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# Low-Profile Multilayer YBCO/MgO Filter Module

Raymond S. Kwok, S. Jerry Fiedziuszko, Torsten Schnabel
Space Systems/LORAL, Palo Alto, CA., USA

Felix A. Miranda, Nick C. Varaljay, Carl Mueller
NASA Lewis Research Center, Cleveland, OH., USA

## ABSTRACT

Multilayer dual mode HTS filter is the smallest known high-performance filter structure, occupies less than 1% in volume as compared to the state-of-the-art dielectric resonator counterpart. It can also be manufactured in form of a flat-pack surface mounted flip-chip module suitable for integration with other components in a cryogenic payload. In this presentation, we report recent advances made in the areas of design and packaging of this vertically stacked multilayer filter. A C-band 4-pole quasi-elliptical bandpass filter in its smallest configuration, implemented using either gold (Au) or YBCO thin film dual mode patch resonators on magnesium oxide (MgO) substrates, will be presented.

## INTRODUCTION

Quasi-elliptical dual-mode cavity and dielectric resonator filters are commonly used in today's satellite multiplexer applications. Although these filters provide superior performance, they are highly labor intensive to produce and have the drawbacks of relatively large size, mass and high production cost. Dual-mode HTS planar filter structures were then proposed as the next generation filter solution [1]. With an advanced cryogenic refrigerator that generally can support a number of filters and other RF components, a 24-channel multiplexing payload, for example, would have less weight, smaller size and improved performance. Among these new structures, the multilayer stacked filter offers the smallest size because it does not require a metal enclosure [2]. More importantly, it can be easily integrated onto the same substrate with other superconducting and semiconducting components. Progress has been made to transform this technology closer to reality. A C-band 4-pole multilayer bandpass filter fabricated with thin films of $YBa_2Cu_3O_{7-\delta}$ (YBCO) on MgO substrates is realized in the "chip" module as a stand-alone product. This filter is compact, having a volume of 0.46 $cm^3$ which represents less than 1% of the volume of dual mode cavities or dielectric loaded resonators (~400 to 2000 $cm^3$). The development, fabrication, testing, and performance of this filter will be discussed.

## YBCO FILM ON MgO

There has been concerns among the researchers in this field regarding the use of the $LaAlO_3$ substrates for YBCO-based microwave components because of the formation of twin boundaries [3], variation in dielectric constant [4], and surface roughening after the HTS deposition process [5]. Other lower loss-tangent substrates such as sapphire [6] and MgO [7], among others, have been considered as an alternative. The latter was chosen for this study because it is twin free and has an isotropic permittivity.
The YBCO on MgO thin films used in this work were obtained from a commercial vendor. The films were grown by thermal coevaporation, and were ~500 nm thick as measured using a surface

profilometer. Before patterning, the films exhibited $T_C \geq 87$ K as determined by using a standard four-probe DC measurement technique. Patterning of the circuits was done at NASA LeRC by chemical etching (etch-back) using diluted phosphoric acid ($H_2O$:$H_3PO_4$;100:1 concentration). Gold versions of the filters were also fabricated at LeRC using electron beam evaporation. The metallization process consisted of 15 nm adhesion layer (either chromium or titanium), followed by a 2.5 μm thick Au layer.

## PACKAGING

A schematic representation of the filter under discussion is shown in Fig. 1. The filter consists of two dual mode patch resonators stacked together in a multilayered configuration. Coupling between the layered resonators is achieved through the slot iris. Coupling between the orthogonal mode of each resonator is achieved through a 45° cut on a corner of the patch resonator. The RF signal is fed to the bottom layer through feed lines directly coupled to the resonator.

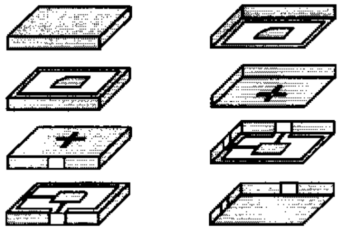


Fig. 1 – Physical layout of a 4-pole dual mode multilayer filter.

It has been reported that stacking of hard substrates, such as MgO and $LaAlO_3$, may introduce interface and grounding problems which result in considerable deterioration of the filter performance [5]. To improve electrical contact between layers, the circuit patterns are mirrored on both sides of a substrate. Dimensions of the patterns are adjusted to allow for slight misalignment in stacking the layers. A gold film was also e-beam evaporated at the edges of each substrate to provide a common ground of the structure. The layers are then pressed together in a custom made aluminum fixture and tested at room and cryogenic temperatures. Figure 2 shows the test fixture inside the vacuum chamber bolted to the second stage of a closed-cycle helium gas refrigerator. The finalized substrates are then glued together using a thermally-match, non-conductive epoxy. By doing so, the deliverable filter is a stand-alone device. The input / output interface can also be modified to a number of configurations for various integration schemes.

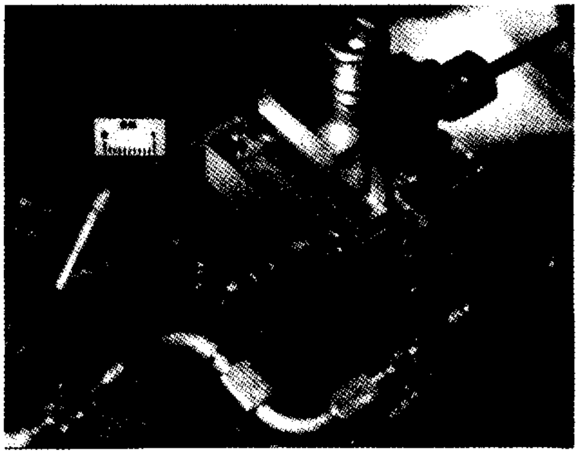

Fig. 2 – Preliminary testing of a multilayer filter inside the vacuum can of a closed-cycle helium gas refrigerator.

## FILTER DESIGN

A 4-pole quasi-elliptical bandpass filter design, with center frequency of 6 GHz and 3% bandwidth, is chosen for this experiement. The normalized input / output resistance are 1.2417. Coupling coefficients are $M_{12}=M_{34}=0.9961$, $M_{23}=0.9222$, and $M_{14}=-0.2778$. Couplings are achieved by the 45° corner-cut or through the iris. Position of the 45° corner-cut determines the sign of the coupling strength. Coupling strength can be calculated by a number of numerical methods [8-11]. Figures 3 and 4 show the coupling coefficients evaluated by a commercial FDTD software [12] at 6 GHz. Substrates are 0.500" x 0.500" x 0.020". Patch resonators are basically 0.300" x 0.300" squares with 45° corner-cut.

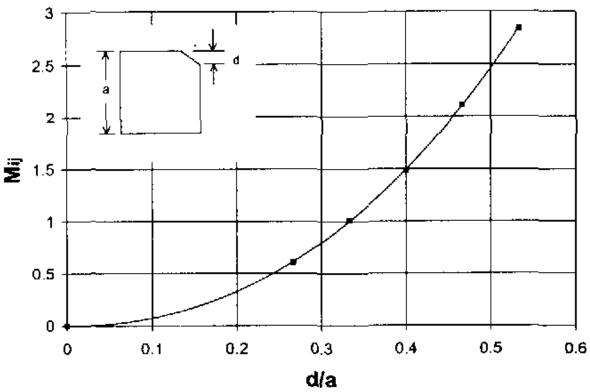


Fig. 3 – Normalized coupling coefficient as a function of the size of a corner-cut, calculated by a commercial FDTD em simulator.

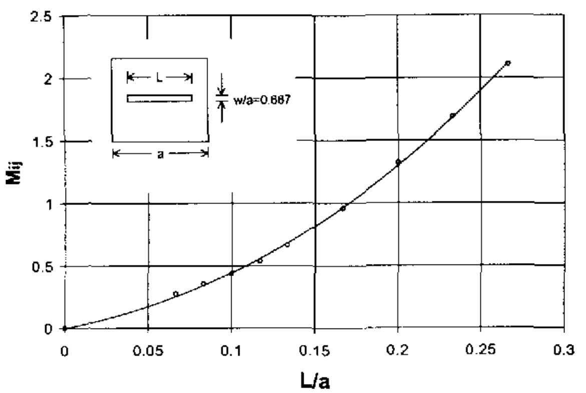


Fig. 4 – Normalized coupling coefficient as a function of the length of a slot iris, calculated by a commercial FDTD em simulator.

## EXPERIMENTS

The transmission coefficient $|S_{21}|$ of the gold version multilayer filter measured at room temperature is shown in Fig. 5. The insertion loss and return loss at the band center is about 3.5 dB and 15 dB, respectively. The two finite transmission zeros are clearly shown as predicted by the prototype circuit.

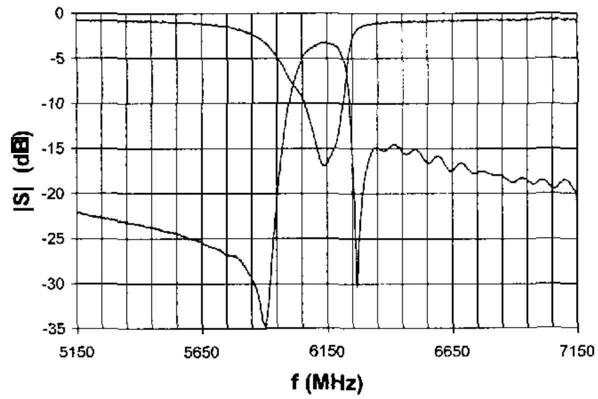


Fig. 5 – Measured Return Loss and Rejection of the Au/MgO multilayer test filter at room temp.

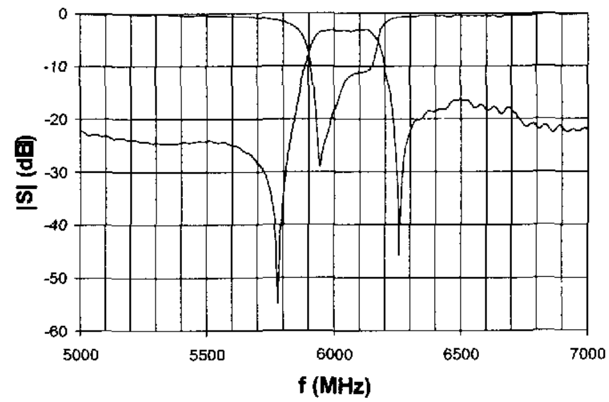


Fig. 6 – Measured Return Loss and Rejection of the YBCO/MgO multilayer filter at 77K (LN).

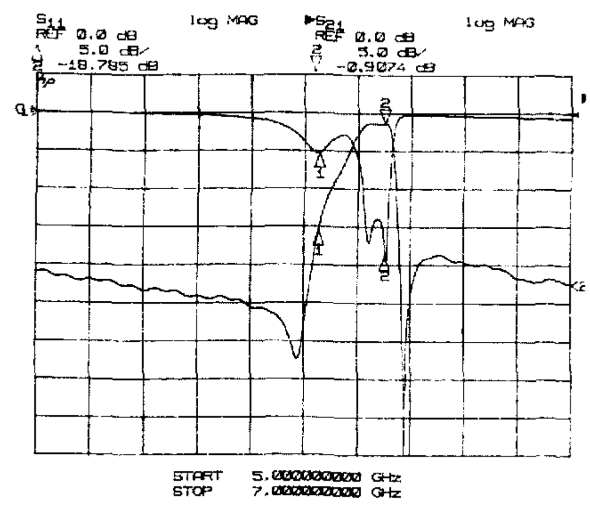


Fig. 7 – Measured Return Loss and Rejection of the YBCO/MgO multilayer filter at 77K vacuum.

The performance of the YBCO version of the filter measured at 77K in liquid nitrogen and in vacuum are shown in Figures 6 and 7 respectively. Insertion Loss as low as 0.9 dB is evidenced even though the design was not fully optimized However, with no tuning capability on this miniaturized design, measurement at low temperature has been very inconsistent. Alternations in contact resistance, layers alignment, orientation of the patch resonators as well as film and substrate variations need to be better managed.

The multilayer filter can also be physically glued together using a thermally-match, non-conductive thin adhesive layer. Such techniques have been successfully applied to convention microwave substrates as well as multilayer circuits of Low Temperature Superconductors. A prototype of this "chip" module filter made of Au/MgO is shown in Fig. 8. The corresponding YBCO/MgO counterpart is being fabricated. Measurement of these filter modules at various temperatures will be presented.

Fig. 8 – A stand-alone multilayer filter chip.

## CONCLUSIONS

The proposed multilayer filter, when fully optimized, can replace existing filters in most of our satellite applications. The benefits include dramatic size and weight savings combined with excellent electrical performance. Further developments in the multilayer technology are needed. However, reported results are quite encouraging.

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