DESIGN OF HYBRID-COUPLED MULTIPLEXERS AND DIPLEXERS USING ASYMMETRICAL SUPERCONDUCTING FILTERS

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ABSTRACT

This paper demonstrates the feasibly of building high temperature superconducting hybrid-coupled multiplexers and diplexers employing filters with asymmetrical frequency characteristics. The design of pseudo-interdigital filters with improved skirt performance is discussed. Experimental and theoretical results are presented for superconducting filters, hybrids and a fully integrated C-band diplexer.

I. INTRODUCTION

The rapid advances in high temperature superconductivity (HTS) have promoted strong interest in the development of compact low-loss microwave multiplexers. There are several possible approaches for realizing multiplexers [1]-[2]. The most common, that are applicable to HTS thin film integrated technology, are manifold-coupled and hybrid-coupled. For extremely low-loss applications, the manifold-coupled approach is viewed as the obvious choice. However, as the number of channels increases, this approach becomes more difficult to implement due to design complexity and size limitations of commercially available HTS wafers. The hybrid-coupled approach, on the other hand, is amenable to a modular concept allowing ease of integration of a large number of channels.

In this paper, we discuss the use of HTS filters with asymmetrical frequency characteristics in the design of hybrid-coupled multiplexers and diplexers. The experimental results of HTS pseudo-interdigital filters built using double-sided HTS films are presented. The measured results for these filters are compared with theoretical results obtained using two different field-theory software packages. The measured performance of a HTS hybrid, designed with a layout that is ideal for use in such applications, is presented.

We also present experimental results for a fully integrated C-band hybrid-coupled diplexer constructed on a Lanthium Aluminate wafer of size 1.4"x1.4". The diplexer consists of three pseudo-interdigital filters and two hybrids. The channel filters have a percentage bandwidth of 4% and are separated by 200 MHz. We also address the effect of the non-uniformities of Lanthium Aluminate wafers on the design of HTS hybrid-coupled multiplexers/diplexers.

II. FILTER DESIGN

Most diplexer/multiplexer applications have stringent isolation requirements which necessitate the use of bandpass filters with transmission zeros (or attenuation poles) to provide high rejection where needed. In conventional Chebyshev bandpass filters, the transmission zeros exist at infinity thereby providing infinite attenuation. In view of [3], introducing extra coupling between non-adjacent resonators will bring some of these zeros into finite locations in the argand diagram, leading to better skirt performance.

We have designed and tested a 3-pole pseudo-interdigital superconducting filter having one attenuation pole on the high frequency skirt. The filter differs from conventional interdigital-type filters in that the short-circuited ends are replaced by open-ended quarter- wavelength lines. Figure 1 illustrates the isolation and return loss performance of the superconducting filter. The experimental performance at 300 K of the same filter realized using gold films is given in Figure 2. It can be seen that the superconducting filter offers more than 3.5 dB improvement in insertion loss performance.

The theoretical performance of this filter was computed using two field-theory simulators [4],[5]. The obtained results are shown in Figure 3. A good correlation is observed between these results and the experimental results given in Figure 2. It can be seen that the theoretical results obtained by both packages confirm the existence of a transmission zero at approximately 4.2 GHz. This zero is an inherent characteristics of this type of filter [6] and is attributed to the coupling which physically exists between the first and third resonators. However, it should be mentioned that this attenuation pole enhances the isolation performance on the upper frequency skirt at the expense of a slight rejection degradation in the lower frequency skirt.

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The location of the transmission zero, for this 3-pole filter, is given approximately by [6]:

$$f=f_0+(BW/2)K_{12}(K_{12}/K_{13})$$

where, f is the transmission zero frequency, f_0 is the filter center frequency, BW is the 3 dB bandwidth, K_{12} and K_{13} are the coupling factors between the resonator elements.

It can be seen that for an ideal Chebyshev filter ($K_{13}=0$), the transmission zeros will exist at infinity. However, in the case of pseudo-interdigital filters with moderate percentage bandwidth, where the resonators are relatively close to each other, one can make use of this extra coupling to improve the skirt performance of the filter.

III. HYBRID DESIGN

A 3-dB thallium HTS thin film superconducting hybrid was designed, built and tested. The four ports of this hybrid are arranged to fit within the diplexer layout described in section IV. The circuit was built using double-sided HTS thallium film on Lanthium Aluminate substrate. The experimental results of the scattering parameters S_{11} and S_{12} are given in Figure 4. Over a bandwidth of 400 MHz, the hybrid exhibits a return loss of 20 dB, a directivity of 23 dB and a + 0.3 dB deviation from the 3 dB coupling level.

IV. MULTIPLEXER AND DIPLEXER DESIGN

Consider the 3-channel multiplexer shown in Figure 5. Each channel consists of two identical filters and two identical hybrids. In order to demonstrate the advantages of using filters with asymmetrical frequency characteristics, let us concentrate on the isolation between channels 1 and 2. It can be readily seen that if we neglect insertion loss and multiple reflections between the various components, the isolation between these two channels can be approximated by.

Isolation measured at output port 1 = Rejection provided by channel 1 filters

Isolation measured at output port 2 = Rejection provided by channel 2 filters + Directivity of channel 1 input Hybrid and/or Return loss of channel 1 filters

The above two equations imply that channel 1 filters must provide higher rejection than that provided by channel 2 filters in order to achieve the same isolation value at the two output ports. The isolation between channels 2 and 3 can be described in this manner. Thus, the pesudo-interdigital filter structure described in section II will be suitable for use in such applications. This filter provides a high rejection on the high frequency side where it is strongly needed and a relatively low selectivity at other side where it is less needed.

We have built and tested an integrated C-band diplexer employing pseudo-interdigital filters. Figure 6 illustrates the diplexer layout. The whole diplexer was constructed on a double-sided Thallium wafer of size 1.4"x1.4". Channel 1 is realized using two filters and two hybrids while channel 2 is constructed using a single filter. The diplexer was designed using a computer-aided design algorithm consisting of an analysis package [4], and a optimization package [7]. The experimental results achieved are shown in Figure 7. It can be seen that the diplexer performs its intended function of separating the composite input signals into two channels. It should be mentioned that these results were obtained without the use of any tuning mechanism.

One of the major considerations in the design of thin film hybrid-coupled multiplexer/diplexers is the phase deviation between the two filter paths which the two signals undergo before they add constructively at the channel output. Defects in the Lanthium Aluminate wafer in the form of non-uniformities or twining may lead to a substantial deviations in the performance of the two identical filters which in turn may degrade the overall performance of the multiplexer.

We have tested a number of identical thallium, YBCO and gold film pesudo-interdigital filters having a percentage bandwidth of 4 % printed on lanthium Aluminate wafers. No substantial deviation is observed between filters printed on the same wafer, and only a slight deviation in observed between filters printed on different wafers. The effect however of this problem on the design of HTS filters with extremely narrow bandwidth (< 1 %) remains to be investigated.

V. CONCLUSIONS

The extra coupling which exists between non-adjacent resonators in pseudo-interdigital filters may be used to improve the rejection performance on the high frequency skirt. Filters with such rejection performance are suitable for use in the design of HTS hybrid-coupled multiplexers and diplexers. The experimental results reported in this paper for superconducting filters, hybrids and a fully integrated C-band diplexer demonstrate the possibility of building such components with no tuning elements. The technique used may be extended to realize HTS multiplexers having a large number of channels.

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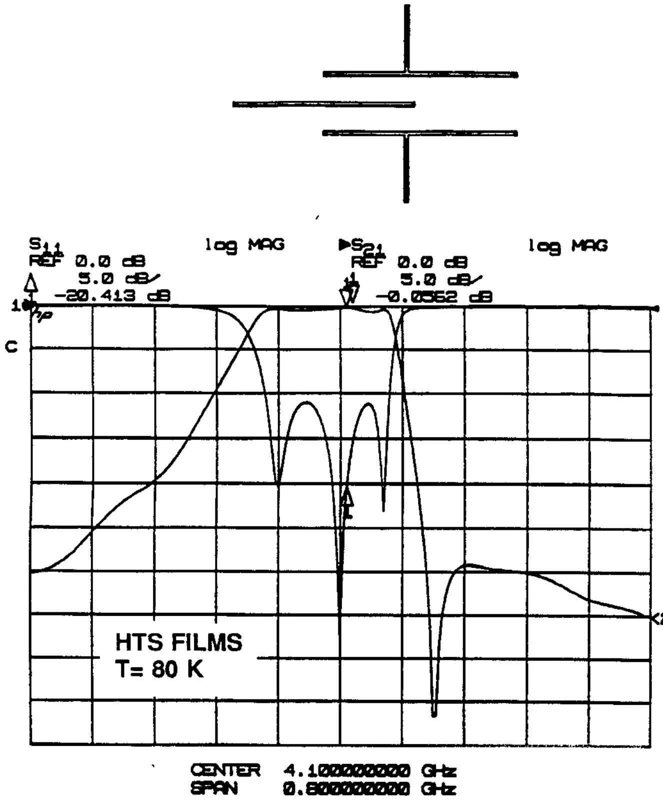

Figure 1. The experimental performance of a superconducting 3-pole pesudo-interdigital filter (HP8510 calibrated at 300 K).

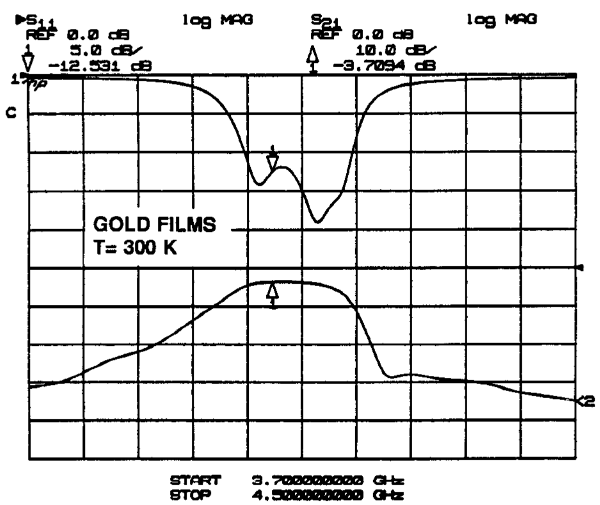

Figure 2. The experimental performance of a similar gold film filter measured at 300 K.

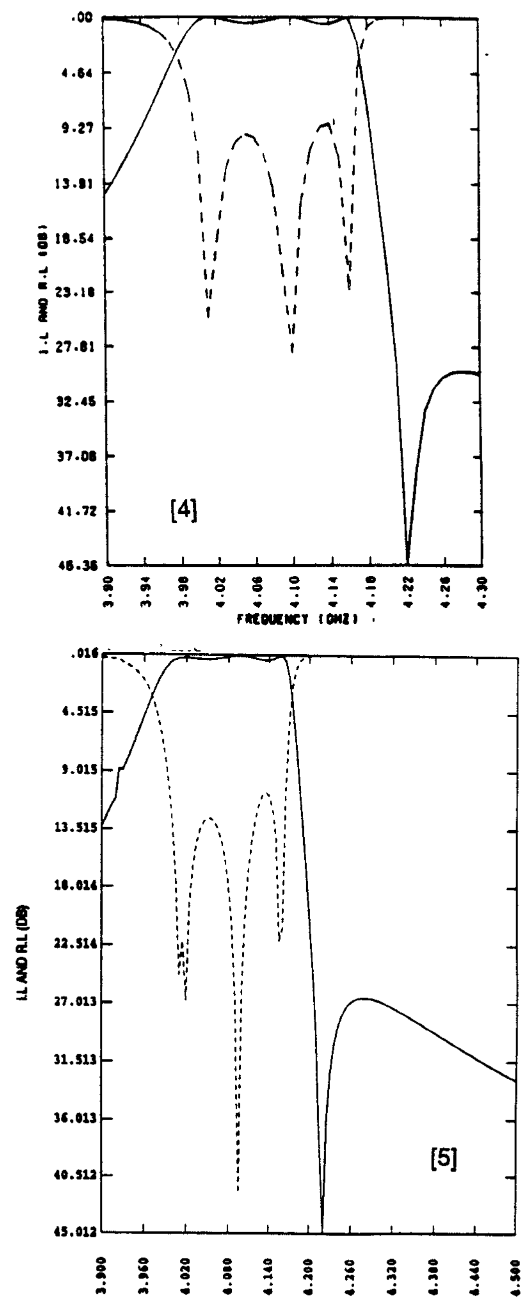

Figure 3. Theoretical results for the superconducting filter shown in Figure 1 obtained using two different field-theory packages [4] and [5].

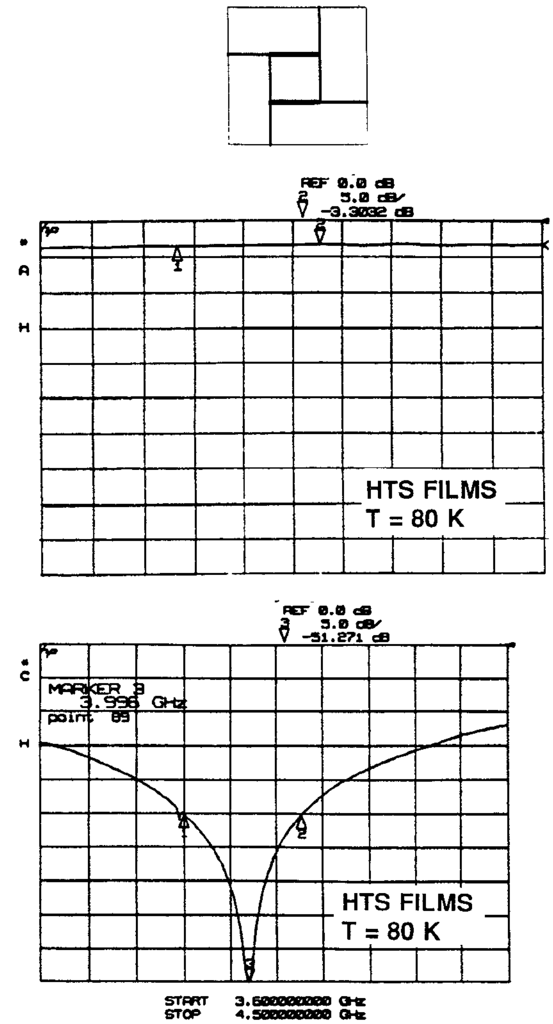

Figure 4 The experimental results of a 3.0 dB HTS thin film hybrid at 80 K.

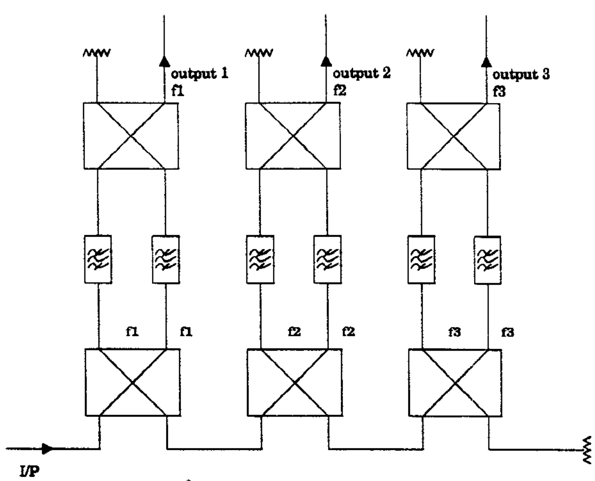

Figure 5 A schematic diagram for a 3-channel hybrid-coupled multiplexer.

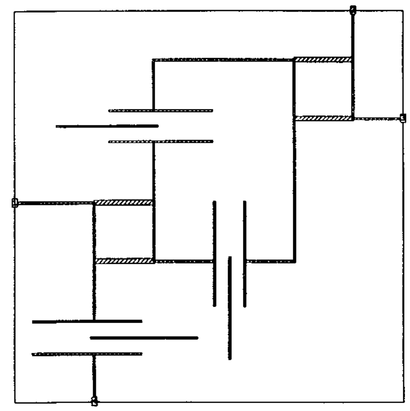

Figure 6. A layout of a fully integrated C-band superconducting diplexer realized on a Lanthium Aluminate wafer of size 1.4" x 1.4".

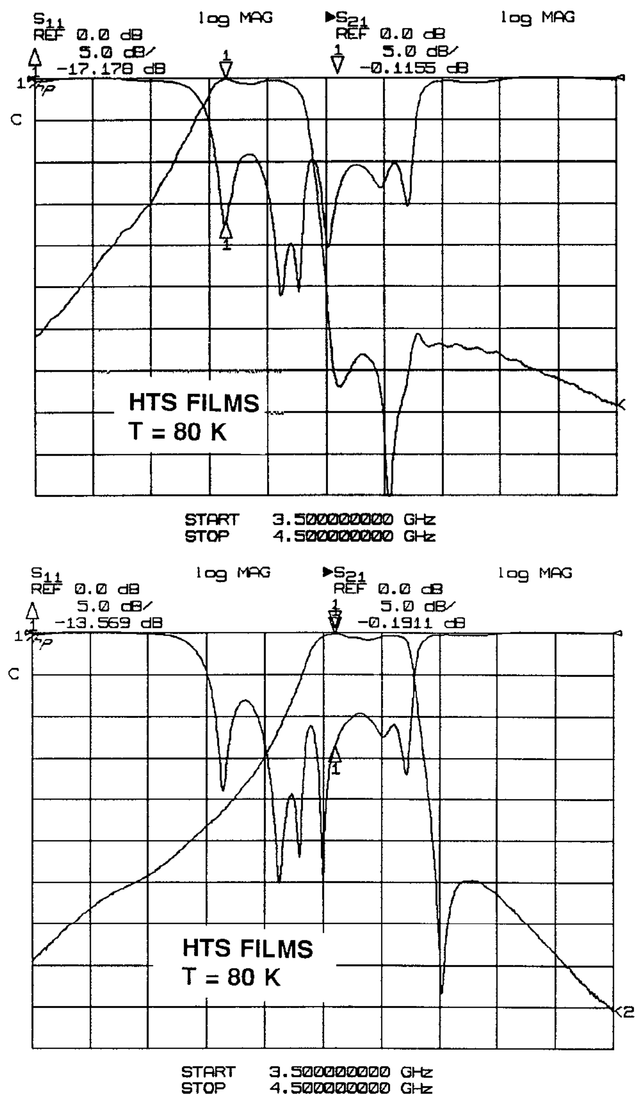

Figure 7. The experimental results for a fully integrated C-band diplexer realized on a double sided Thallium wafer. (HP8510 Calibrated at 300 K).