HIGH-Q TUNABLE YBCO DISK RESONATOR FILTERS FOR TRANSMITTER COMBINERS IN RADIO BASE STATIONS

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ABSTRACT

Results on the development of a tunable HTS resonator structure for transmitter combiners of radio base stations are reported. Design goal was the minimization of the dissipative insertion loss of a one-pole filter with a 3-dB bandwidth of 630 kHz under the impediment of a required tunability of the center frequency between 1.93 and 1.99 GHz and a power handling capability for 10 W transmitted power. At 70 K the quality factor of the utilized disk resonator structure turned out to be limited to 10^5 due to dielectric losses in $LaAlO_3$ substrate, but in a lower temperature range where dielectric losses are no more dominating, $Q_0 \approx 290{,}000$ was obtained for the tunable version.

INTRODUCTION

For RF filters in mobile radio base stations a significant reduction of both power dissipation and size can be achieved if conventional structures are replaced with planar HTS circuits. Whereas several types of planar HTS filters for the receiving stage are now commercially available [1], much less effort has been reported on the development of HTS components for the transmit stage. This is mainly due to the fact that as a consequence of the peaked current density at the edges of planar structures, already at relatively low levels of the stored field energy the surface magnetic field strength exceeds values for which significant nonlinearities occur. In order to overcome this problem an edge-current-free mode of a ring resonator [2, 3] was utilized. The second difficult but challenging task for HTS resonator structures to be used in transmitter combiners is the required electrically controlled tunability. Since the electronic tunability by means of ferroelectric and ferrimagnetic materials is up to now only achievable by cost of a dramatic decrease in the unloaded quality factor [4, 5], a piezoelectric actuator is utilized for the reported device.

SYSTEM REQUIREMENTS AND EXPECTED BENEFIT

As long as multi-carrier HPAs with sufficiently low nonlinear distortion are not available, transmitter combiners are used to combine signals from several RF-channels into a single transmit antenna [6]. A resonator combiner consists of a number of two-port-resonators („one-pole-filters“) associated to the different RF-channels and a manifold for signal combining. The required 3-dB-bandwidth of the one-pole-filters follows from the channel-spacing and flatness-requirements and represents a compromise between dissipative insertion loss in the one-pole-filter and power flows into adjacent channels. In our case the resonator was required to have a tunable center frequency f_0 between

1930 to 1990 MHz (= 3 % tuning range) with a 3 dB bandwidth of $\Delta f = 630$ kHz and a flatness of less than 0.1 dB within $f_0 \pm 50$ kHz. For a transmitted power of $P_{tr} = 10$ W the required energy storage W_{req} in the resonator is characterized by a „circulating power“ $\omega W_{req} = 2 P_{tr} f_0 / \Delta f$ in the order of 60 kW. By replacing a conventional resonator with an unloaded quality factor of $Q_0 = 20{,}000$ with an HTS resonator with $Q_0 = 200{,}000$ the combiner losses for 630 kHz channel spacing (dissipation in filter plus power flows into adjacent ports) can be reduced from about 2 dB to 0.7 dB. This means that for an output power of 10 W per channel the power to be delivered by the HPA can be reduced from 16 to 11.75 W.

DESIGN AND EXPERIMENTAL RESULTS

The disk resonators are made from $YBa_2Cu_3O_{7-\delta}$ thin films double-sided deposited on 2“ diameter and 0.5 mm thick $LaAlO_3$ substrates. Design and test of the filter was performed in 5 subsequent steps in order to allow for a separate experimental study of various measures onto the Q_0-value and the power-handling capability.

In a first step Q_0 of individual disc resonators without tuning capability was characterized in a test housing using one-port weak coupling to the resonator. Fig. 1 depicts the measured temperature dependence of Q_0 (filled circles) together with the estimated contribution $Q_{HTS} = \Gamma / R_{s,HTS}$ from HTS losses (open circles). The latter result is obtained via experimental surface resistance values obtained at unpatterned films with dielectric resonator measurement techniques and with $\Gamma = 3.9\ \Omega$ for the geometry factor. At temperatures below about 30 K the loss contributions from the dielectric losses in the substrate ($Q_{diel} \approx 1/\tan\delta_\varepsilon$) and the conductor losses in HTS film (Q_{HTS}) are in the same order, with Q-values for the individual contribution above about $1.6 \cdot 10^6$ and the contribution from the normalconducting housing walls results in $Q_{hous} > 3 \cdot 10^6$. Since the loss tangent of the used $LaAlO_3$ substrate increases from about $7 \cdot 10^{-7}$ at 30 K to a maximum of $1.1 \cdot 10^{-5}$ at 60 K and then slightly decreases to $8 \cdot 10^{-6}$ at 77 K, dielectric losses strongly dominate HTS losses in the envisaged operational temperature range between 60 to 70 K limit Q_0 to values around 10^5. In order to achieve the goal of $Q_0 \approx 200{,}000$ in this temperature range, a different substrate material (e. g. sapphire or „optimized“ $LaAlO_3$) is needed. In this work no such substrate with reduced dielectric losses was used, but in all following investigations measurements at temperatures of 30 K and below were included in order to obtain results which are not dominated by dielectric losses.

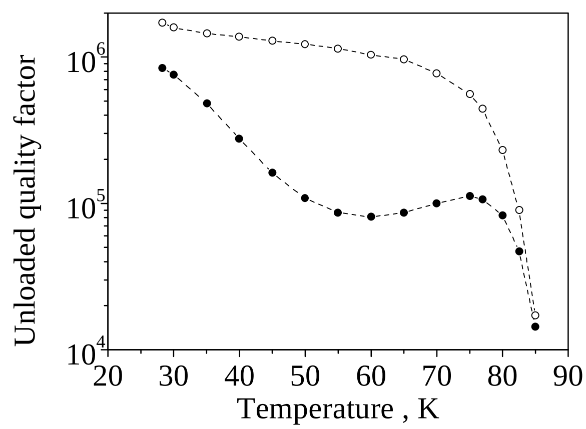

Figure 1: Measured temperature dependence of the unloaded quality factor of the fixed-frequency resonator (filled circles) and contribution $Q_{HTS} = \Gamma / R_{s,HTS}$ of losses in the HTS film (open circles).

After this study of the obtainable Q-value, in a second step a fixed frequency version of the resonator was equipped with coupling elements in order to provide a two-port with a 3-dB bandwidth of 630 kHz, minimum reflection at center frequency and minimum crosstalk between the couplers. After an evaluation of several different coupling concepts, the version shown at the left part of Fig. 2 was selected. It provides about 70 dB isolation between the couplers and a negligible Q-degradation.

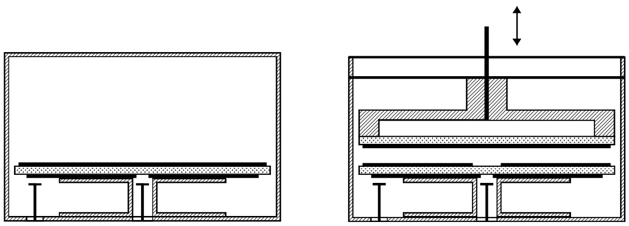

Figure 2: Schematic cross-section of the filter structure. Left part: Fixed frequency version with $f_0 = 1.6$ GHz. Right part: Tunable version with $f_0 = 1.93 - 1.99$ GHz for t = 42.5 - 80 μm.

Power handling capability of the fixed-frequency version (Left part of Fig. 2 with weak coupling to allow for Q_0 measurements) was tested both in a pulsed power and a CW mode. In the former case pulses with period of 10 ms and a duty cycle of 3 % were employed. The results for Q_0 variations with the oscillating power at different temperatures are shown in Fig. 3. In the pulsed power regime no change is observed up to an oscillating power of 800 kW, 700 kW and 90 kW for temperatures of 23 K, 45 K and 76 K, respectively. This corresponds to a transmitted pulse power of 130 W, 115 W and 15 W at the three above given temperatures. A further increase of the circulating power results in a sharp but reversible drop of Q_0 which most likely is associated with a thermal breakdown. As is seen from Fig. 3, with CW measurements a slight decrease of Q_0 already occurred at a lower power level and results at T= 23 K in an 10 % decrease of at $P_c \approx 60$ kW ($P_{tr} \approx 10$ W). By comparing this result with pulse measurements thermal heating of the structure due to dissipation can be identified to cause the reduced power handling and this leads to the conclusion that a proper cooling of the resonant structure is essential for meeting the power-handling requirements.

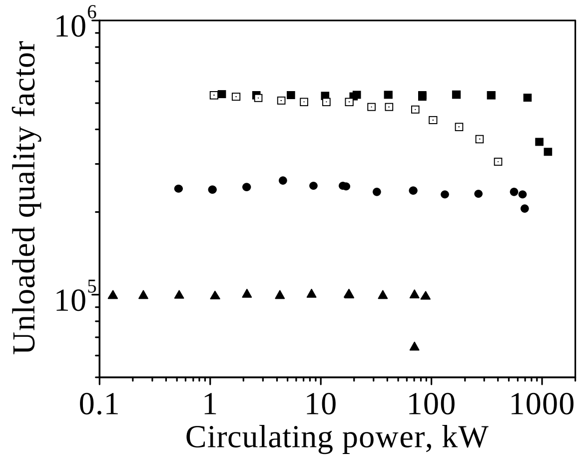

Figure 3: Unloaded quality factor Q_0 versus circulating power, measured in the pulsed power mode (filled symbols) and CW mode (open symbols) at different temperatures T = 23 K (squares), 45 K (circles) and 78 K (triangles).

In the next step the disk resonator filter was modified as shown at the right part of Fig. 2 to enable a tuning of the center frequency by at least 3 %. For this a circular hole is introduced into the ground plane and a HTS „plunger film“ is placed in a variable distance t behind this hole. By that a variable loading by means of a „ring capacitor“ build by the plunger film and the ground plane is realized. Fig. 4 shows the variations of the resonant frequency f_0 with the gap width t between plunger film and ground plane and indicate that a total gap-variation of $\delta t = 36\ \mu$m is sufficient to provide the required 3 % tuning range. The realization of the mechanical displacement by means of a piezoelectric actuator implies the possibility of electrically controllable tuning. In order to reduce the sensitivity to mechanical vibrations several measures, like shifting of mechanical resonant frequencies and damping of mechanical oscillations, have been employed.

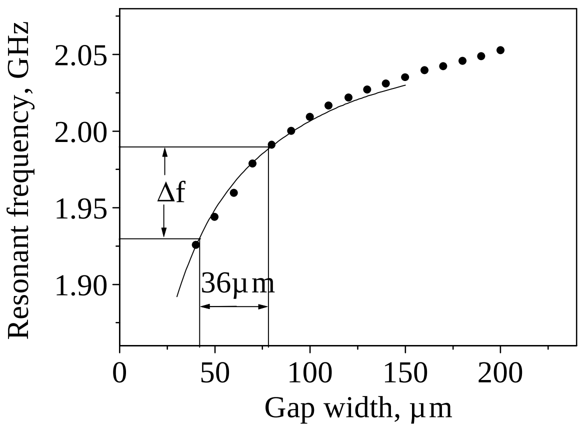

Figure 4: Tuning of the resonant frequency f_0 by means of variation of the gap width t between the plunger film and the ground plane. Solid line represents estimated variation and symbols are measured values.

The necessary normalconducting mechanical tuning structure as shown at the right part of Fig. 2 represents a new resonator which couples to the wanted resonant mode of the disk resonator structure and therefore causes a Q-degradation. By that reason an optimization of the shape and size of the tuning structure for a minimum degradation turned out to be of high importance. For the finally chosen version, the variations of the unloaded quality factor with the plunger position and therefore the resonant frequency is depicted in Fig. 5. In order to get results which are not dominated by substrate losses the comparison is made at T = 23 K. The measured value of $Q_0 \approx 290{,}000$ for small gaps is by a factor of about 2 lower than the value obtained at the same temperature for the fixed frequency version (see Figs. 2 and 3), but shows only negligible variations within the operational bandwidth 1.93 -1.99 GHz. This Q_0-reduction is due to a reduction of the housing contribution from $Q_{hous} \approx 3 \cdot 10^6$ in the fixed-frequency version (Fig. 2, left part) to $Q_{hous} \approx 6 \cdot 10^5$ in the tunable version (Fig. 2, right part). The power-handling of the tunable structure also showed some degradation in comparison to the fixed-frequency version, which has to be further investigated.

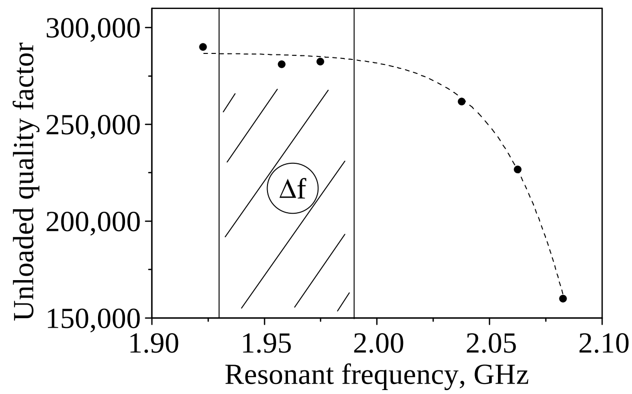

Figure 5: Unloaded quality factor versus resonant frequency (plunger position) for T=21 K

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