Planar superconducting lumped element bandpass filter with spiral inductors

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Abstract — **Experimental results are reported for a novel 4-pole high temperature superconducting lumped element bandpass Chebyshev filter with central frequency 1.7 GHz and 1.2 % fractional bandwidth. High efficiency of the substrate area usage is reached by the application of planar coils as inductance elements. Measurements and simulation results are compared and are found to be in satisfactory agreement.**

I. Introduction

In many applications minimal size of filter structures is very important. Planar filter structures would be preferred due to advantages of printed-circuits technology simplicity and because of their smaller sizes. Modern development of planar high temperature superconducting (HTS) devices makes possible applying these structures as a part of microwave monolithic integrated circuits. The low surface resistance of HTS allows realizing planar bandpass filters with lumped elements which usually have more compact dimensions than circuits with distributed elements. Most known examples of lumped element filters make use of straight microstrip, meander lines or dual-spiral resonators as inductance elements [1-5]. Utilization of planar spiral inductor is more efficient for compact UHF filters. Using spiral coils especially multi-turn coils makes theoretically possible to achieve lower dimensions of inductor element. However, ordinary spiral coil design is complicated by the fabrication of connection between inner terminal of the coil and the rest of the circuit [6]. We report on a structure that avoids such a connection. The aim of the work presented in this paper was developing of a novel type of HTS lumped element bandpass filter with planar spiral inductors and realization of a fourth order filter for 1.7 GHz with 1.2 % fractional bandwidth.

II. Experimental

The equivalent circuit of our bandpass filter is shown Fig.1. In this lumped element circuit all inductors have the same inductance value. This circuit is slightly modified type of circuits which reported in [1,7]. We have chosen a bandpass filter with centre frequency 1.7 GHz, fractional bandwidth 1.2 % and 0.01 dB equal ripple response as a design goal. The equivalent circuit was converted into a planar lumped element structure with microstrip 50 Ω feed lines. The conversion from equivalent circuit was performed using planar coils as inductance element to reach desired compactness and rectangular patches as inverters, which consist of $C_{g1,i}$, $C_{g2,i}$, $C_{c,i}$, and the coupling between patches with the capacitor C of inductor L. The line width of the inductance elements was 50 μm. Besides the spiral inductors the structure contains patches that are used as capacitors together with interdigital capacitors for external coupling. Coupling between filter sections is due to the capacitance between patches. After a number of iteration steps using Microwave Office full-wave electromagnetic analysis software the layout, which is shown in Fig. 2, was attained. In order to verify design principles we report a structure with $1^3/_4$ turn coils. The simulated frequency response was obtained for perfect conductor and lossless substrate material (thickness 0.5 mm and permitivity ε_r = 10). The simulated frequency response is shown in Fig. 3.

The filter was realized from epitaxial YBCO thin film with following properties: T_c = 80 K, thickness t = 0.3 μm and R_s = 2 mΩ at 10 GHz and 77 K, on an 18 x 10 x 0.5 mm^3 sapphire substrate ($\varepsilon_r \approx 10$). Sapphire was buffered with ZrO_2. The ground plane was made by evaporating Al film. Standard lithography process and wet etching were involved. Connections between cables and 50 Ω feed lines to deposited silver layer were made with gold 40 μm wires using ultrasonic wire bonding.

III. Results

Measured filter response at 20 K temperature is shown in Fig. 4. The scalar network analyzer was calibrated with cables at room temperature. The power level in our measurements was -20 dBm. Contribution of dissipative loss at 20 K temperature from the cables, bond wires and contacts is assumed to be between 0.1 and 0.2 dB. Unloaded quality factor of the resonant circuits can be estimated as being between 5000-10000. Such Q-factor

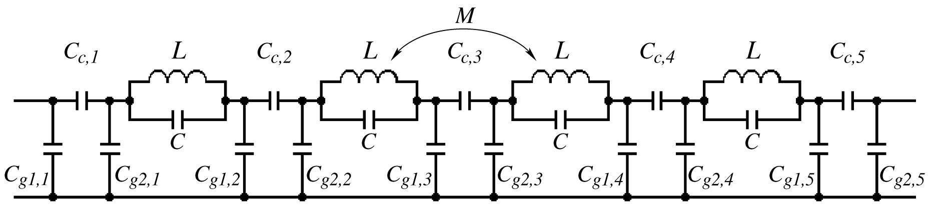

Fig. 1. Equivalent circuit of the developed filter.

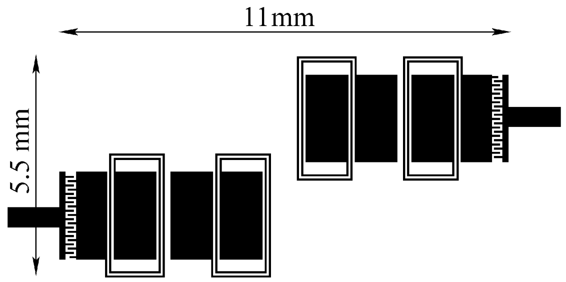

Fig. 2. Layout of the four-pole lumped element bandpass filter.

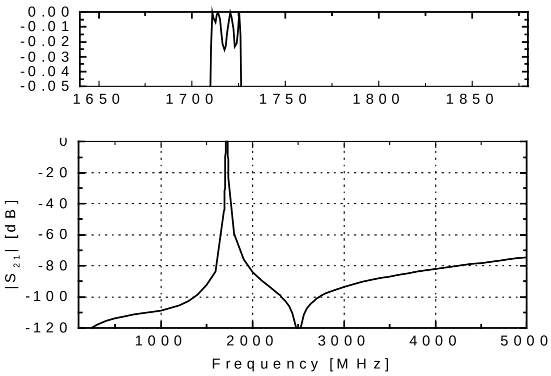

Fig.3. Calculated frequency response of the lumped element filter ($|S_{21}|$ - solid line, $|S_{11}|$ - dash line).

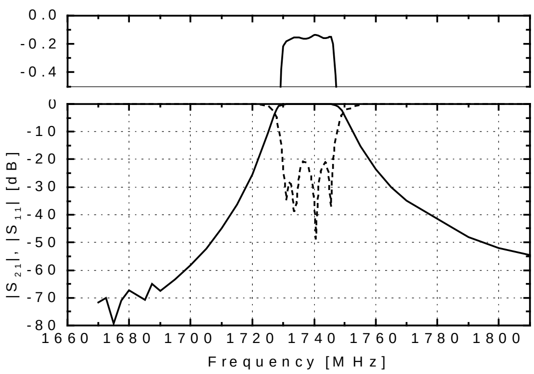

Fig.4. Measured frequency response of realized lumped element filter at 20 K temperature ($|S_{21}|$ - solid line, $|S_{11}|$ - dash line).

was obtained for very low width of inductor lines w=50 µm, only one side of the substrate coated with YBCO thin film (the other side serving as ground plane was covered by–Al films) and for a filter structure without shielding. Mounting of our filter was implemented by using Cu covered low permittivity dielectric plate with soldered cables. To connect the ground plane of the filter structure to the copper plate silver epoxy was used. Tuning was performed by sapphire pieces positioned over the interdigital input and output coupling capacitors. During measurements no shielding was used to prevent radiation loss. The return loss and the minimum insertion loss were found to be 20 dB and less than 0.2 dB, respectively at 20 K. For example, an identical filter realized in copper has displayed a Q-factor less than 50 and an insertion loss near 15 dB at 20 K temperature.

IV. Conclusion

We have presented a novel lumped element four-pole filter with $1^3/_4$ turn planar coils as inductance elements. Now we work on simulation and fabrication of a filter with more than 2 turns. This type of structures has very effective surface usage. The dimensions of this filter can be about 4 times smaller of the filter with half-loop inductor presented in [8]. Reported filter measurements are in good agreement with theory though a frequency shift about 30 MHz is present. This shift can be explained by taking into account non-ideal knowledge of the anisotropic substrate effective permittivity and thickness.

To meet the correct center frequency more precise data on the substrate parameters has to be used in calculations.

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