HIGH-TEMPERATURE SUPERCONDUCTOR-SHIELDED HIGH POWER DIELECTRIC DUAL-MODE FILTER FOR APPLICATIONS IN SATELLITE COMMUNICATIONS

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ABSTRACT

We introduce a novel high-temperature superconductor (HTS)-shielded dual-mode resonator based on the degenerated fundamental mode of a dielectric hemisphere [1]. By employing coupling with electric probes and dual-mode splitting with dielectric rods, we have built an HTS-shielded dual-mode two-pole filter at a center frequency of 6.4GHz with a bandwidth of 0.4% and an insertion loss of -0.02dB.

INTRODUCTION

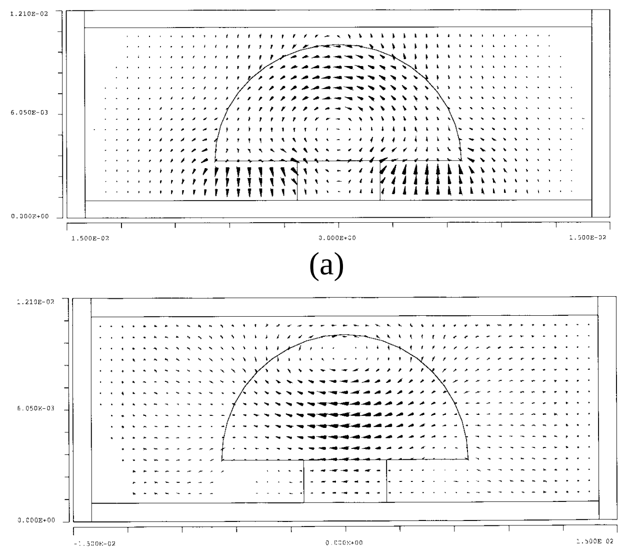
One of the most important areas of commercial applications for filters based on HTS-shielded dielectric resonators are output multiplexers (OMUX) in communication satellites. In comparison to bulky normal-conducting waveguide or conventional dielectric filters the use of the HTS-technology results in reduction of mass and volume and therefore in a reduction of the satellite payload. When combining HTS-technology with dielectric materials with high permittivity (ε_r>10) and low dielectric losses (tan δ<10^{-5} at 77K) such filters provide high quality factors (Q_0>10^5) and therefore low insertion loss. Consequently, this results in a reduction of the power dissipated in the filter, thus minimizing the required cooling power of the cryocooler in use. Typically, power levels of 10-100W are passed through filters of less than 1% bandwidth at 1-20GHz. In case of conventional waveguide filters the insertion loss values are at the order of a few tenths of dB. This results in a power loss of a few watts in the OMUX. For the same bandwidth the insertion loss values of filters based on HTS-shielded dielectric resonators are usually in the range of 0.001-0.01dB giving rise to a few tenths of watts of power loss in the OMUX. However, possible losses in the input/output connectors and the combining manifold network have to be taken into account as well. Another figure of merit is the separation between the filter mode and the nearest cavity or dielectric mode. As the induvidual OMUX-passbands are adjacent to each other, higher order cavity or dielectric modes have to be well separated from the filter mode in use.

The ultimate aim of this work is to build a quasi-elliptic four-pole filter for application in satellite communications. We present first results on a quasi-elliptic four-pole filter at 300K.

PRINCIPLE OF OPERATION

The dual-mode filter is based on the degenerated fundamental mode of a dielectric hemisphere mounted on a ground plane of a cylindrically shaped metallic shielding cavity. The cover of the shielding cavity is formed by an HTS thin film. The dielectric hemisphere is separated from the ground plane by a cylindrical dielectric spacer. According to Figure 1a the mode exhibits a field distribution with the electric field oriented mostly parallel to the contour of the hemisphere. Similar to the $TE_{01\delta}$-

mode of a cylindrically shaped dielectric the losses on the metallic wall of a shielding cavity of appropriate size become very small resulting in high quality factors Q_0. Furthermore, the mode of the hemisphere is linearly polarized on the ground plane resulting in two degenerated orthogonal modes. As shown in Figure 1b, the magnetic field of the fundamental mode is oriented mainly parallel to the ground plane within the dielectric hemisphere. The maximum of the magnetic field strength is located within the dielectric hemisphere.



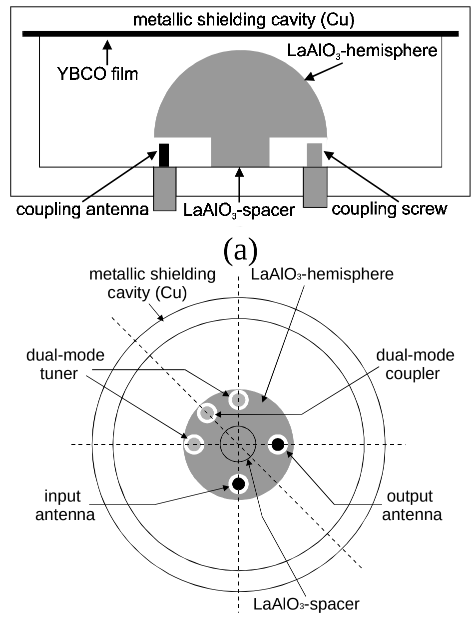
(a) (b)

Figure 1: Distribution of the (a) electric and (b) magnetic fields of a dielectric hemisphere mounted on the ground plane of a cylindrically shaped metallic shielding cavity (*zy*-plane at *x*=0).

In comparison to the conventionally employed $HE_{11\delta}$-dual-mode [2] of a dielectric cylinder larger unloaded quality factors Q_0 are expected for the hemisphere. The resonator losses consist of conductor losses in the HTS thin film and the normal-conducting walls and dielectric losses. Q_0 can be calculated from

$$Q_0 = \left(\frac{R_s^{HTS}}{G^{HTS}} + \frac{R_s^{sc}}{G^{sc}} + \kappa \cdot \tan\delta \right)^{-1}$$

with R_s being the surface resistance and G a geometric factor which can be calculated from the distribution of the magnetic surface fields. The index *sc* denotes the normal-conducting walls of the shielding cavity. The factor $\kappa \leq 1$ discribes the fraction of electric field energy stored in the dielectric. The resonance frequencies, field distributions and geometric factors were calculated using the computer code MAFIA [3].



(a) (b)

Figure 2: Schematic side (a) and top (b) view of the HTS-shielded dielectric dual-mode two-pole filter with a center frequency of 6.4GHz and a bandwidth of 0.4%. The dual-mode filter consists of a dielectric hemisphere (*r*=6.8mm) made of single crystalline $LaAlO_3$ (ε_r=23.6) which is placed in a cylindrically shaped metallic shielding cavity (*r*=14mm, *h*=10mm) made of OFHC-copper. The hemisphere is separated from the ground plane by a dielectric spacer (*r*=2.3mm, *h*=2.3mm) made of $LaAlO_3$.

There are two main issues for a dual-mode filter design, namely sufficiently strong external coupling (Q_{ext}<100) and dual-mode splitting ($\Delta f/f \approx 1\%$, corresponding to the desired bandwidth) without additional losses. Moreover, the design has to be optimized for power handling capability (PHC). Coupling by coaxial antennae and dual-mode splitting as well as tuning by dielectric rods passed through holes in the ground plane was found to meet these requirements, if a high permittivity dielectric spacer is employed to enhance the electric field strength close to the ground plane (Figure 2a,b). The antennae are positioned at a right angle with respect to each other so that each antenna predominantly couples into one of the fundamental modes of the dual-mode filter. The frequencies of the individual fundamental resonances could be adjusted by the two dual-mode tuners made from sapphire. Coupling between the modes could be varied with the dual-mode coupler which is also made from sapphire.

Using the computer code MAFIA, we obtained a center frequency of 6.4GHz, a maximum bandwidth of 0.6%, G^{HTS}=1400Ω, G^{sc}=1700Ω and κ=0.86, where G^{HTS} and G^{sc} are the geometry factors of the HTS film and the metallic shielding cavity. κ is the filling factor of the dielectric hemisphere and the dielectric spacer. At 6.4GHz, $R_s^{HTS}\approx 125\mu\Omega$ (thin film of $YBa_2Cu_3O_7$ (500nm) on $LaAlO_3$ at 77K with T_c=88.3K), $R_s^{sc}\approx 9m\Omega$ (OFHC copper at 77K), $\tan\delta$ of $LaAlO_3 \approx 2\cdot 10^{-6}$ [4], the unloaded quality factor is expected to be $1.4\cdot 10^5$. The most adjacent modes were found to be at 5.9GHz and 7.3GHz.

For the use at higher power levels important figures of merit are the maximum magnetic and electric field levels on the surface of the HTS film. These quantities are computed via the field calibration factors c_E and c_B. Generally, these depend on the resonator geometry and on the mode in use. They are calculated from

$$c_E = \frac{E_{\max}}{\sqrt{\omega \cdot W}}, c_B = \frac{B_{\max}}{\sqrt{\omega \cdot W}}$$

where E_{max} and B_{max} are the maximum electric and magnetic field strength on the surface of the HTS film. W is the total electromagnetic energy stored in the dielectric resonator and $\omega = 2\pi f$ is the frequency of the corresponding mode. Using the computer code MAFIA, we obtained c_B= 5.3μT/W$^{1/2}$ and c_E=0.6kV·m^{-1}/W$^{1/2}$. Using state-of-the-art YBCO thin films [5] this corresponds to a power handling capability of more than 100W in two-pole filter operation.

In comparison to normal-conducting waveguide filters the HTS-shielded dielectric dual-mode filter can also be used at higher frequencies (10-20GHz). Frequency-scaling of our filter design results in Q_0´s of about 86,000 (72,000) at 15 (20)GHz.

EXPERIMENTAL RESULTS

As shown in Figure 3, the insertion loss (*IL*) of the HTS-shielded dielectric dual-mode two-pole filter at a center frequency of 6.385GHz and a bandwidth of 20MHz is ≈-0.02dB at 77K.

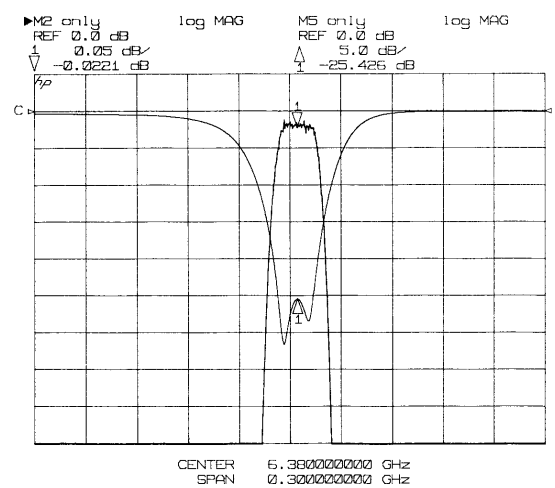


Figure 3: *IL* and return loss of the HTS-shielded dielectric dual-mode two-pole filter at 77K.

The *IL* was measured after performing a TRL calibration at 77K. Due to the *IL* contribution of the coupling antennae, namely ≈-0.02dB at 77K, and a TRL calibration accuracy of ≈+0.02dB, the total *IL* of the filter is ≈-0.02dB. This corresponds to a measured unloaded quality factor of ≈85,000 at 77K. The external coupling Q_{ext} for each antennae and the coupling factor $k_{1,2}$ is 143 and $7.3\cdot 10^{-3}$ [6].

The measured in-band insertion loss was smaller than -0.05dB for power levels up to 35W, which corresponds to the maximum available output power of the amplifier in use (Figure 4).

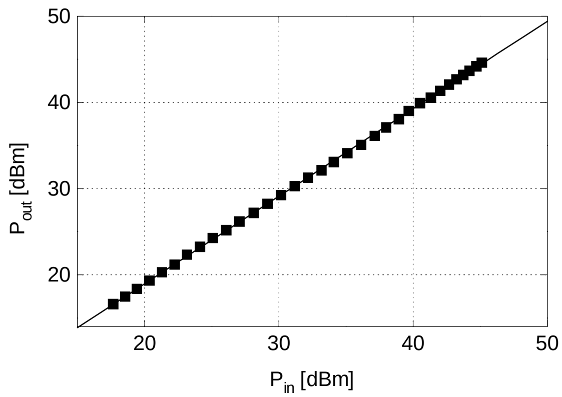


Figure 4: PHC of the HTS-shielded dielectric dual-mode two-pole filter at 77K.

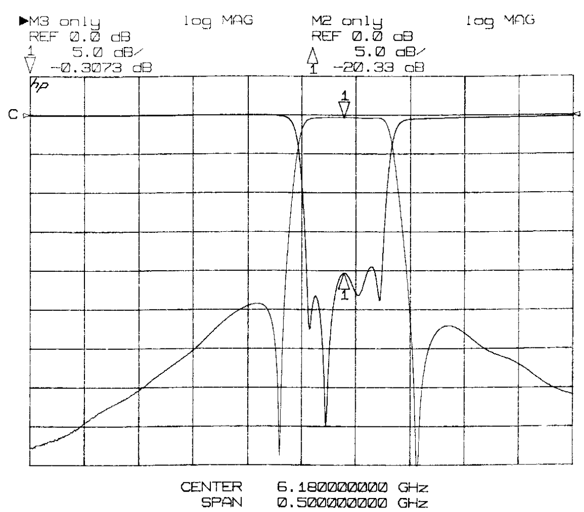


Figure 5: *IL* and return loss of the quasi-elliptic four-pole filter at 300K.

Using two dielectric hemispheres separated by a metallic aperture we have constructed a quasi-elliptic four-pole filter. As shown in Figure 5, the *IL* at room-temperature is -0.3dB at a center frequency of 6.23GHz and a *BW* of 1% corresponding to a Q_0 of about 10,000 [6] which is currently limited by losses in the glue which attaches the dielectric spacer to the hemisphere. Currently, a superconducting version of the quasi-elliptic four-pole filter is under construction.

CONCLUSIONS

A novel HTS-shielded high power dielectric dual-mode two-pole filter based on the orthogonal modes of a dielectric hemisphere has been introduced. Q_0 of 85,000 at 77K corresponding to an *IL* of -0.02dB at a *BW* of 20MHz have been achieved at 6.4GHz. A power measurement at 77K demonstrates that this filter is able to support microwave power levels of 35W and more.

ACKNOWLEDGMENT

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