ENLARGEMENT OF TUNING RANGE IN A FERRITE-TUNED CAVITY THROUGH SUPERPOSED ORTHOGONAL AND PARALLEL MAGNETIC BIAS

C. Vollinger, F. Caspers, CERN, Geneva, Switzerland

Abstract

Conventional ferrite-tuned cavities operate either with bias fields that are orthogonal or parallel to the magnetic RF-field. For a cavity that tunes rapidly over an overall frequency range around 100-400 MHz with high Q, we use ferrite garnets exposed to an innovative new biasing method consisting of a superposition of perpendicular and parallel magnetic fields. This method leads to a significant enlargement of the high-Q cavity tuning range by defining an operation point close to the magnetic saturation and thus improving ferrite material behaviour. A further advantage of this technique is the fast tuning speed resulting from the fact that tuning is carried out either with pure parallel biasing, or together with a very small change of operating point from perpendicular bias. In this paper, several scaled test models of ferrite-filled resonators are shown; measurements on the set-ups are compared and discussed.

INTRODUCTION

Ferrite-loaded cavities are partially filled with ferrite material and then exposed to a changing external magnetic bias field. This allows a tuning of the resonance frequency as a function of the external magnetic bias. The concept of using either parallel or perpendicular magnetic biasing to reach a certain frequency range is known for many years. The notation parallel and perpendicular magnetic biasing describes the orientation of the external bias field with respect to the magnetic RF-field. The tuning results from the dependence of the relative permeability μ_r of the material on the strength of the external field. It is, however, usually not taken into account that also the magnetic Q of the material changes as a function of the external field strength and its *orientation*. A qualitative change of the magnetic Q of the ferrite, depending on the bias field orientation was demonstrated in [1].

For the design of a high-Q ferrite-loaded cavity, we intent to make use of a superposition of perpendicular and parallel magnetic bias fields, a so-called 2-directional magnetic bias. This idea was originally proposed by Smythe [2] with the goal to obtain either reduced losses (*i.e.* high cavity Q) or an enlarged tuning range for a given Q-factor.

In [3], it was demonstrated that frequency tuning by means of a 2-directional magnetic bias can be advantageous in comparison with the classical 1-directional biasing methods as it allows to enlarge the achievable tuning range if the operation point is well chosen. In this paper we demonstrate that, in addition, high-Q factors can be reached with 2-directional bias. To this purpose, we carried out measurements on several scaled test models of ferrite-filled resonators within an overall frequency range of 100-400 MHz and compared results obtained from classical 1-directional bias with those of the innovative 2-directional bias. All tests pre-requisites for an application which requires a rapid tuning, a doubling of the resonance frequency, and unloaded cavity Q-factors of at least 1500, *i.e.* values that are considerably larger than the typical Q-factors < 100 [4] known for ferrite-loaded cavities.

MEASUREMENT WITH ORTHOGONAL BIAS

Test for Doubling of f_{res}

For our tests, we used a ferrite garnet G-510 from Trans-Tech Inc. that was available in small and large rings. The small rings have an inner diameter (ID) of 70 mm and an outer diameter (OD) of 127 mm, and the large rings have ID=200 mm and OD=350 mm. Three cylindrical test cavities, all coaxial resonators of a re-entrant type were built with two different topologies as shown in Fig. 1.

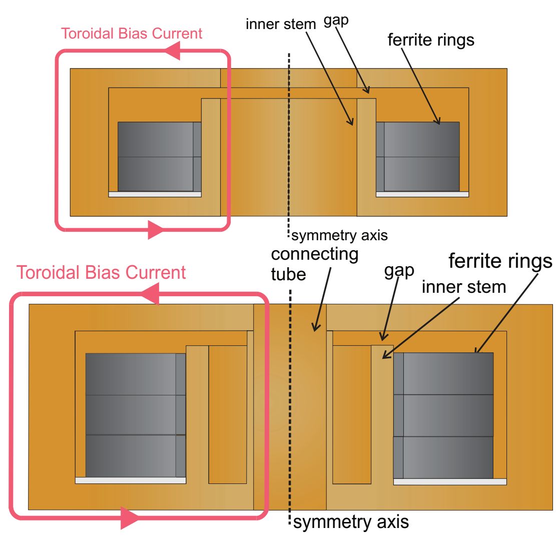

Figure 1: Drawings of the cross-sections of the re-entrant cavity resonators (2 topologies).

The first resonator is made of brass and houses the small rings whereas the second is made of aluminum and houses the large rings and were built to test the achievable tuning range. As shown in Fig. 1 (top), these test cavities have an open gap that produces unwanted radiation. As the resonance frequency $f_{\mathrm{res}} \sim 1/\sqrt{\mu_{\mathrm{rf}}}$, a factor of approximately five is required in change of relative permeability to obtain a doubling of resonance frequency. The measurements show with the brass cavity reached a tuning of $f_{\rm res}$=147...311 MHz with pure orthogonal bias as is shown in Fig. 2 (top), *i.e.* a doubling of the resonance frequency could be achieved, albeit with very low Q-factors caused by the open (radiating) gap. A more detailed description of this cavity can be found in [3] where also more extensive measurement cycles are shown. The larger test cavity made of aluminum could achieve a doubling of $f_{\rm res}$ as well, and reached a tuning of $f_{\rm res}$=93...187 MHz with pure orthogonal bias as is shown in Fig. 1. Again, we observe a limitation of Q-factors caused by radiation via the gap. A more precise estimate of obtainable Q-factors is shown in the next section. All cavity parameters and the measured results are given in table 1.

Table 1: Measured resonance frequency $f_{\rm res}$ and Q-factors for pure perpendicular (orthogonal) magnetic bias.

	$H_{\rm perp}$/mT	Q	$f_{\rm res}$/MHz
Cav. 1 (brass)			
ID=64 mm, OD=132 mm	30	< 10	147
height=40 mm	200	396	311
Cav. 2 (aluminum)			
ID=196 mm, OD=354 mm	35	76	93
height=56 mm	301	200	187

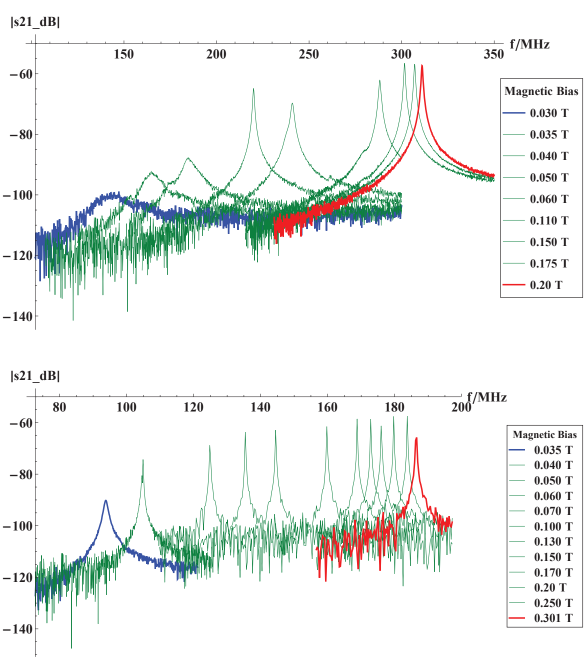

Figure 2: Measurement of S_{21} with pure perpendicular bias. Top: Cavity 1 (brass); Lower: Cavity 2 (aluminum).

Test for High Q-values

In a next step, we built a cylindrical re-entrant cavity of copper to determine the unloaded Q-factors that were achievable with the chosen ferrite. Since this cavity should also be tested with 2-directional magnetic bias, we inserted a copper tube into the inner stem, which connects the top and the bottom of the outer pillbox cylinder. This way, radiation via the open gap on the inner stem could be avoided and cables for a toroidal coil could be pulled through the tube (see Fig. 1, lower picture for topology).

The purpose of the test was the determination of high Q-factors and no importance was given to the tuning range as these were already shown in the previous section. Consequently, the cavity could be operated with a low filling factor of merely three large ferrite rings. This corresponds to a filling of approx. 25% of the cavity volume with ferrite. The decision of loading the cavity with merely three rings made it possible to equip this set-up with a toroidal coil and compare Q-factors achieved with pure orthogonal biasing with those obtained from 2-diretional magnetic bias. The use of more than three ferrite rings would have required an external support structure for the cavity. Figure 3 shows a picture of the final set-up in the aperture of a laboratory magnet. The comparison of Q-factors of orthogonal magnetic bias with 2-directional magnetic bias is shown in the next section. It should be noted that if a tuning range has to be determined from measurements with such a small ferrite quantity compared to the total volume of the cavity, filling factors have to be considered to obtain a correct estimate.

Table 2: Measured Q-factors for pure perpendicular bias on closed copper cavity with approx. 25% ferrite material.

$H_{\rm perp}$/mT	Q	$f_{\rm res}$/MHz
40	711	176
45	2794	183
60	5066	199
200	5247	228
300	5149	232
400	5071	234

We exposed the cavity to a pure orthogonal bias in the range of 40...400 mT and measuremed Q-factors. As expected, a gradual increase of the cavity Q with increasing magnetic bias could be observed (see Table 2). Note that below 40 mT, no resonance peak could be detected, hence, the lowest Q=711 was measured at 40 mT; however, already at 45 mT, a Q of almost 3000 can be seen. Q-factors above 5000 can be observed with very high perpendicular magnetic bias from 200 mT on, but no significant increase is seen when the bias is further raised, neither does $f_{\rm res}$ increase any more. The tests confirmed that tuning with high cavity Q is possible.

2-DIRECTIONAL BIAS

The method of 2-directional bias works as follows: First, the ferrite is exposed to a perpendicular magnetic bias that brings the material in a magnetized state and fixes an operating point. The tuning is then carried out by means of an additional magnetic bias field oriented parallel to the magnetic RF-field. The test cavities presented here all fit into the aperture of a laboratory magnet that provides the perpendicular bias, even after the toroidal coils for the parallel magnetic bias were added. This way, comparison tests

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of pure orthogonal biasing with 2-directional biasing could be carried out. We equipped the small brass cavity with 19 toroidal windings whereas the copper cavity obtained n =15 windings to provide a parallel bias (see Fig. 3).

Figure 3: Re-entrant test cavity made of copper with toroidal coil for 2-directional magnetic bias testing.

Measurements were carried out with constant perpendicular magnetic bias and varied parallel bias. For the parallel bias field, we quote the biasing current in A since the magnetic field strength has a $1/r$-dependence, *i.e.* is different for the two cavity geometries. The parallel magnetic field strength can be calculated from the bias current I_{bias} from $B_{\text{par}}= \mu_0 n\, I_{\text{bias}}/2\,\pi\, r_{\text{m}}$ (where r_{m} is the mean of the radius of the ferrite ring, and n is the number of toroidal windings.) It can be seen from Fig. 4 that for the brass cavity, an applied perpendicular basing of 15 mT, together with a parallel bias current of 0...350 A gives a frequency tuning of 225...300 MHz. Table 3 shows a comparison with the same tuning carried out at a different operation point with a perpendicular biasing of only 15 mT which results in a considerable smaller change of resonance frequency. The results show how an appropriate choice of tuning point can be used to enlarge the tuning range in a ferrite-tuned cavity while identical parallel tuning fields are applied. A more extensive testing of the brass cavity can be found in [3].

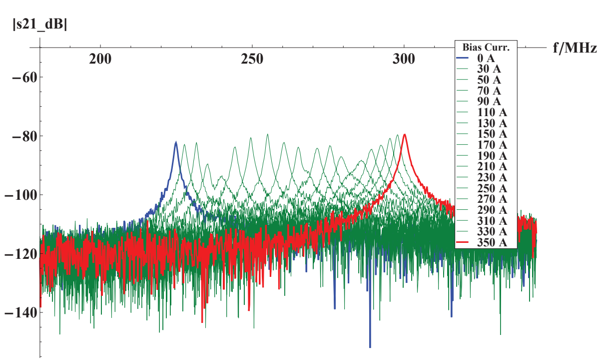

Figure 4: Measurement of S_{21} with constant perpendicular bias of 50 mT and varied parallel bias on the brass cavity.

The copper cavity was measured with various perpendicular biases and with parallel biasing currents of 0...400 A. Table 4 shows the results for H_{perp}=35 mT and 45 mT.

Table 3: Measured f_{res} and Q-factors for const. perpendicular and varying parallel bias (brass cavity with open gap).

H_{perp}/mT	I_{bias}/A	Q	f_{res}/MHz
15	170	168	322
	350	256	334
50	170	180	265
	350	200	300

We observe a higher cavity Q with increasing perpendicular biasing fields and at the same time a reduction of tuning range. In the case of H_{perp}=35 mT, all measured Q-factors are above 1500; note that no resonance could be detected for I_{bias}=0. In the case of H_{perp}=45 mT, the lowest Q-factor measured is 2794, considerable above the requested $Q > 1500$. The tuning range, however, is small in both cases as a consequence of the low ferrite-filling factor.

Table 4: Measured Q-factors for constant perpendicular and for varying parallel magnetic bias (copper cavity).

H_{perp}/mT	I_{bias}/A	Q	f_{res}/MHz
35	0	-	-
	200	1512	179
	300	2164	188
	400	2561	196
45	0	2794	183
	200	3773	188
	300	3839	192
	400	3629	196

CONCLUSION

We presented an innovative new biasing method that consists of a superposition of perpendicular and parallel magnetic fields. This 2-directional biasing method was tested on several scaled test cavities filled with ferrite garnets and exposed to different tuning schemes. It can be seen that the 2-directional biasing method allows an enlargement of the possible tuning range compared to the method of pure perpendicular biasing. Further, we could demonstrate that high Q-values can be achieved with this method in spite of the fact that the overall cavity Q is dominated by the magnetic Q of the ferrite.

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