A 10 GHz Thin Film Lumped Element High Temperature Superconductor Filter

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Abstract - A narrow band thin film lumped element filter centered at 10 GHz has been fabricated using thallium-based high temperature superconductor technology. This filter does not suffer from the undesired spurious responses seen in thin film distributed filters using HTS technology. The measured filter has 2.5 dB insertion loss at band center, 3% bandwidth and is within 50 MHz of the desired center frequency. Measurements were made to confirm the broad spurious free stopbands from 1 GHz to 21 GHz.

Introduction

Narrow band microwave filters are one of the first serious applications for high temperature superconductor (HTS) thin films. A bank of narrow band HTS filters could be a key component in future microwave channelized receivers. Various distributed filter structures using HTS thin films have been reported[1,2]. Although quite acceptable passband performance has been obtained, these filters suffer from spurious responses in the stopband due to slab modes in the dielectric substrate. Here we are reporting on a thin film lumped element filter with broad spurious free stopbands fabricated using HTS technology. Similar filters have been built[3] using conventional thin film technologies at broader bandwidths (10% - 50%) where the low Q of the printed spiral inductor is acceptable. When high Q HTS thin films are used, narrow band (1% - 3% bandwidth) thin film filters with low insertion loss become practical. The printed lumped element approach used here also results in a much smaller filter when compared to an equivalent distributed filter.

Design

The fourth order lumped element prototype for this filter was obtained using SFILSYN[4] and is shown in Fig. 1. The initial layout for the filter is shown in Fig. 2. The substrate is 20 mil (.508 mm) thick Lanthanum Aluminate ($LaAlO_3$) with an assumed relative dielectric constant $\varepsilon_r = 24$. The capacitive PI networks are realized as two printed patches which provide shunt capacitance to ground and a series capacitance due to the coupling between them.

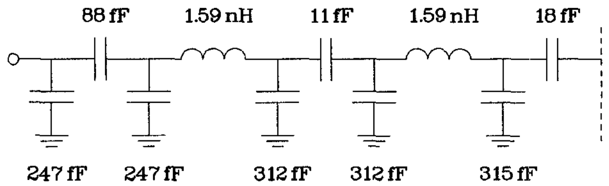

Fig. 1. Lumped element prototype for the 10 GHz filter.

For this narrow band design the coupling between patches is quite small which results in a large gap. To reduce this gap and maintain tighter control over the coupling a redundant patch was added to each PI network resulting in three shunt capacitors and two series capacitors in each network. The modified filter layout is shown in Fig. 3.

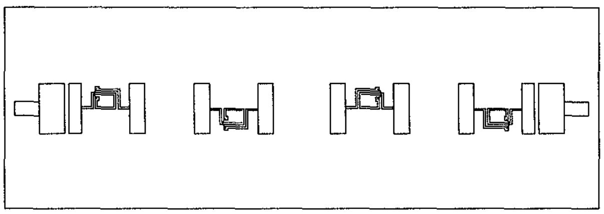

Fig. 2. Initial layout for the 10 GHz HTS filter. The substrate is 100 by 300 mils (2.54 by 7.62 mm).

The filter was designed using a full wave electromagnetic simulator[5] by subdividing the circuit into several components. The particular simulator used here requires that the circuit conform to a uniform grid. A grid spacing of 0.5 mil (12.7 μm) was chosen for the inductor analysis, Fig. 4.

The inductor dimensions were optimized manually for the desired series inductance and their parasitic capacitance was extracted using a simple PI model. The parasitic capacitance of the inductors was subtracted from the desired shunt capacitance of the adjoining capacitor networks.

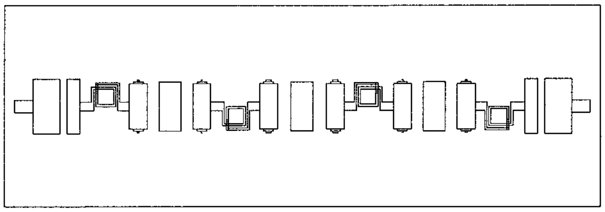

Fig. 3. Modified layout for the 10 GHz HTS filter. The substrate is 100 by 300 mils (2.54 by 7.62 mm).

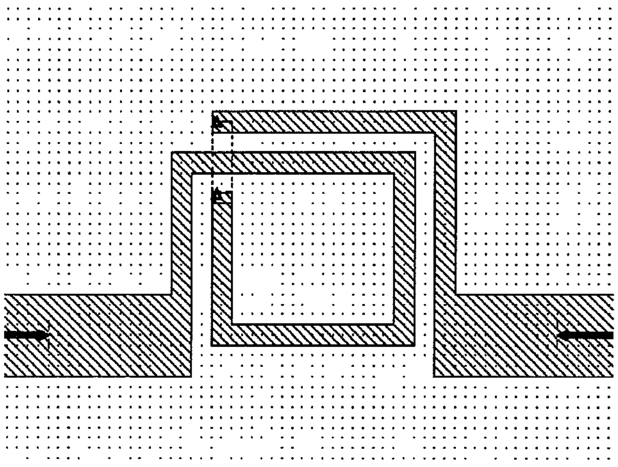

Fig. 4. Input to the electromagnetic field solver for the printed spiral inductor. Grid spacing is 0.5 mil (12.7 μm).

The capacitor networks were then designed by comparing the computed S-parameters to the those of the ideal network at 10 GHz, the desired center frequency. A grid spacing of 1 mil (25.4 μm) was chosen and the structure was fine-tuned using small patches of metal (Fig. 5) in the same way a circuit is often tuned experimentally. This is a fundamentally different approach to optimizing a circuit on the computer compared to the more traditional approach of varying widths and lengths of transmission lines in a microwave linear simulator.

Because the individual structures are small and were analyzed at a single frequency, the analysis time was under two minutes in most cases and the inductors and capacitor networks could be manually optimized. To obtain the predicted filter response S-parameters were obtained for the individual networks at 31 points from 9.7 GHz to 10.3 GHz which required an overnight analysis on the field solver. The computed S-parameter black boxes were cascaded using a microwave linear simulator and the predicted filter response was obtained. One potential error in this design procedure is that parasitic couplings between networks are ignored. At this time it is not practical to analyze the complete filter on the field solver; therefore tuning the complete filter is also impractical.

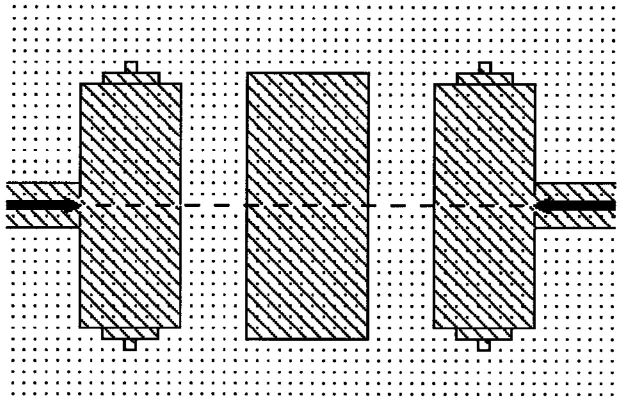

Fig. 5. Input to the electromagnetic field solver for the modified capacitor network. Grid spacing is 1.0 mil (25.4 μm).

HTS-Films and Fabrication

The $Tl_2CaBa_2Cu_2O_8$ thin films are produced in a two-step process. In the first step an amorphous film is deposited onto a 2 inch (5.08 cm) diameter $LaAlO_3$ substrate by laser ablation. In the second step this amorphous precursor is heated to 800 - 850 °C, in an over-pressure of O_2 and Tl_2O, to form an epitaxial superconducting thin film. These films typically exhibit $T_c \geq 100$ K with $\Delta T_c \leq 1$ K. The surface resistance R_s is typically ≤ 0.5 mΩ at 10 GHz and 77 K.

The filters were fabricated in a four-step process. In the first step ohmic contacts are applied to the HTS film by e-beam evaporation of Au; these contacts exhibit contact resistance $\leq 1\times10^{-5}$ $\Omega{\cdot}cm^2$. In the second step the HTS film is patterned by wet etching. The dielectric layer is formed with a preimidized polyimide, and we have shown that this polyimide has negligible loss at frequencies below 100 GHz. The polyimide also serves as a passivation layer to protect the HTS film. In the last step thick (~ 3 μm) Au is deposited to form the metal crossovers in the inductors. The resistance of one of these crossovers is approximately 0.4 Ω.

Twelve of these circuits were fabricated on a 2 inch wafer as 200 by 400 mil (5.08 by 10.16 mm) circuits and diced after processing. The circuits were soldered to carriers and tested at 81 K in a glove box using Wiltron K connector launchers and an HP8510C network analyzer. Cooling was done by attaching the carrier to a copper block that was partially submerged in liquid nitrogen.

Results

The measured results for the filter are shown in Fig. 6. The insertion loss is 2.5 dB which may improve as the processing of the dielectric crossovers improves. The computed average Q for this filter is 330, which is low due to the high resistance of the crossover contacts. The actual filter bandwidth is about 290 MHz, which is greater than the desired 200 MHz bandwidth and may be due to couplings between networks that were not modeled or modifications made to the circuit after the final design was completed.

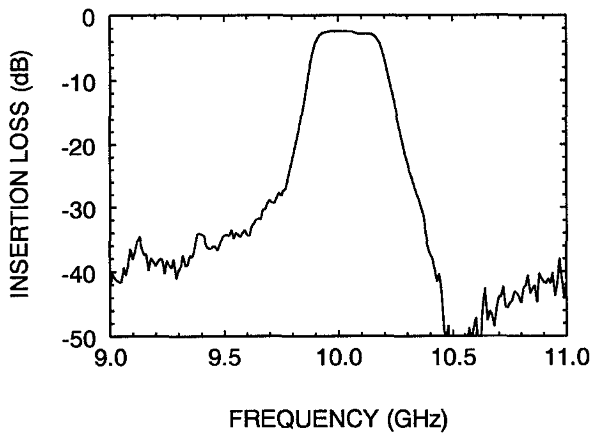

Fig. 6. Measured insertion loss for the thin film lumped element HTS filter.

A broadband plot of the stopband performance is shown in Fig. 7. Note the lack of spurious responses down to -40 dBc. This is because the filter is truly semi-lumped over a broad frequency range; there are no resonant quarter-wave or half-wave distributed elements to launch energy into the substrate. The spurious performance demonstrated here may make it possible to place several of these filters on the same substrate in a microwave channelized receiver application.

Conclusion

A 10 GHz thin film lumped element filter with 3% bandwidth has been fabricated using thallium-based high temperature superconductor technology. Cross-overs for the printed spiral inductors were realized using a polyimide dielectric layer and conventional thin film gold. The measured filter exhibited 2.5 dB insertion loss at band center and was within 50 MHz of the desired center frequency. It may be possible to improve the insertion loss performance by reducing the resistance of the gold to HTS contacts at the cross-overs.

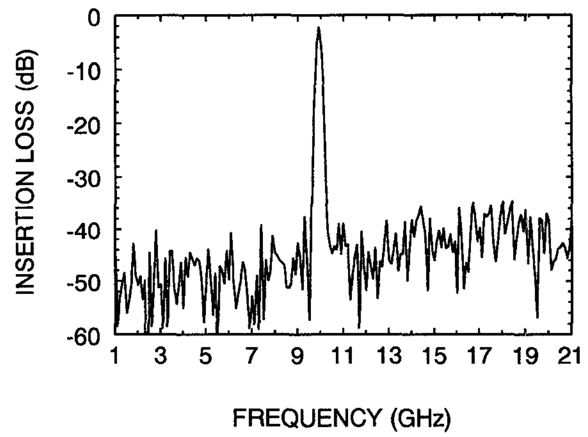

Fig. 7. Measured stopband performance for the thin film lumped element HTS filter.

The most significant achievement was broad spurious free stopbands from 1 GHz to 21 GHz. This filter does not suffer from the undesired spurious responses seen in distributed filters using the same HTS fabrication technology. Because this filter does not generate spurious modes in the substrate, it may be possible to put several filters on the same substrate in microwave systems applications.

References

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[5] *Em*, Sonnet Software, Liverpool, NY.