High T_c Superconducting CPW Bandstop Filters

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***Abstract*— We have designed and tested a superconducting coplanar waveguide bandstop filter. At a center frequency of 2.84 GHz, a 94% bandwidth low-pass Chebychev design resulted in a filter with less than 0.5 dB in the passband and more than 40-dB insertion loss in the stopband at 35 K. The filter was fabricated by dry etching a laser ablated $YBa_2Cu_3O_7$ layer on a $LaAlO_3$ substrate. Using a cold-wafer probe, accurate, calibrated measurements on the filter and individual lines sections were carried out.**

I. Introduction

THE INCREASED usage of the electromagnetic spectrum in the low-GHz region has stimulated the development of new microwave components. In particular, the low-loss characteristics of high T_c superconductors can be exploited to produce devices with superior performance. This has been demonstrated in the past with bandpass filters [1]–[3], antenna applications [4], and more recently by Conductus using a 19-pole design [5]. In this letter, high T_c thin-film bandstop filters are described. Bandstop filters are necessary in applications such as radio astronomy where low-level signals are increasingly being masked by out of band signals. Work on bandstop filters has been reported by STI, who used a six-bank optically switchable bandstop filter [6], and by Lancaster *et al.* [7], who employed a lumped-element approach. We have designed a prototype 3-GHz bandstop filter in coplanar waveguide (CPW). Coplanar waveguide structures facilitate increased packing density without the need for relatively thin substrates as in the case of microstrip transmission lines. A hairpin-like design was selected, because of its compact size. For this topology, CPW contributes to decreased coupling between the $\lambda/4$ sections.

II. Bandstop Filter Design

The bandstop filter specifications are shown in Fig. 1. A low-pass Chebychev prototype filter with 94.75% bandwidth and 0.1-dB ripple was designed using an expert system for planar filter design implemented within the Microwave Design System of Hewlett Packard [8], [9]. With 0.1-dB ripple in the passband and skirt selectivity 2 ($=\mathrm{BW}_{0.1\,\mathrm{dB}}/\mathrm{BW}_{-35\,\mathrm{dB}}$) a five-pole design exhibits at least 35-dB attenuation in the stopband [10], [11]. A nonredundant filter prototype with five-unit

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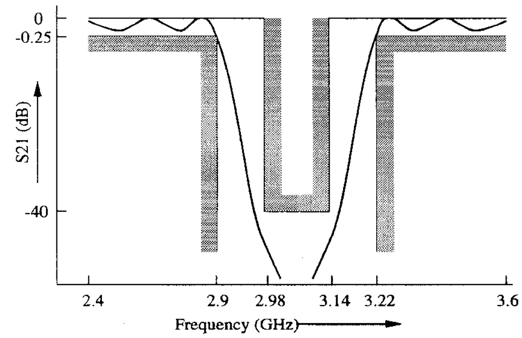

Fig. 1. Specifications for the bandstop filter.

elements and five S-plane inductances was chosen. Due to the asymmetry of the filter, the input and output impedances are unequal. Simulations indicated that this mismatch increases the insertion loss by 0.05 dB and the center frequency decreases 1.6%. Applying the S-plane equivalence of the cascade of an inductance and an unit element as depicted in Fig. 2 [12], [13], odd and even impedances can be obtained for the equivalent parallel line quarter wave elements

$$Z_{oe} = Z_0\left[Y_0L + 1 + \sqrt{Y_0L(Y_0L+1)}\right] \tag{1}$$

$$Z_{oo} = Z_0\frac{Y_0L + 1 + \sqrt{Y_0L(Y_0L+1)}}{2Y_0L + 1 + 2\sqrt{Y_0L(Y_0L+1)}}. \tag{2}$$

When using CPW transmissions lines, the shorted elements are easily realized and the given transformation leads to realistic impedance values. The step from impedance values to geometries is described in [14] and [15] and the results are shown in Fig. 3 and Table I. In our design, we restricted ourselves to a mask resolution of 2.5 μm, so that the dimensions of Table I although nonoptimal values are very close to the values obtained from (1) and (2). Including this finite lithographic resolution, end effects, and the short lines connecting the $\lambda/4$ sections increases the filter's insertion loss by 0.15 dB accompanied by a resonant frequency decrease of 1.15%. Our modeling was performed assuming ideal coupled lines neglecting coupling and dispersion. To validate this approximation, an electromagnetic simulation was carried out using HP's Momentum to model slotlines instead of the metallization, which is essential for CPW structures. Although coupled lines were a reasonably good approximiation of the CPW bandstop structure, Momentum predicted a slightly larger bandwidth.

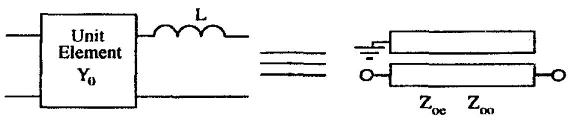

Fig. 2. S-plane equivalent circuit.

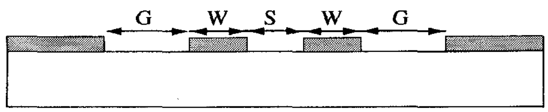

Fig. 3. Assignment of the geometry variables.

TABLE I
IMPEDANCE VALUES AND CPW GEOMETRY

	Impedance (Ω)		Geometry (μm)		
UE nr.	Z_{oe}	Z_{oo}	W	S	G
1	58.20	32.98	30	37.5	25
2	62.90	30.02	27.5	20	25
3	62.35	29.59	25	17.5	25
4	61.44	29.79	25	20	22.5
5	56.54	31.50	25	27.5	17.5

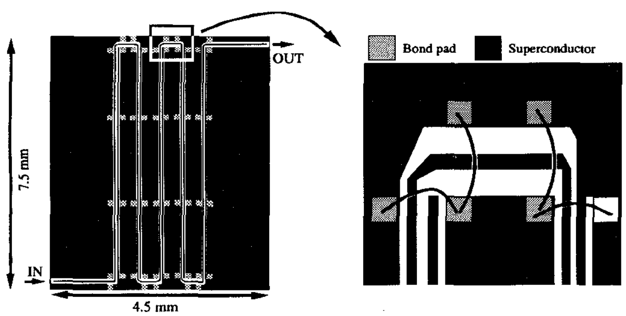

Fig. 4. Layout of the filter with bonding wires.

III. Filter Fabrication and Measurement Results

The superconductor and gold contact pads were grown and etched using standard techniques. The sample was bonded using a Kaijo FB118CH hybrid gold wire bonder. A drawing of the filter as well as a close up of a corner detail of the filter with bonding wires is shown in Fig. 4. In addition to the corners, two equally spaced extra bonding pads were introduced to assure equal phase of both ground planes.

A calibration substrate was mounted on the cold finger and at room temperature a standard LRM calibration was performed. Although at low temperatures the probe contacts an extremely cold object, the thermal resistance of the probe is high enough to avoid cooling of the probe or heating of the sample [16]. This allows room temperature calibration data to be used during the low-temperature measurements.

The filter measurement result is shown in Fig. 5. The shape of both traces is similar, demonstrating that Momentum can accurately simulate the behavior of the slotlines. The influence of kinetic inductance was demonstrated by measuring at 77 K. The center frequency decreased to 2.74 GHz accompanied by an increase in insertion loss of 0.6 dB.

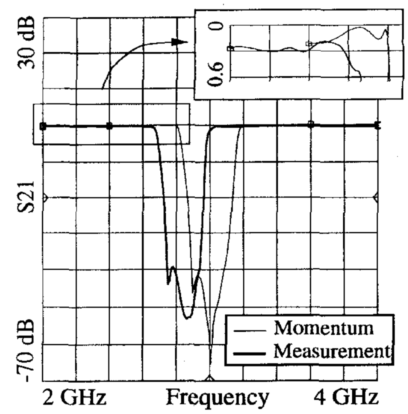

Fig. 5. Measurement at 35 K versus Momentum simulation.

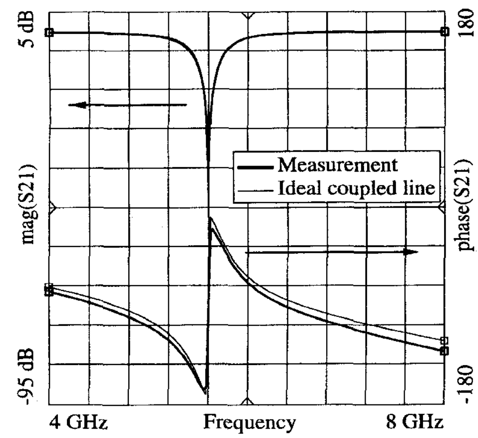

Fig. 6. Coupled line section: simulation versus measurement at 35 K.

Separate measurements were carried out on a coupled line pair as depicted in Fig. 6. Because of the limited area of the sample, the measurement data was collected from 4–8 GHz. The model incorporates compensation for the difference in phase velocity. It would appear that the behavior of a coupled line section can be accurately predicted. Small deviations are attributed to the room temperature calibration and the difference in dielectric constant of the superconductor substrate ($\varepsilon_r = 23.7$) and the calibration substrate ($\varepsilon_r = 9.8$). End effects and the 90° angles at the input and output of the coupled line section were also neglected during the simulation.

IV. Conclusion

A superconducting bandstop CPW filter was designed and tested. This first prototype displayed good behavior at 2.84 GHz, 3.5% off the target center frequency. Using a cold wafer probe and room temperature calibration, measurements showed that the behavior of individual CPW coupled line sections can be represented with standard models. The influence of bonding wires on the filter characteristics was negligible. Increasing the lithographic resolution down to 1 μm, employing a symmetrical design, and incorporating the effects of coupling sections within the design, a very low-loss ($\leq$0.35 dB) bandstop filter should be feasible.

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