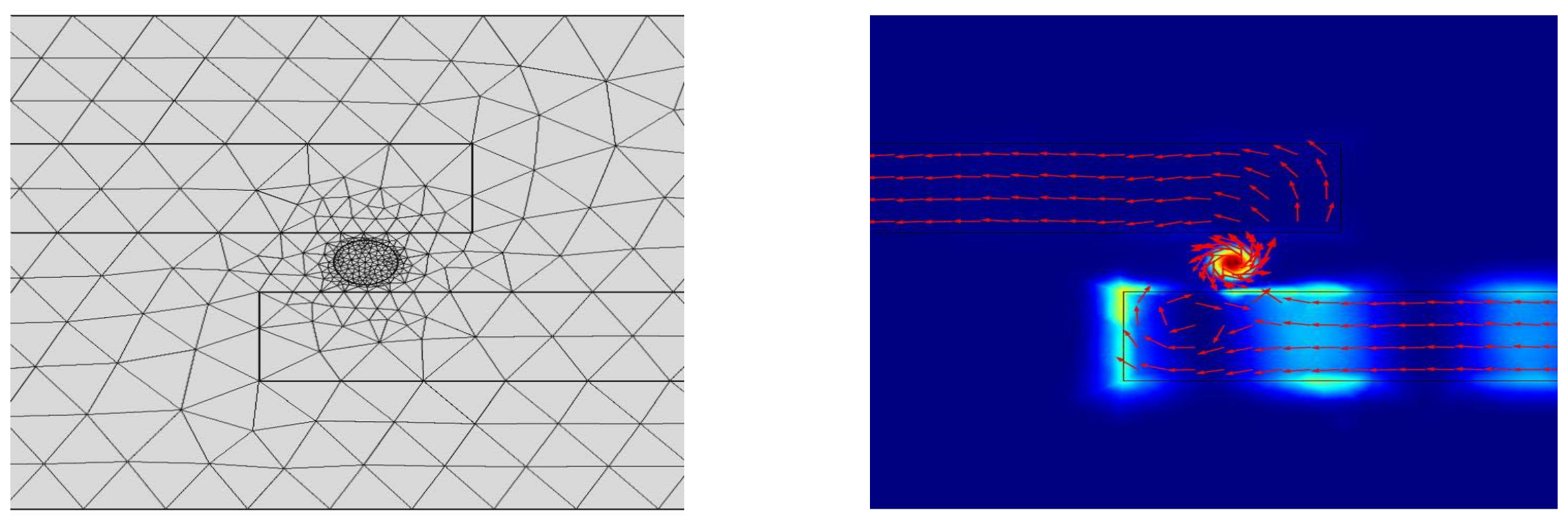

Figure 1. Waveguide microstrip structure with a normally magnetized ferrite disk resonator.

Based on COMSOL Multiphysics solver, we show that small ferrite disk with magnetostatic (MS) oscillations can be used as effective biosensing sensor for biological objects with chiral properties.

Computational Methods: The spectral problem of the ferrite (MS) resonator are obtained with COMSOL Multiphysics solver, by using the electromagnetic module.
Yttrium-Iron-Garnet (YIG) small resonator is placed on a waveguide microstrip structure (Figure 2),with the following properties (Table 1):

Substrate	FR-4 ($\varepsilon_r = 4.4$)
Thickness	1.52[mm]
Characteristic Impedance	50Ω

Table 1. Microstrip parameters

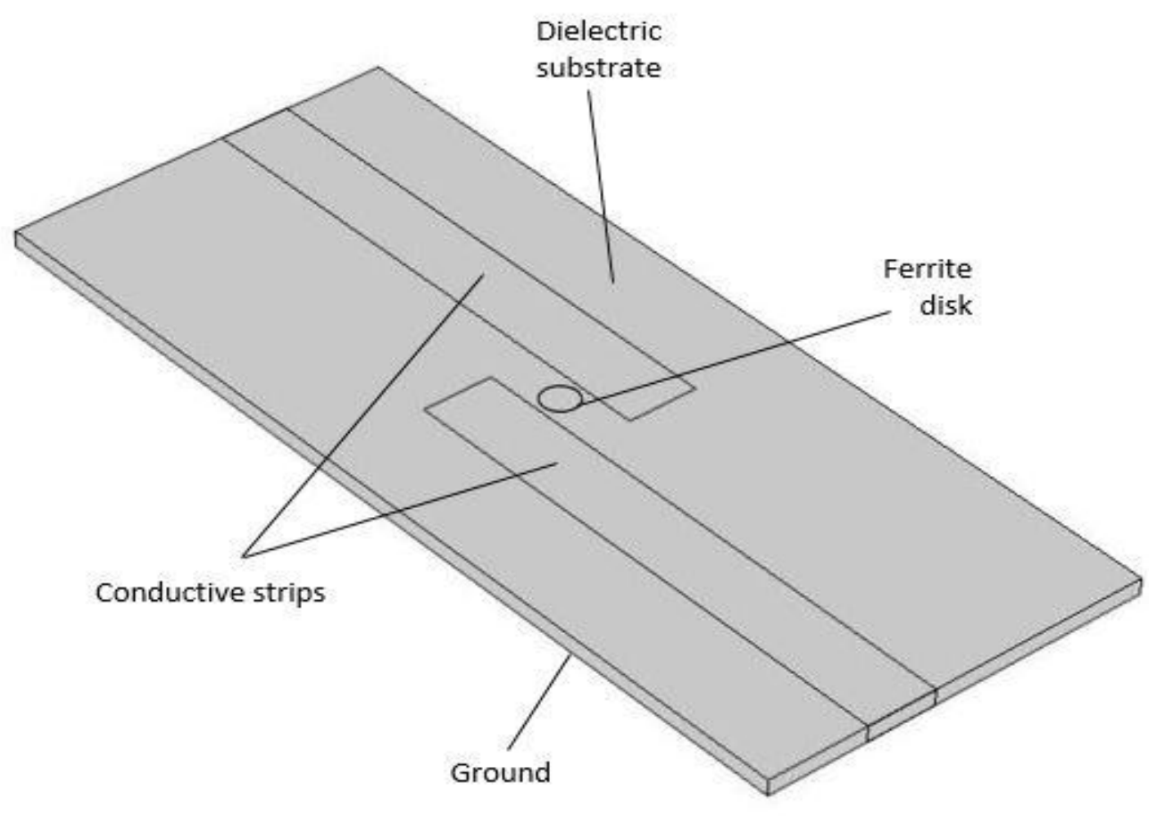

Figure 2. A microwave microstrip structure, with ferrite (MDM) sensor.

The electric field equation we solve in our model can be derived directly from Maxwell's equations and given by:

$$\nabla \times \frac{1}{\overleftrightarrow{\mu_r}}(\nabla \times E) - k_0^2\left(\varepsilon_r - \frac{i\sigma}{\omega\varepsilon_0}\right)E = 0$$

where outside the YIG, $\overleftrightarrow{\mu_r}$ is the unite matrix.
Inside the YIG, we use the permeability tensor for bias magnetic ($\vec{H}_0 = 4900 Oe$) field in z-direction, as shown in Ref [2] :

$$\overleftrightarrow{\mu_r} = \begin{bmatrix} \mu & j\mu_a & 0 \\ -j\mu_a & \mu & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad \mu = \left(1 + \frac{\omega_0\omega_m}{\omega_0^2 - \omega^2}\right) \qquad \mu_a = \left(\frac{\omega_0\omega_m}{\omega_0^2 - \omega^2}\right)$$

Diameter	3[mm]
Thickness	0.05[mm]
Saturation magnetization $4\pi M_s$	1880[Oe]
ΔH	0.4[Oe]

Table 1. YIG (ferrite disk) parameters

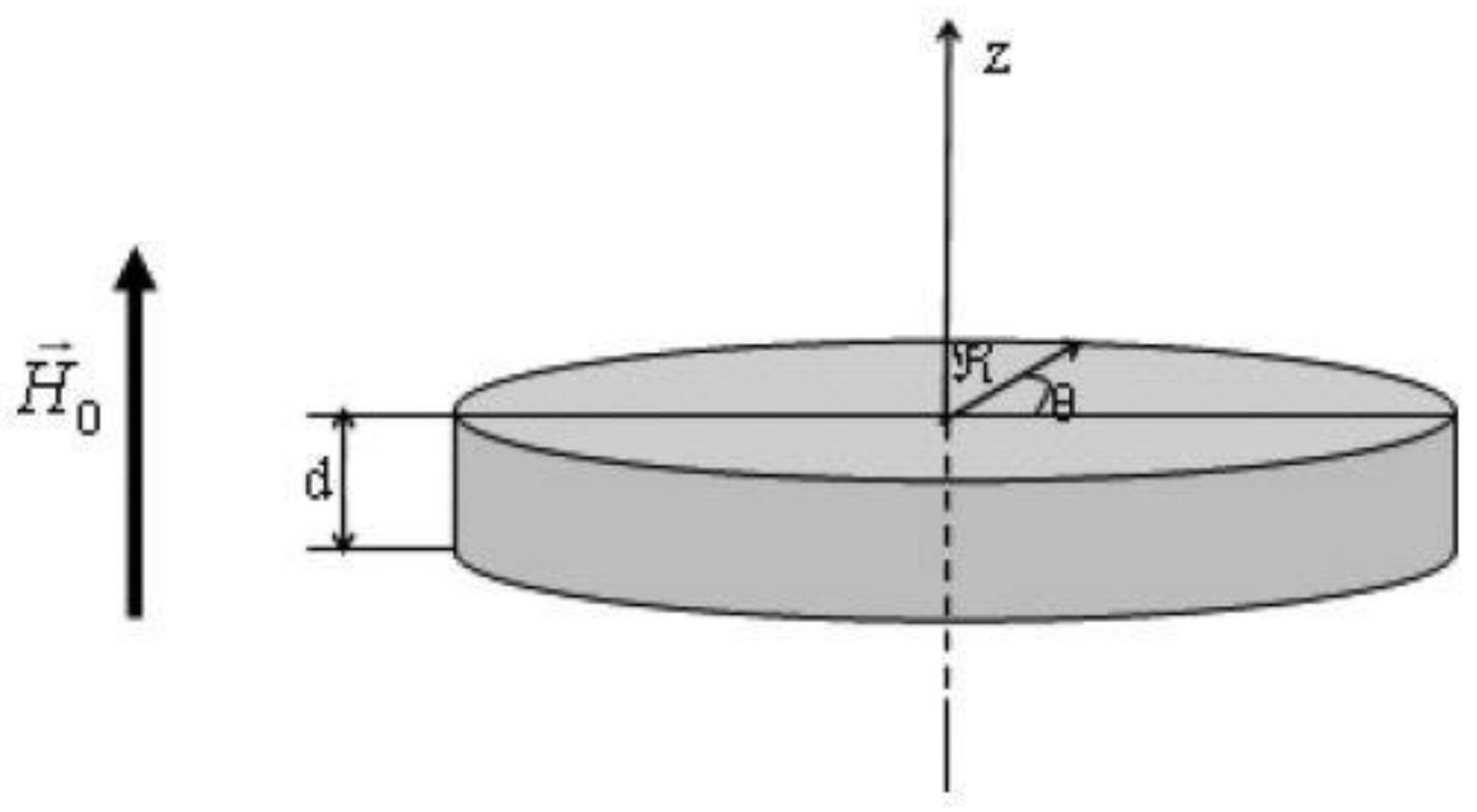

Figure 3. Ferrite resonator

Results: Figure 4 shows the spectral characteristics of the ferrite disk resonator. Both radial and azimuthal modes [3] are marked by numbers n=1,2,3,…. (azimuthal modes are denoted by single prime).

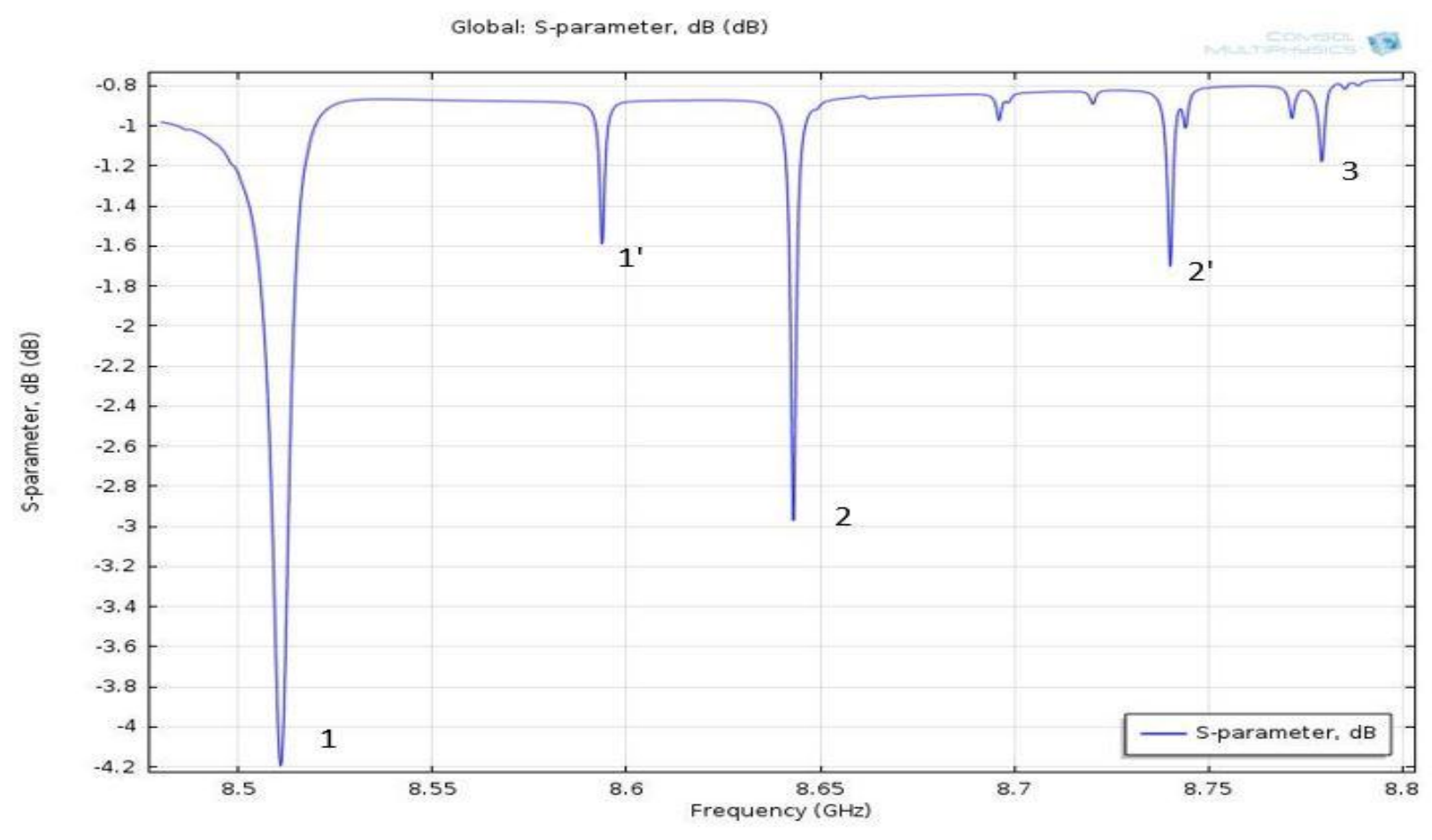

Figure 4. Reflection coefficient for a thin film ferrite disk on a microstrip structure.

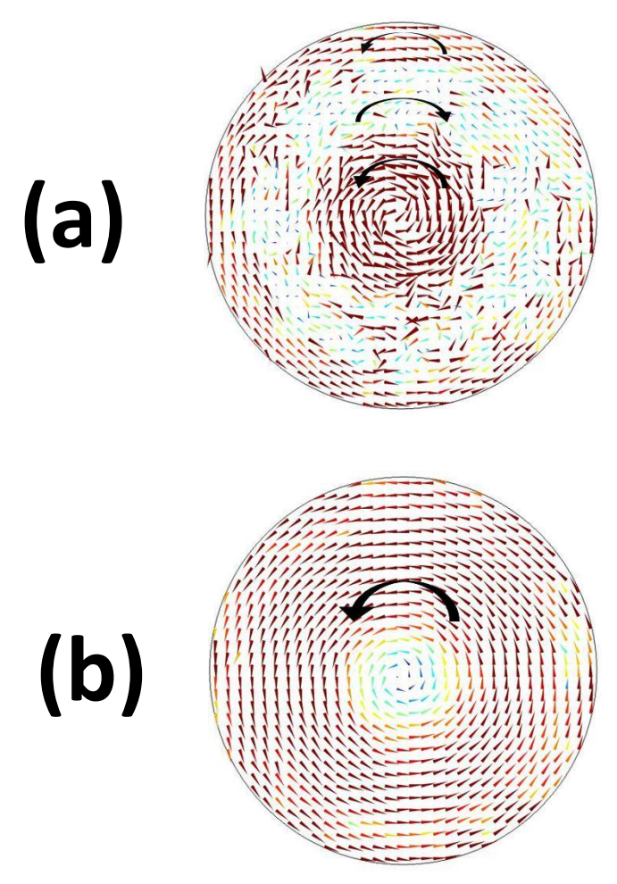

Figure 5. Poynting vector above a ferrite disk surface at (a) 1st resonance and (b) 2nd resonance

Figure 5 shows vortex behavior in the near-field of the ferrite disk at 1^{st}(n=1) and 2^{nd} (n=2) resonance frequencies.
For effective localization of energy, at micron and submicron near field regions, we use a thin metal wire as a field concentrator, placed on the surface of the ferrite:

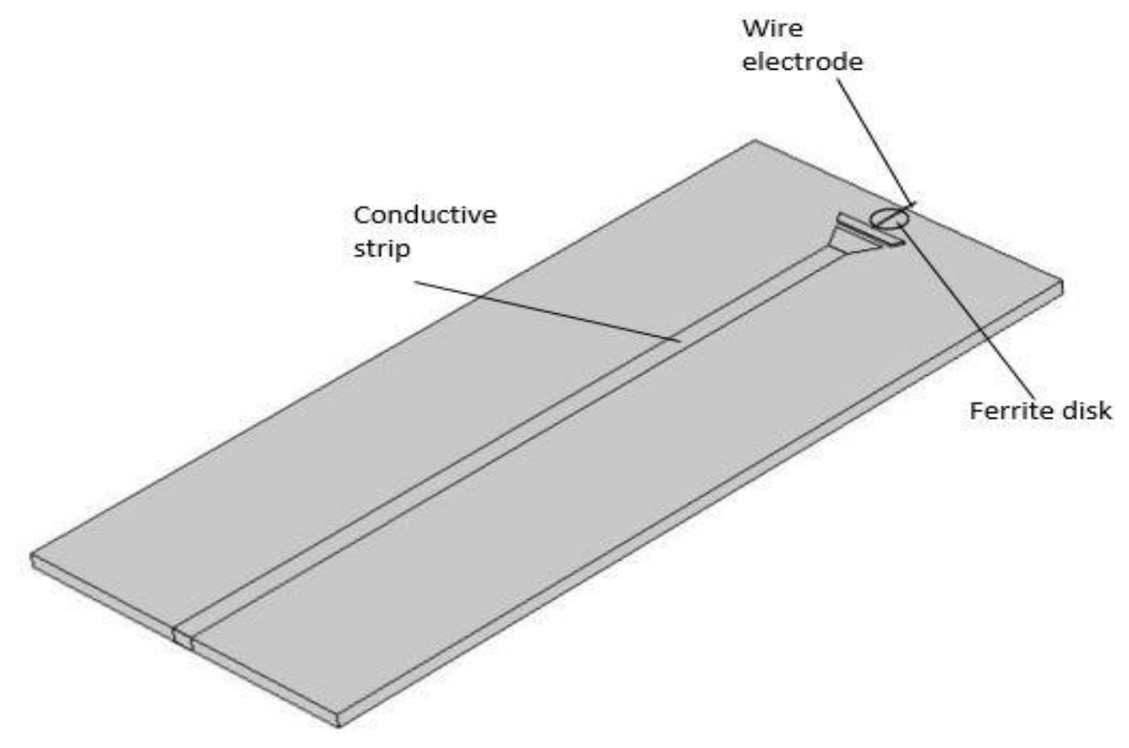

Figure 6. A sensor with wire electrode for localized material characterization

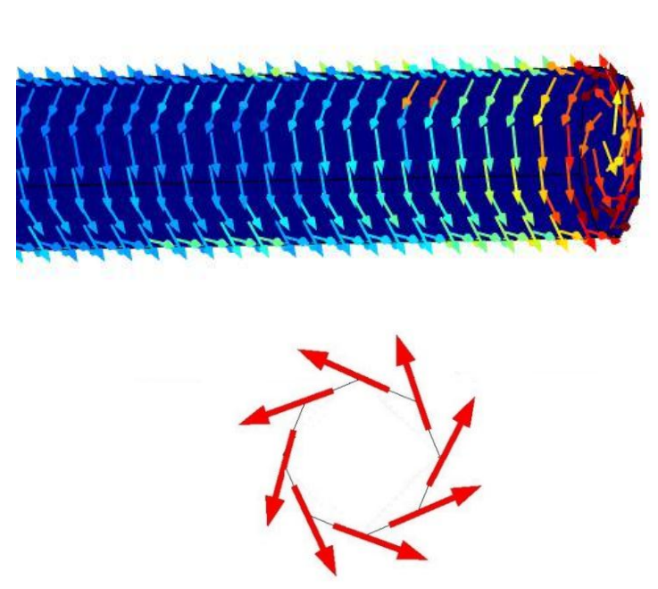

Figure 7.Power flow density on butt end of a wire at 1st frequency resonance.

Figure 7 shows the reflection coefficient of a sensor at different parameters of a symmetrical dielectric loading. Figure 8 shows experimental result of a sensor with left-handed helix as chiral load.

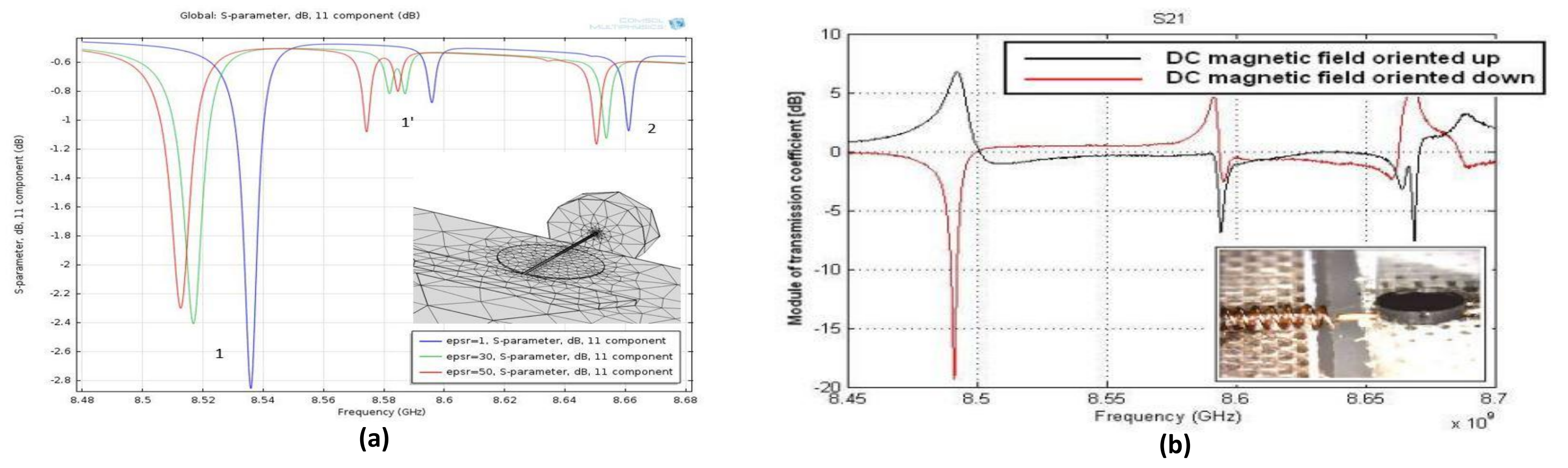

Figure 7. (a)Reflection Coefficient of a sensor at dielectric loads (b)Transmission coefficients for a small left-handed helix particle at different orientations of a bias field (experimental results)[4].

Conclusions

- The MS resonance are characterized by a very high quality factor (10^3), this can be effectively used for material characterization,
- The handedness of the power flow density depends on a direction of the bias magnetic field $\vec{H}_0$. This property allows chirality discrimination of biological objects.

References

1. E. O. Kamenetskii, R. Joffe, and R. Shavit "Microwave magnetoelectric fields and their role in the matter-field interaction", Phys. Rev. **E 87**, 023201 (2013).
2. Pozar, M. David, "*Microwave engineering*", John Wiley & Sons, Inc. 1998.
3. E. O. Kamenetskii, M. Sigalov, and R. Shavit,J. Phys.: Condens.Matter 17, 2211 (2005).
4. E.O. Kamenetskii, E. Hollander, R. Joffe, and R. Shavit, "Unidirectional magnetoelectric-field multiresonant tunneling", arXiv: 1407.5522 (2014).

Excerpt from the Proceedings of the 2014 COMSOL Conference in Boston