# Study of magnon-phonon coupling in YIG loaded split ring resonator using COMSOL5.3a™

COMSOL CONFERENCE 2018 BANGALORE

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## Abstract

SRRs have lately garnered appreciation in the scientic community for their abilities to constitute such materials, which, unlike their counterparts made up of magnetic elements, show high magnetic energy density over a very confined space and consumes less power. They are made up of nonmagnetic materials and are lightweight options against bulkier ferrite in the high-frequency range (GHz). We are studying the phonon-magnon coupling by investigating the resonance of SRR loaded with YIG ferrite film. The observations are based on experiments as well as simulation results obtained by using RF module of COMSOL5.3a.

## Introduction

- Almost all naturally existing elements have positive ($\epsilon$) and ($\mu$). Subwavelength devices are engineered to exhibit negative constitutive parameters and hence show different propagation charateristics [1]. They find applications in noise cancelation, invisibility cloak, superlens, etc.Split Ring Resonator (SRR) is one such 'metamaterial'.
- The principle is that the current carrying stripline conductor excites the SRR inductively, and the slit adds capacitive effect creating resonance, The SRR resonance is tuned by providing magnetic bias to a YIG film kept in contact with it resulting in magnon-phonon coupling.

## Computational methods

There were two simulation setups. One without magnet and other with magnet.

- Boundary conditions for without magnet film:
  - PML for open boundary
  - Lumped port boundary conditions for input and output
  - PEC for metallic parts
- Boundary conditions for with magnet:All were same except scattering boundary conditions for open boundary.
- Solver for without magnetic film: Iterative solver( Default)
- Solver for with magnetic film: Direct Solver
- Meshing Techniques used: Swept mesh, Free tetrahedron.

## Results for SRR

The device as shown in fig. 1 was simulated to find out the relation between resonant frequency and permittivity, perimeter of the ring, and air gap size [3].

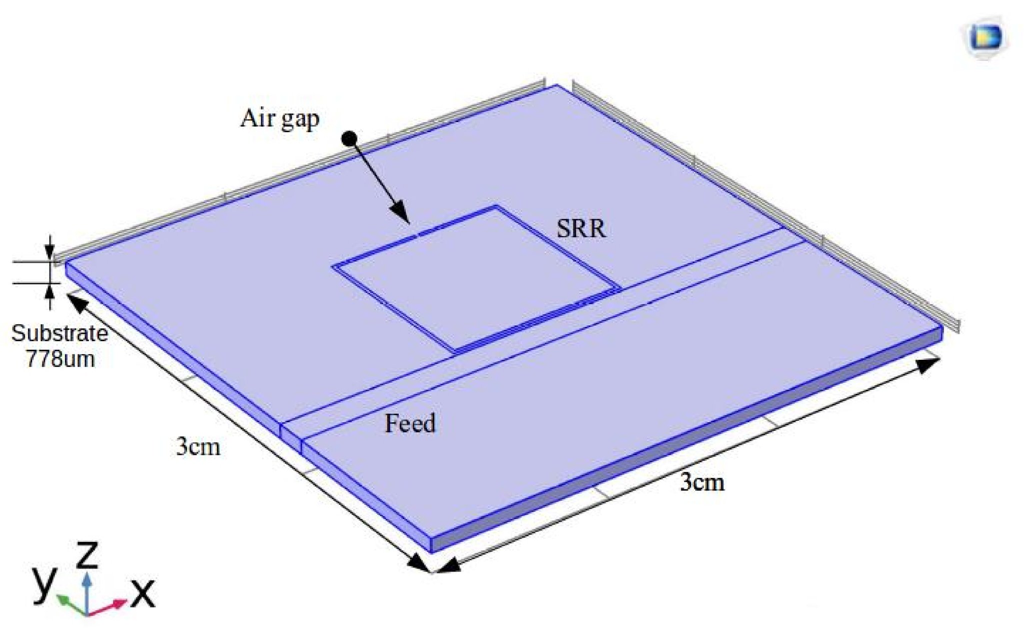


**Figure 1:** A 3cm x 3cm x 778 $\mu$m, ROGER 4003 Laminate is sandwiched between SRR and stripline/feed. It is a 10 mm square ring with an air gap of 0.2 mm. The feed is 1.68 mm wide. The YIG Film is placed on top of SRR.

The observation is as given in fig. 2.

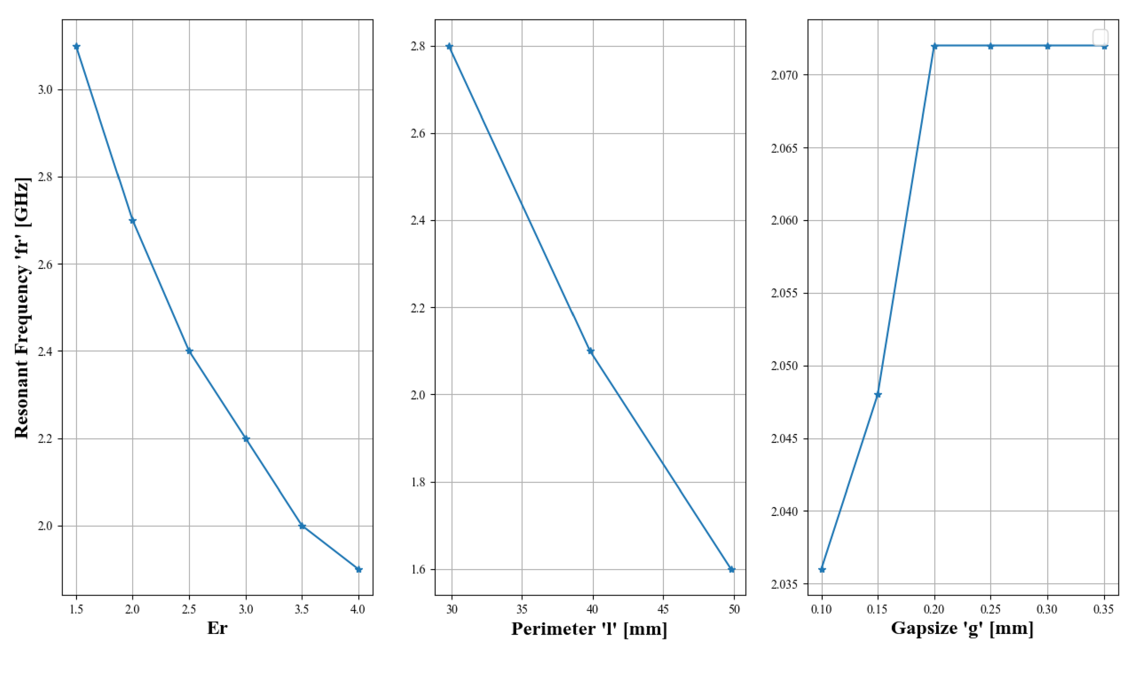


**Figure 2:** The resoanant frequency can be seen decreasing with increase in the permittivity and edgelength whereas reverse is true for the gap size.

Since, the observations for edge length (perimeter of ring excluding gap length) were recorded keeping permittivity constant and vice versa. Therefore,

$$f_r \propto \frac{1}{l\epsilon}$$

But $n = \sqrt{\epsilon_r \mu_r}$, where $n$ is the refractive index and $\mu_r$ = 1 for the case. Therefore,

$$f_r \propto \frac{1}{ln}$$

## Results for YIG loaded SRR

- The FMR appears to be travelling from one end to the other, getting coupled to SRR resonances one by one, gaining strength as they come near to $f_{SRR}$. Their magnitude again decreases as they move away. Consider 0.5T, 1T and 1.2T curves in fig.3(a). The coupling between both resonances results in shift in original $f_{SRR}$. This happens due to the influence of off-diagonal elements of permeability tensor.
- It was observed that the FMRs occuring at 5th and 6th position follow the Kittels equation and then after some extent they become static (see fig. 3(b)). For 1st to 4th position no change has been observed with increase in fields.
- In order to determine the strength of coupling $\delta$[3], of two resonances, a two state model is adopted which was developed for a SRR in contact with a YIG film. Accordingly, the anti-crossing between the $f_{SRR}$ and the FMR can be described by a 2x2 matrix whose solution is as given as:

$$f_{\pm} = \frac{(f_{SRR}+f_{YIG})}{2} \pm \sqrt{(f_{SRR} - f_{YIG})^2 + 4\delta^2}$$

where YIG resonance is given by Kittel's equation as shown:

$$f_{YIG} = \gamma\sqrt{B_a(B_a + \mu_0 M_{sat})}$$

where $M_{sat}$=Magnetic saturation of ferrite film

$B_a$= Applied bias (T)

$\gamma$=2.8e11(Hz/T)

- Fig. 3(c) shows the plots of the solutions $f\pm$ with respect to applied baising field. The strongest coupling is shown between SRR resonance and pure FMR at $\sim$ 550G. The $f_{FMR}$ is then taken to be that deduced from the fig.3(b), and the solutions are plotted.

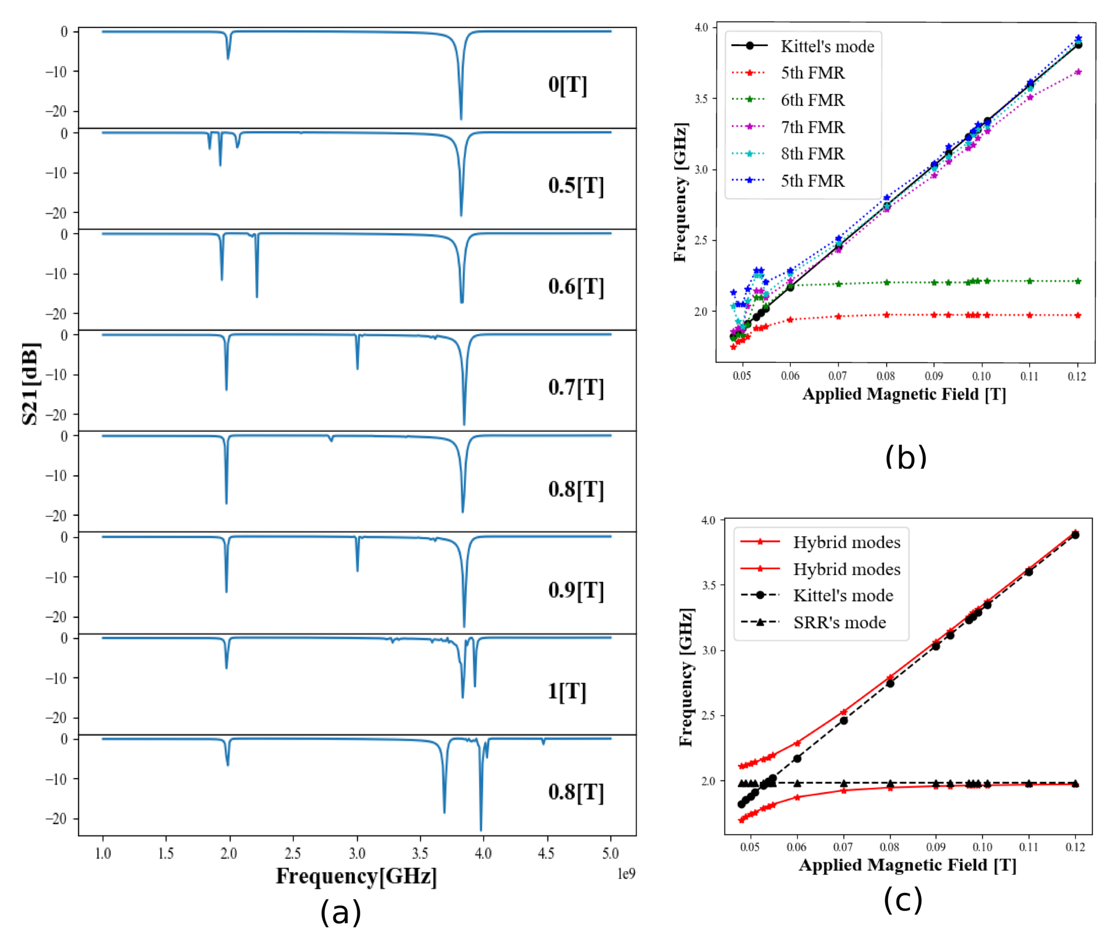


**Figure 3:** (a) S21 curves for few values of applied bias to show the hybridization of resonances. (b) The various resonances peaks and their fit in accordance to Kittel?s Equation. (c) The anti crossing between the hybridized and SRR modes is visible, and is around 0.4GHz. for 7th FMR peak.

## Conclusion

The magnon-phonon coupling was successfully studied. The maximum coupling strength was found to be 0.4GHz. The work can be further extended for studying the BVSW and MSSW, which were precluded for now. There are many alterations in SRR design that are possible, they also can be studied.

## References

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[3] B. Bhoi et.al.,"Robust magnon-photon coupling in a planar-geometry hybrid of inverted split-ring resonator and YIG film", Scientific reports, Vol.7, No.1, pg-11930,2017.