MAGNETICALLY TUNABLE DIELECTRIC RESONATORS AND FILTERS

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Abstract
Electronically tunable dielectric resonators and filters operating at frequency about 2 GHz containing axially magnetized ferrite elements have been investigated. Employing axially magnetized ferrites 40 MHz tuning range was obtained with Q-factor greater then 3000. For such structures tuning speed of the order of milliseconds was achieved. The measurements of the trial narrow band filter showed 18 MHz bandwidth at 2.2 GHz without degradation of the RL characteristic and losses lower than 0.8 dB.

Keywords: *dielectric resonators, filters, Q-factor, ferrites*

1. Introduction

Magnetic tuning of dielectric resonators was introduced several years ago [1-2]. In first experiments described in papers [1-2] pieces of a ferrite materials were attached on the resonator and the whole resonant structure was situated between electromagnet poles. None theory of tuning was presented. Full-wave electromagnetic solutions for dielectric resonators employing axially [3-4] magnetized ferrite elements have been developed and tested on resonant structures operating near 10 GHz. Electromagnetic analysis for axially symmetric resonant structures has been performed by means of the Rayleigh-Ritz technique [3-4] Current industrial needs require development of electronically tunable dielectric resonators operating at frequencies about 2 GHz that have unloaded Q-factor greater then 3000, tuning time milliseconds and tuning range up to 50 MHz. In mobile telecommunications base stations tunable filters with even smaller tuning range in the order of 5 MHz are also of interest. This paper describes theoretical and experimental work on magnetically tunable dielectric resonators and filters operating at frequencies near to 2 GHz.

2. Experimental

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2.1. Dielectric resonators containing axially magnetized ferrite rods

Proposed resonator structure contains centrally situated and axially magnetized ferrite rod as a tuning element as it is shown in Fig.1. For a ferrite material magnetized along z-axis its permeability is a tensor with three independent components:

$$\overleftrightarrow{\mu} = \begin{bmatrix} \mu & -j\kappa & 0 \\ j\kappa & \mu & 0 \\ 0 & 0 & \mu_z \end{bmatrix} \tag{1}$$

Computations of tuning characteristics of a dielectric resonator containing ferrite elements require data on permeability tensor components versus static magnetic bias. Theories describing tensor components versus external static magnetic filed for weak biasing fields are rather inexact [5-6] so we used experimental data in our theoretical considerations.

Tensor components shown in Fig.2 were measured at 9.4 GHz on a lithium ferrite rod having saturation magnetization $4\pi M_s$= 260 mT. According to general theories of microwave ferrites [5-6] material having $4\pi M_s$= 58 mT should have at 2 GHz similar permeability tensor components.

Computed tuning characteristics for few lower order modes of a ferrite loaded dielectric resonator used in our experiments have been obtained. Computations have been performed employing Rayleigh-Ritz technique described in [3-4]. Tuning range for the $TE_{01\delta}$ mode is about 40 MHz and can be extended either by using ferrite material with higher saturation magnetization or by using ferrite rod having larger diameter. For the quasi $TE_{01\delta}$ mode tuning range is related to the range of μ_z component variations. For hybrid modes other components of permeability tensor (namely κ and μ) play more important role in tuning. One has to take into account that increase of the tuning range reduces Q-factor of the resonant structure. Numerical analysis of our resonant structure has shown that its Q-factor is predominantly limited by the magnetic losses of the ferrite element. To achieve maximum Q-factor and maximum tunability of a $TE_{01\delta}$ mode resonant structure the figure of merit of ferrite material defined as $(1-\mu_z)/\tan\delta_{\mu z}$ has to be maximized. This can be done only experimentally since at microwave frequencies the magnetic losses of commercially available materials are not given by manufacturers.

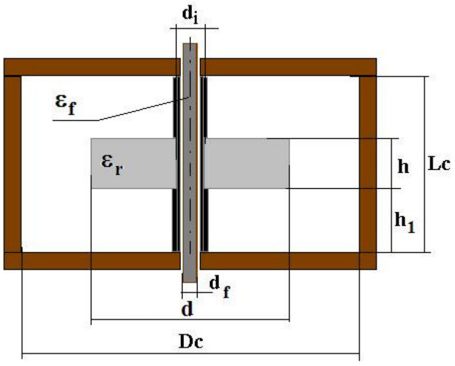

Fig.1. Schematic diagram of a tunable dielectric resonator containing axially magnetized ferrite rod.

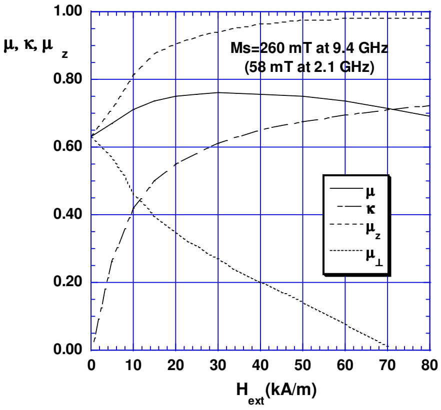

Fig.2 Permeability tensor components versus bias for axially magnetized ferrite rod.

3. Results and discussion

There are some experimental data on measurements of μ_z and $\tan\delta_{\mu z}$ at frequency range from 2.5 GHz to 20 GHz [9] but these experiments were performed only on a few ferrite materials made by one vendor. Also saturation magnetization values for those ferrites were not appropriate for their applications in our experiments at 2 GHz. Results of measurements of μ_z and $\tan\delta_{\mu z}$ for ferrite materials used in our experiments are shown in Table 1. We used TE_{011} mode cylindrical dielectric resonator technique [8] to perform these measurements.

Table 1. Results of measurements of scalar permeability at 2.1 GHz on demagnetized samples

Material	Ms (mT)	μ_z	$\tan\delta_{\mu z}$	$(1-\mu_z)/\tan\delta_{\mu z}$
G-42	42	0.87	$1.26\text{x}10^{-3}$	103
G-63	63	0.65	$3.80\ \text{x}10^{-3}$	92
G-510 (Trans-Tech)	55	0.75	$1.09\ \text{x}10^{-3}$	230

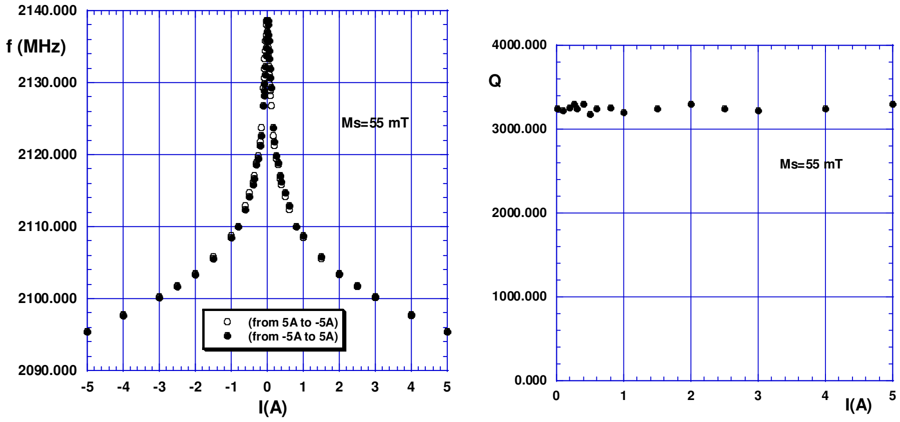

Fig.3 Experimental tuning characteristics (left) and Q-factors (right) for $TE_{01\delta}$ mode dielectric resonator with ferrite rod having saturation magnetization 55 mT (ferrite manufacturer Trans-Tech, USA). Diameter of ferrite rod is 11.4 mm.

It is seen that of three investigated materials Trans-Tech G-510 aluminum doped garnet has the largest figure of merit. Tuning characteristics and Q-factors of the $TE_{01\delta}$ mode dielectric resonator with axially magnetized rod (diameter of 11.4 mm), made of G-510 garnet are shown in Fig.3. One can observe hysteresis of tuning curves which is clearly visible in a narrow current range. Q-factor of the resonant structure remains almost constant in the whole tuning range.

3.1. Tunable trial filter

On the base of computed and measured results a trial two-pole filter has been designed, realized and measured. The dielectric resonators with ferrite rods have been placed in cylindrical enclosures and the iris in the common wall has been cut to provide the coupling needed. The assumed filter bandwidth was 5 MHz and the RL better than 20 dB. The iris size and location has been computed by means of the 3D E-M simulator - QuickWave. The realized filter has been measured and the results are shown in Fig.4. As can be seen the filter changes its center frequency from 2226.5 MHz to 2208.5 MHz due to change of the current from 0 to 0.5 A without degradation of the RL and IL characteristic. The pass band losses remain on the similar level below 0.8 dB. The filter can be tuned even more but then the characteristics are deteriorated. After the full tuning cycle (current up to 1.25 A and down to minus 1.25 and then back to 0 A) the filter characteristic returns back to initial one.

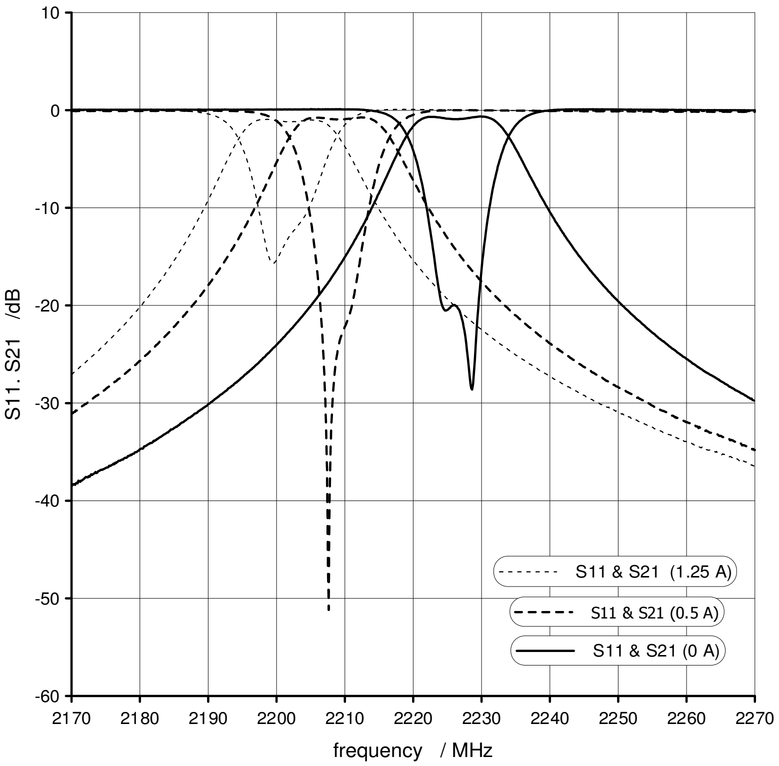

Fig. 4. Measured characteristics of the filter tuned by means of ferrite rod.

4. Conclusions

The Rayleigh-Ritz theory was successfully applied to compute the characteristics of the tunable resonators. For dielectric resonators employing axially magnetized ferrites tuning range in the order of 40 MHz was achieved with Q-factor greater then 3000. The tuning speed in the order of milliseconds was obtained. Constructed dielectric resonator filter containing axially magnetized ferrites allowed tuning range of 18 MHz for tuning current limited within 0 - 0.5 A. The filter characteristics do not change significantly and losses are below 0.8 dB.

Acknowledgments

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