PRELIMINARY DESIGN STEPS FOR THIN-FILM SUPERCONDUCTING FILTERS*

R. R. Bonetti and A. E. Williams

COMSAT Laboratories, Clarksburg, MD 20871-9475

Abstract

Techniques which aid in the design and development of microstrip filters on high-dielectric-constant substrates are presented. While the procedures are valid for most types of coupled-line filter structures, they are particularly useful as the initial steps in designing superconducting MIC filters. Numerical examples are given for both Chebychev and elliptical designs, and experimental results are provided for a 4-pole, modified hairpin microstrip filter built on a lanthanum galate substrate. Experimental measurements at liquid nitrogen temperatures show excellent agreement with the predicted performance.

INTRODUCTION

Recent developments in high-temperature superconducting (HTS) films (1),(2) should lead to new applications for narrowband MIC filters. One potential application is in communications systems, such as satellite transponders, that use narrowband channelization. Currently, the major obstacle to the miniaturization of narrowband channel filters is the intrinsically low MIC resonator unloaded Q (50 to 500) compared with coaxial and waveguide structures (5,000 to 10,000). A low unloaded Q introduces a high midband insertion loss, as well as substantial degradation in selectivity and gain slope at the band edges (see Figure 1). However, the availability of high-quality superconducting films will allow the design of MIC structures with performances equivalent to those of waveguide and dielectric-loaded cavities (at low RF power levels). This should result in significant reductions in mass and size.

The first step in prototyping MIC HTS filters is to build a conventional film (gold or copper) device on the same substrate where the HTS film will be deposited. This step provides both a benchmark for performance comparison and a first iteration for the final superconducting circuit design. Two substrate materials with lattice constants favorable for growth of perovskite-derived HTS films have been successfully tested in the microwave range: lanthanum aluminate ($LaAlO_3$) (1) and lanthanum galate ($LaGaO_3$) (2). The prototyping of narrowband MIC filters using these substrates involves two major problems:

- The microwave properties of these materials as a function of temperature have not yet been rigorously characterized (*e.g.*, a few percent error in the dielectric constant will lead to large center frequency variations).
- Due to accuracy limitations in most circuit models, available CAD programs do not yield an acceptable analysis for most filter structures for dielectric constants greater than 18.

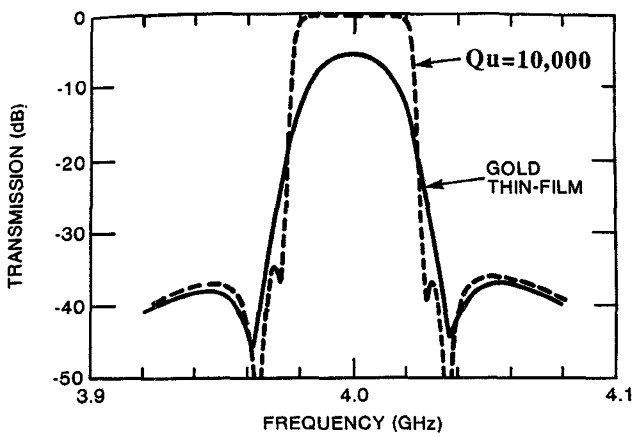

Figure 1. Six-pole Elliptic-Function Filter Response Computed for Two Different Values of Unloaded Q (150, typical of MIC circuits; and 10,000, typical of dielectric-loaded cavity and potential HTS film realization)

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This paper presents measurements of the dielectric constant and loss tangent at both ambient and liquid nitrogen temperatures for lanthanum galate and aluminate substrates. A simple technique is described to correct available CAD programs in order to obtain a good match between modeled and measured results. Experimental results obtained with a hairpin filter on lanthanum galate confirm the accuracy of the measurements and the validity of the proposed design approach.

MEASUREMENT OF SUBSTRATE PROPERTIES

A common method for measuring MIC substrate properties is to build a weakly coupled circular ring resonator that is large compared to the wavelength of interest (because of the modal distortion that occurs in small-radius circuits). However, this procedure may require circuit sizes that are too large for currently available HTS film deposition techniques. An alternative structure is the square ring resonator (Figure 2a). While this circuit is not limited by field distortions, it has four bends that must be included in the modeling. This presents a problem when accurate CAD bend models are not available, but it can be solved by measuring the bend effect in an independent circuit (Figure 2b). The unknown end effect can then be determined by a third circuit—the weakly coupled straight line (Figure 2c). Thus, measurement of the three circuits' resonant frequencies provides sufficient information for derivation of the dielectric constant. Care must be taken to minimize intercircuit couplings, as well as substrate edge and wall effects.

The above technique was used for room temperature measurement of the dielectric constant. A second technique, based on measurements performed on a 2-pole filter, was employed both to confirm the results obtained with the first set of measurements and to derive the substrate dielectric loss tangent temperature variation. Figure 3 is a schematic of the 2-pole filter configuration. This method yields greater precision than that obtained using weakly coupled resonators.

Because of uncertainties introduced by errors in available software packages, the actual resonator couplings were modeled from measured results obtained from an automated technique based on the reflection coefficient's poles and zeros locations (3). The results obtained at C-band for both galate and aluminate substrates are summarized in Table 1. The dielectric constant values at 77 K were derived from the filter's center frequency shift.

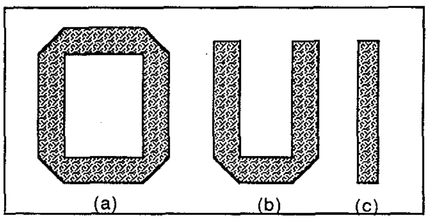

Figure 2. Test Circuit Patterns for Substrate

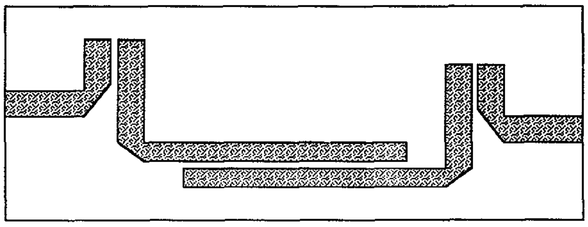

Figure 3. Test Circuit for Loss Tangent Measurements

Table 1. Measured Substrate Parameters

	$LaAlO_3$		$LaGaO_3$	
T (K)	Dielectric Constant	tan ∂	Dielectric Constant	tan ∂
300	23.6 ± 0.2	$(10 \pm 3) \times 10^{-4}$	24.3 ± 0.2	$(7 \pm 2) \times 10^{-4}$
77	23.2 ± 0.2	$(5 \pm 2) \times 10^{-4}$	23.1 ± 0.2	$(20 \pm 6) \times 10^{-5}$

PROTOTYPE DESIGN

A 4-pole, C-band, 150-MHz bandpass filter with a 0.05 ripple Chebychev response was designed on a lanthanum galate substrate using a modified version of the hairpin configuration (4). In this design, input and output couplings are realized by parallel-coupled lines with 45° of electrical length, while the remaining couplings are realized by quasi-90° lines. Figure 4 is a schematic of the filter pattern and illustrates the procedure used to measure the coupling between the first and second resonators, using the technique described in Reference 3. The dielectric detuner consists of a block of high-dielectric-constant material placed on top of the appropriate MIC resonators. The coupling values thus obtained were used to recompute the coupled-line even- and odd-mode impedances, which in turn were employed to determine the effective line spacings. With these corrected spacings, the CAD-generated responses provided a much better correlation with the measured filter data.

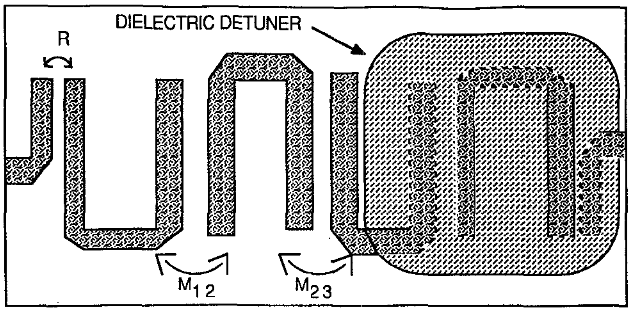

Figure 4. Schematic of the 4-pole Filter and Illustration of Coupling Measurement

MEASURED PERFORMANCE

Figure 5 shows the measured transmission and return losses of the prototype 4-pole filter at ambient temperature, compared to the uncorrected and the modified CAD computed responses. In Figure 6, the measurements at liquid nitrogen temperature are compared to the corrected CAD computations. The initial design and the corrected values for line widths and coupled-line spacings are shown in Table 2.

CONCLUSIONS

Measurements of the substrate properties of lanthanum galate and aluminate at ambient and liquid nitrogen temperatures have been presented. These measurements were used to design a C-band, 4-pole hairpin filter. A technique to improve the prediction accuracy of commercial CAD programs for high-dielectric-constant substrates was introduced and successfully tested with the prototype.

ACKNOWLEDGMENTS

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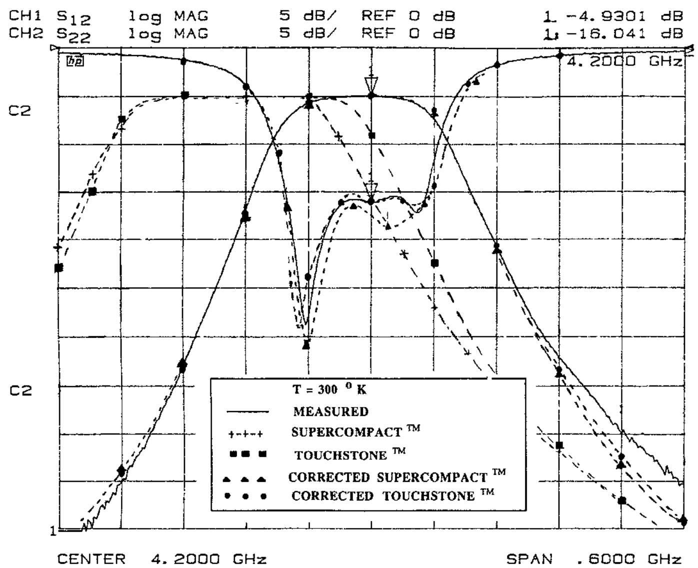

Figure 5. Measured Response at Room Temperature and CAD Simulations

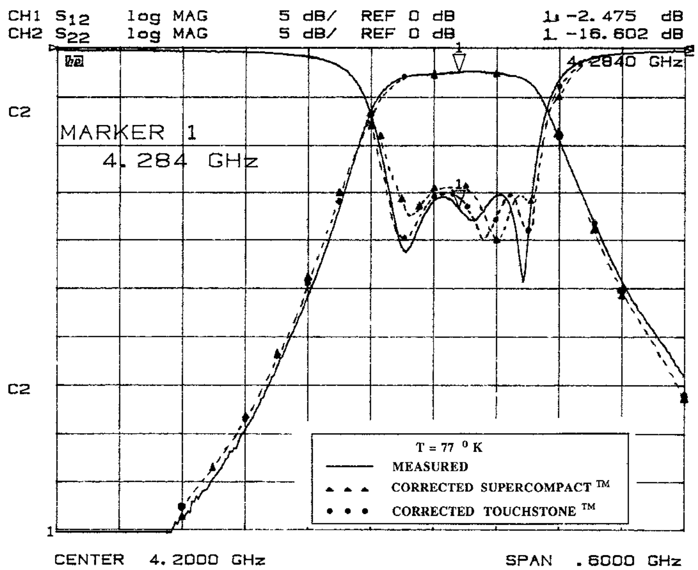

Figure 6. Measured Response at Liquid Nitrogen Temperature and Corrected CAD Simulations

Table 2. Coupled-Line 4-Pole Filter Design Parameters

	Design		Computed		Corrected	
Coupling	Z_{oe}	Z_{oo}	W (mil)	S (mil)	W (mil)	S (mil)
R	78.34	31.91	4.2	1.8	4.12	2.4
M(1,2)	49.3	43.9	8.6	33.6	7.46	41.0
M(2,3)	48.6	44.5	7.8	42.8	7.46	53.4