Characterization of Microstrip Discontinuities on $LaAlO_3$

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Abstract

The difference between microstrip coupled line filter designs using quasi-static and full-wave analyses on $LaAlO_3$ is discussed. Comparative data for CAD predictions and direct measurement for selected microstrip discontinuities on $LaAlO_3$ substrates is presented, as well as measured and predicted filter performance.

Introduction

The fabrication of high quality high-temperature superconducting (HTS) thin films depends on several important parameters. One of the parameters critical to the high frequency performance of the HTS films is the choice of substrate material. The material most commonly used is $LaAlO_3$ which has a loss tangent $\sim 10^{-4}$ at 77 K and $\epsilon_r \sim 23$ [1]. The low loss tangent makes this a reasonable substrate for high frequency applications.

Unfortunately, typical microwave analysis software has limited accuracy for substrates with dielectric constants greater than $\epsilon_r = 18$ [2]. Accurate analyses of filter elements are particularly affected by these limitations because of their interaction through substrate radiation. Proper design of a filter structure utilizing superconducting elements is extremely important because a major part of the insertion losses of the filter could be due to reflection losses.

Recent fabrication and testing has demonstrated problems with the design of parallel line coupled bandpass filters in the Ku frequency band on $LaAlO_3$. Previous filter design using the same procedures at X-band frequencies showed remarkable success [3], and compared well with the performance predicted by Touchstone [2]. The design of superconducting microstrip matching networks needed for low noise amplifiers (LNAs) or stable oscillators will have similar difficulties if the matching network uses coupling elements. In this paper we present data showing the difficulties mentioned above, and possible solutions to these problems.

Parallel-Coupled Bandpass Filter

The design of the filters was accomplished by standard techniques using a low-pass prototype to determine a set of even and odd impedances [4]. Impedence inverters must then be designed to satisfy the even and odd impedances required by the filter. One of the most common types of impedance inverters used is a pair of coupled microstrip lines.

There are several methods to used to design the physical dimensions of the coupled microstrip lines. Two widely used methods [5], [6] are implemented by Touchstone , however, these methods are quasi-static and the range of dielectric constant limited to $\epsilon_r < 18$. A comparison of coupled line performance between a full-wave analysis [7] and a quasi-static analysis [2] showed significant disagreement. A four-pole coupled line filter consisting of five ideal coupled line elements was designed for a center frequency of 13 GHz, 2% bandwidth, .001 db ripple. The effect of this disagreement is shown in Figure 1, where a single pair of filter elements in the 4-pole 2% ideal coupled line filter has been modified by the difference between the two analyses. This increased insertion loss is solely due to the increased reflection loss as a result of the the error in modeling the coupled line filter element.

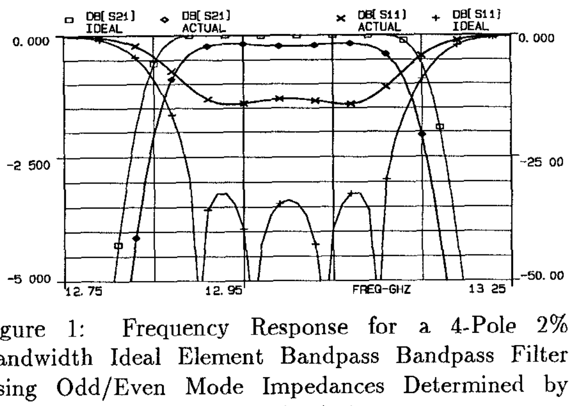

Figure 1: Frequency Response for a 4-Pole 2% Bandwidth Ideal Element Bandpass Bandpass Filter Using Odd/Even Mode Impedances Determined by Quasi-Static and Full-Wave Analysis

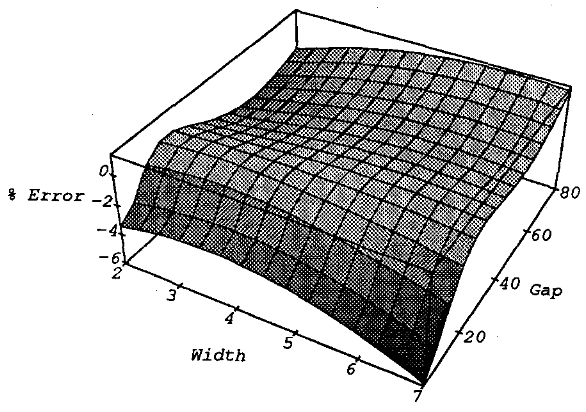

Figure 2: Error In Odd-Mode Impedance Calculated by Quasi-Static Analysis as Compared to Full-Wave Analysis (Dimensions in .001")

The difference between the two analyses when calculating the even and odd impedances of coupled microstrip lines is shown in Figure 2 and Figure 3 respectively. The data shown here is for a .020" thick $LaAlO_3$ substrate, and the widths and spacings are those most likely used in a 2% bandpass filter.

Filter Performance

We fabricated two filters using quasi-static designs with 2% and 10% bandwidth, .01 dB ripple, f_0=13 GHz, with gold (Au) and YBCO HTS material. All four filters showed poor performance with regards to ripple and return loss. Measurement performance of the gold 10% bandwidth filter is shown in Figure 4.

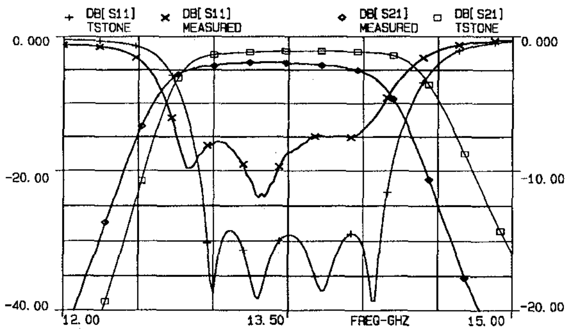

Figure 4: Comparison of Quasi-static and Measured Results for a 4-Pole Coupled-Line Microstrip Filter on $LaAlO_3$ Substrate

The performance was considerably different from the performance indicated by Touchstone. The primary reason for the poor performance predicted by quasi-static methods is the poor modeling of the coupling through the high dielectric substrate. A study of individual microstrip discontinuites reveals similar results.

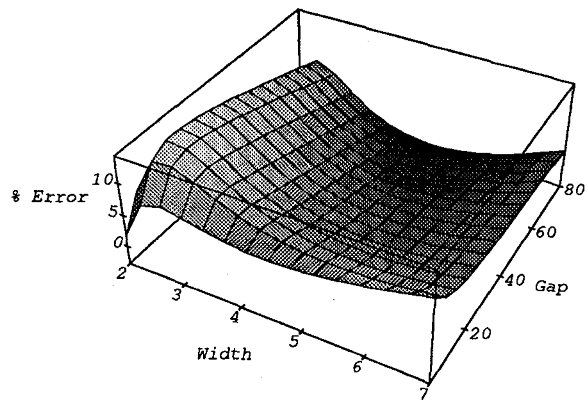

Figure 3: Error In Even-Mode Impedance Calculated by Quasi-Static Analysis as Compared to Full-Wave Analysis (Dimensions in .001")

A new design was performed using the results of full-wave analysis and a new filter was fabricated in Au on a .020" thick $LaAlO_3$ substrate. The performance predicted by full-wave analysis (loss-less case) is shown with the measured results Figure 5.

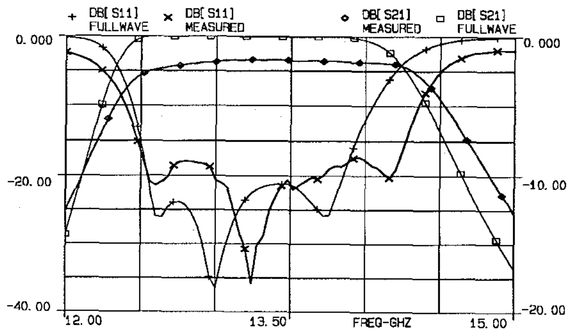

Figure 5: Comparison of Full-Wave and Measured Results for a 4-Pole Coupled-Line Microstrip Filter on $LaAlO_3$ Substrate

Microstrip Discontinuities

We selected for measurement, several microstrip discontinuities that would commonly be used for a microwave integrated circuit (MIC). The discontinuities selected were a gap, rectangular stub, radial stub, and parallel line DC block (Figure 6).

Individual microstrip discontinuities were fabricated on .020" $LaAlO_3$ substrates, measured in a modified Design Technique fixture, and calibrated with a two-tier LRL calibration procedure [8] [9]. All line widths leading to the discontinuities were .008". The gap element was .008" wide, the stub element .008" wide by .016" long, the DC block was .060" long with a .002" gap, and the

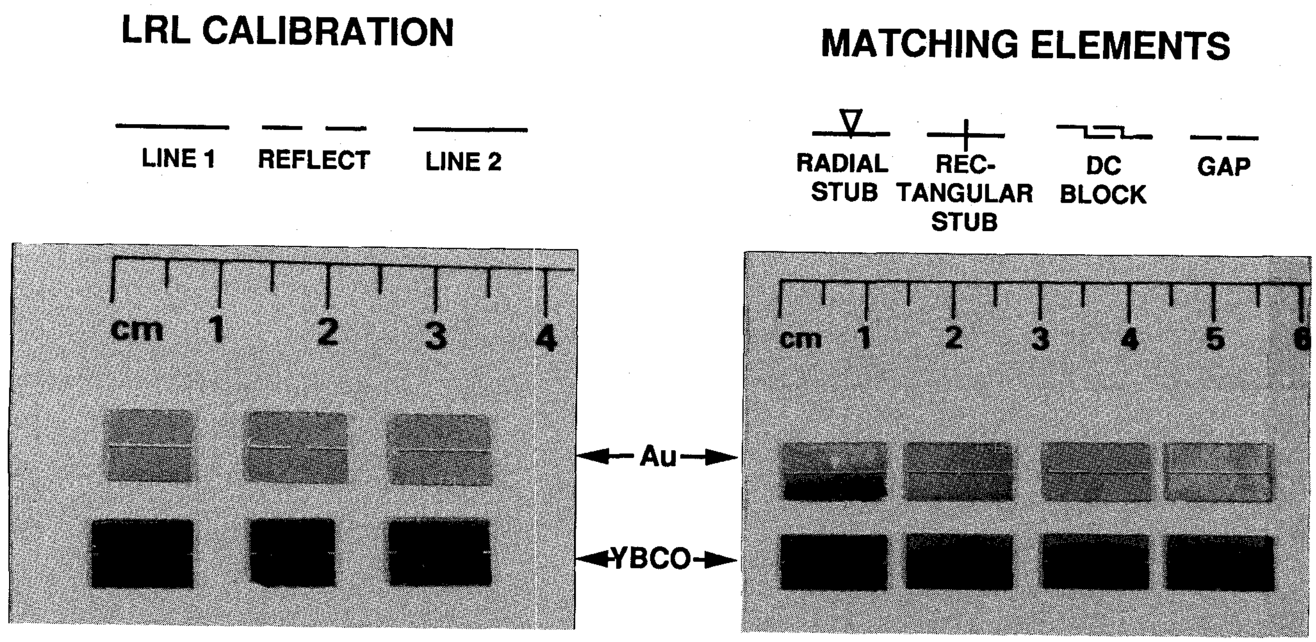

Figure 6: Microstrip Discontinuities

line stub dimensions were .065" x .002" x 45^0. Results for the DC block, gap, and stub elements are shown below for measured (MS***), full-wave analysis (EM***), and quasi-static analysis (TS***) in Figures 7, 8, and 9. The coupling of the gap is clearly over estimated by the quasi-static results, which correlates to the analysis of the coupled line structure. The agreement between the full-wave analysis and measurement of the DC-block is very good, demonstrating a different resonant frequency than that predicted by quasi-static analysis. The analyses and measurement of the radial line stub discontinuity show reasonable agreement, since the performance of the stub is not highly dependent upon substrate coupling.

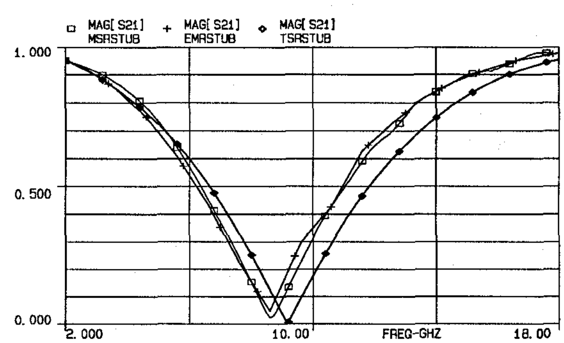

Figure 8: Comparison of S_{21} for a Radial Line Stub Structure (Au Film)

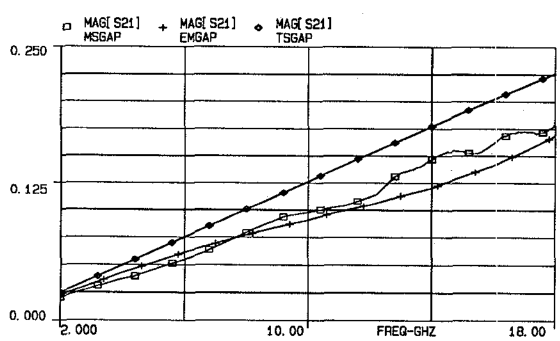

Figure 7: Comparison of S_{21} for a Gap Structure (Au Film)

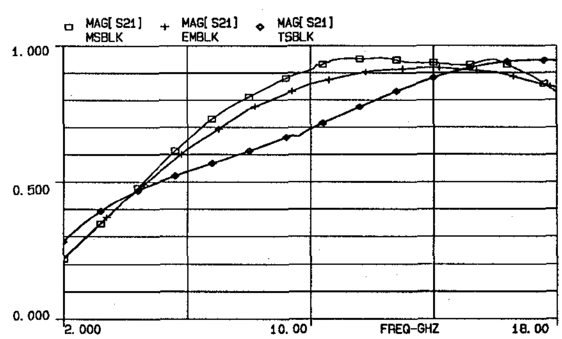

Figure 9: Comparison of S_{21} for a DC Block Structure (Au Film)

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