

# YIG ferrite magnetostatic wave cascaded resonators

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In this paper is presented a microwave tunable band-stop resonators based on the combination of two cascaded magnetostatic wave (MSW) resonators, working at frequencies greater than 10 GHz (X-Band) in comparison with a single resonator. Measurements performed at different DC biasing magnetic fields demonstrate a tunability between 10 GHz and 17 GHz. The attenuation ranges between 20 and 25 dB at the central frequency domain (11 - 12 GHz and 13 - 16 GHz) and between 34 and 40 dB at the limits of the frequency domain (10 - 11 GHz ... 16 - 17 GHz) showing a better attenuation for the two cascaded resonators in comparison with a single resonator.

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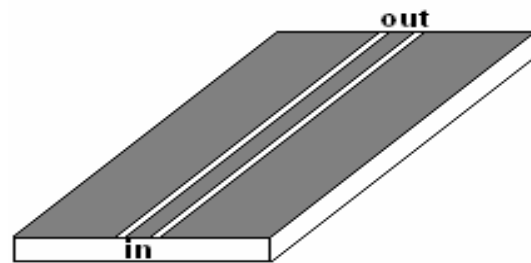
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## 1. Introduction

Yttrium Iron garnet (YIG) is at the present the only epitaxially grown ferromagnetic material for MSW device applications. As an example of planar MSW devices can be straight edge resonators (SER) [1-4]. The Straight edge Resonator consists of a ferromagnetic resonant cavity placed on a thin film transducer structure (microstrip lines or coplanar waveguide). Until now, mainly microstrip circuits realized onto alumina substrates have been used for the excitation of propagating or resonating signals. Recently, the investigation was extended to configurations based on silicon substrates, with clear improvements in the electrical matching of the device due to the possibility to apply the micromaching technology in both band-pass and band-stop devices [5, 6]. As a novel technical solution, coplanar waveguides (CPW) realized onto a silicon substrate have been used in this work to excite a single resonator as well as a cascaded configuration including two identical resonators. Further to the obvious improvement in using the CPW technology, which is suitable of better integration and packaging with respect to the microstrip one [7-9], also the improvement obtained in the electrical performances for both the single and the cascaded configurations will be discussed.

## 2. Magnetostatic waves resonators

As an improvement of the MSW excitation has been studied coplanar waveguide transmission line. The configuration of a coplanar waveguide structure consists of thin metallic film on the surface of a dielectric or semiconductor wafer with two ground electrodes widely to infinite (G) and parallel to the strip (S) is showing in Fig. 1.



*Fig.1. CPW transmission lines used as a transducers for MSW resonators.*

This novel transmission line really lends itself to nonreciprocal magnetic device applications because of the built-in circularly polarized magnetic vector at air – dielectric boundary between the conductors. Practical applications of the coplanar waveguide have been experimentally demonstrated by measurements on resonant isolators and differential phase shifters fabricated on low- loss dielectric substrates with high dielectric constants. The coplanar configuration of the transmission system not only permits easy shunt connection of the external elements in hybrid integrated circuits, but also adapts well to fabrication of monolithic integrated systems. For the above reason, the approximations introduced in the prediction of the radiation resistance of a SER are better described by the CPW configuration. To obtain a band-stop configuration, the MSW SER was top coupled with a CPW transmission line (i.e. with the microwave magnetic field lines involving the entire sample) [10]. The scheme of a single resonator and cascaded resonators are shown in Fig. 2. The structures has been obtained by coupling a Yttrium Iron Garnet (YIG) film straight edge resonator (SER) excited with magnetostatic waves (MSW) by means of a coplanar waveguide line on a silicon substrate. For this experiment

a silicon substrate with a bulk resistivity of  $5000 \Omega \times \text{cm}$  and a thickness of  $400 \mu\text{m}$  was used for realizing the CPW, while rectangular samples of  $28 \mu\text{m}$  YIG epitaxially grown on  $300 \mu\text{m}$  gadolinium gallium garnet (GGG) have been chosen for the SERs, mounted on a thru-reflect-line (TRL) test fixture. The SERs were  $2 \text{ mm}$  long and  $500 \mu\text{m}$  wide. A  $50 \text{ ohm}$  line was obtained by imposing a central conductor width  $W=300 \mu\text{m}$  and a slot  $S=150 \mu\text{m}$ . De-embedded measurements have been performed at frequencies from  $F=11 \text{ GHz}$  ca to  $F=16 \text{ GHz}$  ca. As well established, the resonator response vs. frequency is critically dependent on the material properties. The intrinsic magnetic full line width  $\Delta H$  enters the definition of the quality factor of the SER, and it usually begins to introduce a sensitive spreading of the resonance at frequencies higher than those in the X-Band (more than  $12 \text{ GHz}$ ), still working at acceptable levels for devices like oscillators characterized by quality factors in the order of thousands.

Since the cascaded resonators are close each other along the CPW line, an interaction between them is, in principle, possible on the short side of the resonator, being the wave vector value dominated by the size of the short side. Actually no effective coupling has been experienced, thus demonstrating that the resonators are independent between them.

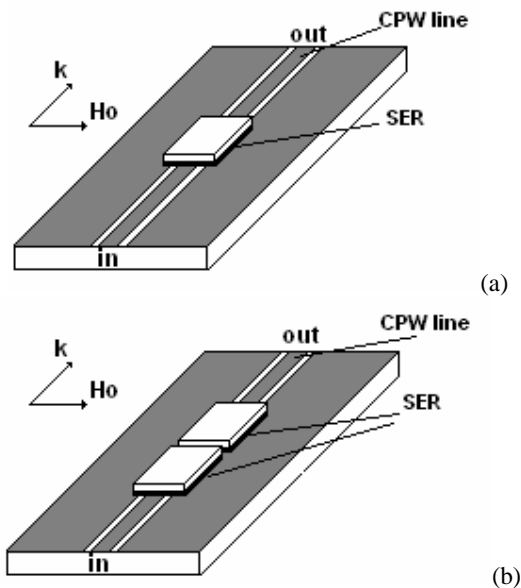


Fig. 2. Schematic structure for the single SER resonator (a) and for the cascaded ones (b) in the band-stop configuration, which uses a CPW transmission line.

A qualitative description of the *notch* enhancement is proposed in Fig. 3, where the response of the first single SER is considered as the first absorption level for the microwave signal, to be considered as the baseline (zero-line) for the second, cascaded SER. In fact, the obtained improvement between the two configurations corresponds to an almost doubled negative peak measured with respect

to the single one, as it turns out comparing the results from Fig. 2 and Fig. 3. As a further demonstration of the improved electrical performances given by the CPW solution, a similar configuration, tested by using a  $50 \text{ ohm}$  microstrip structure, evidenced lower quality characteristics in the same operative frequencies with respect to the present one based on the CPW technology [11].

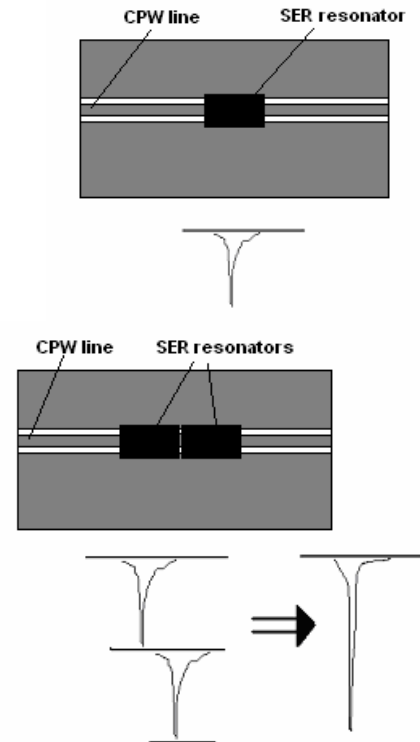


Fig. 3. Qualitative description of the improvement of the electrical response for the cascaded resonator configuration with respect to the single one. The second, cascaded SER experiences a lowered zero-level, and doubles the negative peak of the single SER device.

It is more difficult to understand the suppression of the second order mode with respect to the main one. Strictly speaking, from a circuitual modeling point of view, it is not possible to predict the enhancement of the first mode with respect to the second one when identical resonators are cascaded. Actually, this can be understood only by introducing a small change in their properties, due to statistical differences in the sample cutting and in the alignment procedures, with small deviations coming from the thickness too. All of these characteristics have been evidenced by means of a visual inspection of the measured structures, and the main responsible for enhancing the microwave response of the cascaded resonators has been recognized in the alignment procedure, which should be good enough for the coupling with the RF magnetic field, but not ideal for having the best electrical performances of the cascaded structure.

### 3. Results and discussion

Measurements on the SERs were performed by using a computer assisted Hewlett-Packard network analyzer test set. The resonators were biased with a DC magnetic field whose strength was changed between  $H_0 = 0.1$  T and  $H_0 = 0.3$  T in the plane of the YIG layer, anti-parallel with respect to the microwave propagation direction (wave vector  $\mathbf{k}$ ), in order to excite a MSW mode and to provide a frequency tenability between 10 GHz and 16 GHz ca. The  $S_{21}$  value for the single YIG SER exhibits amplitude ranging between -20 dB and -15 dB for the most part of the measured frequencies. Experimental results on the transmission parameter  $S_{21}$  for a band-stop SER with a single resonator and with two resonators are presented in Fig. 4 and in Fig. 5. As evidenced, a second order spurious mode is still present and is clearly visible in the single resonator response, while the cascaded configuration presents two advantages with respect to the single one.

The double YIG resonator structure shows a better response as compared to the single SER one, with  $S_{21}$  lower than -25 dB from 11 GHz to 16 GHz, and with peaks lower than -40 dB and the higher order modes almost suppressed, generally more than 20 dB with respect to the main mode, thus demonstrating an improved selectivity as compared to the single SER response.

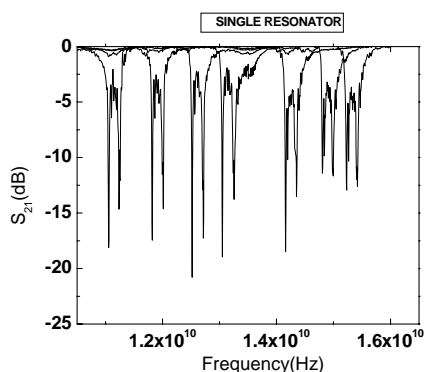


Fig. 4. The  $S_{21}$  transmission parameter for the single resonator.

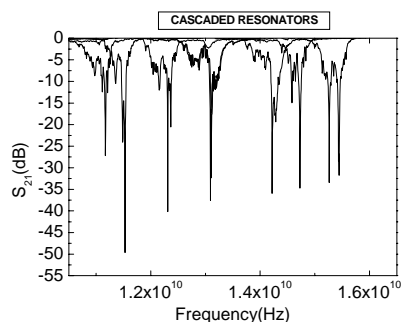


Fig. 5. The  $S_{21}$  transmission parameter for the cascaded resonators.

### 4. Conclusions

MSW resonators using YIG ferrite thin film and coplanar waveguide transducers in a band-stop configuration have been realized and tested. An improved electrical response has been obtained by using single and cascaded SERs loading the CPW line with respect to microstrip devices. The utilization of two cascaded resonators, besides to enhance the attenuation of the signal is also useful for suppressing high order modes. This is obtained by using SERs almost identical between them, but not perfectly aligned. In this case, the mode better coupled, i.e. the main one, is enhanced with respect to higher order modes.

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