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HIGH TEMPERATURE SUPERCONDUCTOR HIGH POWER RF-DEVICES

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The application of high temperature superconductors (HTS), microwave filters and multiplexers for communication satellites and for terrestial mobile communication base stations in the low GHz (2–4 GHz) frequency range is discussed.

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Important short-term applications of high temperature superconductors (HTS) are microwave filters and multiplexers for communication satellites and for terrestrial mobile communication base stations in the low GHz (2–4 GHz) frequency range. They offer an option to reduce significantly mass and volume of the microwave components due to the utilization of planar thin film HTS-, and hybrid dielectric/HTS-structures. Furthermore, due to their superior Q-factor both selectivity and sensitivity of receivers and power efficiency of transmitter units can significantly be improved. Channel filters of output multiplexers (OMUX) for C-band (3.4–4.2 GHz) communication satellites (usually four-pole 1% fractional bandwidth quasi elliptic filters) must handle microwave power of 60–100 W.[1] Resonators for transmitter combiners for mobile communication base stations

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typically have to handle 5–10 W.[2] DCS 1800 system with one-pole and fractional bandwidth of 0.03% filters in 1.805–1.880 GHz may serve as an example for this applications.

Frequency selectivity of filters (two-ports) and multiplexers (multi-ports) relies on stored electromagnetic field energy W and is directly related to the group delay time τ. If a time-harmonic wave (frequency f) with power P_{inc} is incident at one port of a multiport, the power P_{diss} dissipated in conjunction with the storage of energy is given by

$$\frac{P_{diss}}{P_{inc}} \approx \frac{2\pi f\tau/Q_0}{1 + 2\pi f\tau/Q_0},$$

with Q_0 being the unloaded quality factor of the structure. Since a degradation of the frequency response is associated with power dissipation, the ratio P_{diss}/P_{inc} should not exceed a certain limit. If dissipative passband insertion loss of $L_{max}/\mathrm{dB} \approx 4.343 \cdot P_{diss,max}/P_{inc}$ is considered as the limit for the tolerable degradation, the minimum quality factor of the components is given by

$$Q_0 > 27.3 \frac{f\tau}{L_{max}/\mathrm{dB}}.$$

An important consequence of this equation is that relatively high values of Q_0 are needed for components which are highly frequency selective and therefore possess a high group delay. The required group delay in transmitter combiner, e.g. DCS 1800, is about 530 ns, leading to $f \cdot \tau \approx 960$. Therefore Q_0 of higher than 130 000 is required if $L_{max} = 0.2$ dB is needed. In the case of the filters for a typical satellite OMUX, $f \cdot \tau \approx 140$ leading to a required Q_0 of about 130 000 if $L_{max} = 0.03$ dB is necessary for high power efficiency.

In conventional technology Q-factors of even large size components like waveguide and shielded dielectric structures are limited to values of 10 000–20 000.[1] Q-factors of planar thin film HTS-, and hybrid dielectric resonator/HTS-structures range up to the values of at least one order of magnitude higher. As an example, Q-factors of 400 000 have been achieved for 4 GHz disk resonators on 1 mm thick sapphire substrates at temperature of 60 K.[3]

The field energy W_{total} stored in a filter is given by

$$W_{total} = \tau \cdot P_{inc}$$

and a power handling capability of the individual resonators composing the filter can be characterized by the maximum oscillating power $P_{osc,max} = \omega_0 W$, where ω_0 is the circular resonant frequency of the resonator. For the two examples of DCS 1800 combiner and C-band OMUX the resonators have to be able to handle values of oscillating power in the order of 60 and 15 kW respectively. Presently available HTS films exhibit at temperature of about 70 K strong nonlinear response (field penetration, thermal effects) if the surface magnetic field strength exceeds the value H_{max} of about 50 A/cm. Since a low surface resistance is only available in epitaxial thin films, HTS devices have to be realized as a planar device. A drawback of these planar structures is that current flowing in parallel to the edges of the structure is forced to form a peaked distribution. Since this peak current value is about 10 times higher than the mean value, the surface magnetic field strength at the edges exceeds H_{max} even for relatively low values of the oscillating power. HTS microstrip transmission line resonators can typically handle not more than 100 W of oscillating power which is much too low for the above mentioned applications.

At present, two different approaches are suited to overcome this problem, namely the use of hybrid dielectric/HTS resonators and the newly developed concept of the planar "edge-current free" disk and ring resonators operating at TM_{010}-mode.

Usually single mode hybrid dielectric/HTS resonator consists of a dielectric cylinder with end-plates made from epitaxial HTS films and shielded by copper cavity.[4] Usually the TE_{011} mode of the dielectric resonator is employed. The highest Q-value for sapphire ($\varepsilon_r = 10$)/YBCO hybrid resonator was measured to be around 10^6 at 5.6 GHz and 50 K.[4] For the size reduction, single crystalline lanthanum aluminate ($\varepsilon_r = 24$),[5–7] rutile ($\varepsilon_r = 105$),[6,8] and some high dielectric constant ceramics[9] (e.g. $BaO{-}TiO_2$) are utilized, which typically have Q-values of 100 000–200 000 up to an oscillating power of about 100 kW at 5–10 GHz and 50 K. Dual-mode operation of hybrid resonators is made possible by using different geometry and different modes. For instance, 1%-bandwidth channel filters for C-band satellite OMUX have been fabricated utilizing the HE dual-mode of high dielectric constant ceramic cylinder with HTS image-plate.[9–11] These filters demonstrated capability to handle power of 30–50 W at 77 K. Another geometry of a dual-mode dielectric resonator, namely a lanthanum aluminate hemisphere mounted on a dielectric spacer, operating in degenerated fundamental mode was used to build a 0.25%-bandwidth two-pole channel filter prototype.[12,13] The cover of the shielding cavity was made from an HTS film allowing the size reduction without degradation of the unloaded Q-factor of the resonator. Up to the power level of 32 W (limited by available power amplifier) the filter response remained unchanged.

Employing the planar disk or ring resonators operating in rotational symmetric current-edge-free TM_{010} mode offers, in comparison to the hybrid dielectric/HTS resonator concept, a higher degree of miniaturization.[14] Single disk resonators on sapphire substrates with resonant frequencies of (2–4) GHz exhibit unchanged unloaded Q-factor as high as 400 000 up to the oscillating power of around 100 kW and at temperature of about 60 K.[3,15] Power handling capability of a disk resonator can be improved by increasing the thermal contact between the wafers and the package. For instance a 2 GHz disk resonator on a lanthanum aluminate substrate mounted in a helium-filled exchange-gas chamber demonstrated unchanged Q-value of about 100 000 (limited by the loss tangent of lanthanum aluminate) up to oscillating power of 0.5 MW.[16] A 0.4%-bandwidth two-pole channel filter prototype was fabricated using coupled ring resonators on 1 mm thick lanthanum aluminate substrates.[3] This filter demonstrated capability to handle power of 100 W at 77 K. A 0.03% bandwidth tunable resonator for transmitter combiner of mobile communication base stations was built using a ring resonator and movable by means of a piezoelectric actuator "plunger" film.[17] The filter is able to handle power of 10 W at 40 K and 5 W at 60 K.

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