HYBRID DIELECTRIC/HTS RESONATORS AND THEIR APPLICATIONS

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ABSTRACT

Interest in HTS material applications has exploded in the past few years fueled by continuing progress in superconductor fabrication techniques. However, in typical microwave structures utilizing these materials in the form of thin films, HTS compatible dielectric substrates and their dielectric losses are a performance limiting factor. This paper presents a novel concept of using dielectric resonators in conjunction with HTS materials. This hybrid approach offers several advantages: dielectric resonator materials have extremely low losses at cryogenic temperatures, reduced size in comparison to traditional dielectric resonators, exceptional temperature stability, tunability, and versatility (any HTS material can be easily substituted in the proposed filter structures).

Basic dielectric /HTS resonator structures are shown. Novel filter configurations utilizing these resonators and experimental results are presented.

INTRODUCTION

Introduction of practical HTS materials has sparked a tremendous amount of research into potential applications for this important new technology. A natural target for this attention is in the microwave components field, where resistive losses are severe. Current HTS materials (thin films in particular) offer the possibility of over two orders of magnitude improvement in resistive losses. These losses are usually small in conventional microwave circuitry, but are crippling in narrowband filter applications, as are used on satellite communications transponders.

Filters and multiplexers are a major contributor to the weight, size, cost, and power dissipation of the satellite. In a typical transponder, there are often at least 50 narrowband filters, each using a bulky waveguide design. With the size reductions possible in other(active) components, these filters are a true stumbling block to radical miniaturization of the satellite transponder. If HTS materials could be used in these applications in a reasonable way, considerable savings in size, mass, power dissipation, and cost might be achieved. In this paper, a novel technique combining the low electrical resistance of HTS materials and the size reductions available using dielectric resonators is presented.

HYBRID DIELECTRIC /HTS RESONATORS

In the past, a number of different filter configurations based on high dielectric constant, low loss ceramics have been developed[1,2,3]. These techniques involved suspending a cylindrical resonator inside a waveguide cavity below cutoff. One of the basic advantages of a dielectric resonator as compared to a dielectric filled cavity is the significant reduction of conductive losses affecting the overall Q factor of the structure. Evanescent fields outside of the dielectric resonator practically vanish of a properly designed metal enclosure of the resonator.

Therefore dielectric losses (loss tangent) dominate and determine the Q factor of the dielectric resonator. However, such a structure is somewhat larger than a same frequency metal wall cavity filled with a similar dielectric. Using traditional metals for partial walls of the dielectric resonator and creating "post" dielectric resonators, quarter, or half cut image resonators results in significant degradation of the Q factor due to conductive losses in partially metal coated dielectric resonators. Typical modes used and their field distributions are shown in Figure 1. These resonators can be easily designed using published formulas[4,5,6]. Using newly developed HTS materials practically eliminates conductive losses and the excellent dielectric properties (Q factor) of the typical structures are retained. This is the basic idea for hybrid dielectric/HTS resonators. Utilization of these resonators further reduces the size and weight of the filter structures, due to reduced size of the enclosures. Such reductions are very important in size and weight constrained satellite applications.

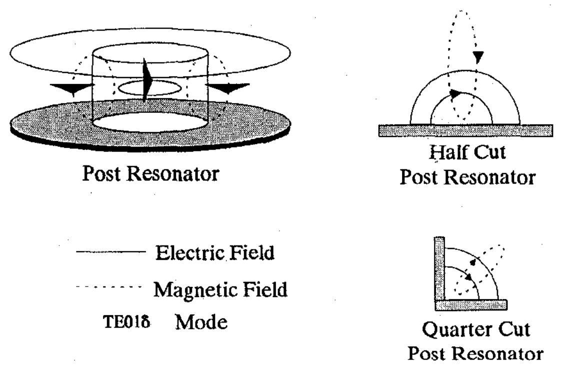

Figure 1 Field Distributions for Various Dielectric Resonator Configurations

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A great deal of research into HTS fabrication has been spent finding suitable substrate materials and developing reliable methods of thin film deposition. Recent developments have produced good films, typically on Lanthanum Aluminate or a related compound. However, these substrate materials seriously degrade device performance due to their relatively high loss tangent. Recently ceramics from a number of companies have shown exceedingly high Q factor at low temperatures. Figure 2 shows the Q factor of a Er=25 ceramic over a range of temperatures. Kobayashi[7] has reported that this type of ceramic can achieve Q factors of over 140,000 at 77K. This characteristic has been used to measure the quality of HTS films[8]. Virtually eliminating dielectric losses leaves only dissipation due to the finite conductivity of the cavity walls. Either the cavity can be enlarged(limited by waveguide moding) or the metal walls replaced with HTS material. HTS walls are particularly attractive since they can be placed directly in contact with the dielectric with little degradation of performance, producing a highly miniature, extremely high Q resonator. In addition, the HTS substrate itself may be of any material.

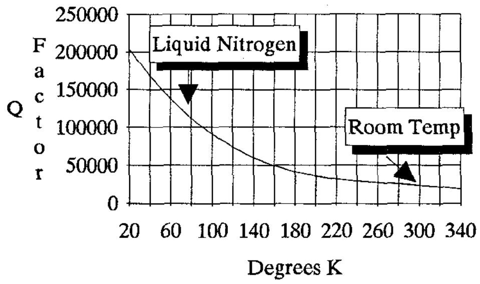

Figure 2 Q Factor of High Dielectric Constant Ceramic

FILTER CONFIGURATIONS

Since HTS thin films have been primarily deposited on flat substrates, the filters presented use HTS on the ends of the resonators only. They are optimized to concentrate the fields most strongly in the HTS regions.

Figure 3 shows the configuration of a 3 pole hybrid dielectric resonator post filter using HTS material. The TE011 mode provides one pole per resonator and has the advantage of its fields being strongest at the endwalls, maximizing the effect of the HTS conductivity. Q factor expected for this filter using a high quality thin film is over 50000 at 77K, where reflection losses will be dominant. Figure 4 shows a half cut dielectric resonator filter. The design has the advantage of requiring only one side with HTS material, reducing size and cost at the expense of lowered Q factor. An further extension of this idea is to cut the resonator down to quarter size, offering the minimum volume, but with two sides of HTS and reduced Q factor. A further advantage of the quarter cut design is the effective elimination of spurious HE modes. This type of design has been used at low frequencies for cellular ground stations [9]. Any of these designs may be easily extended to include non-adjacent resonator couplings through simple mechanical means and are thus suitable for steep satellite channel filters.

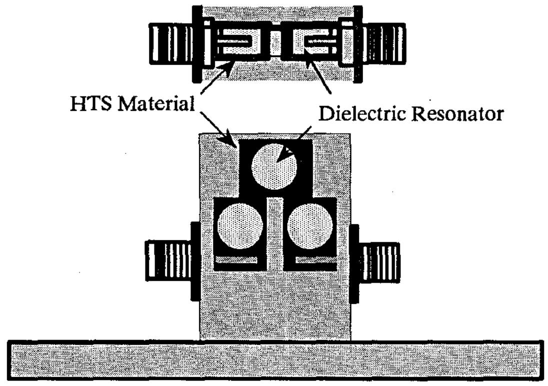

Figure 3 Single Mode Post Dielectric Resonator/HTS Filter

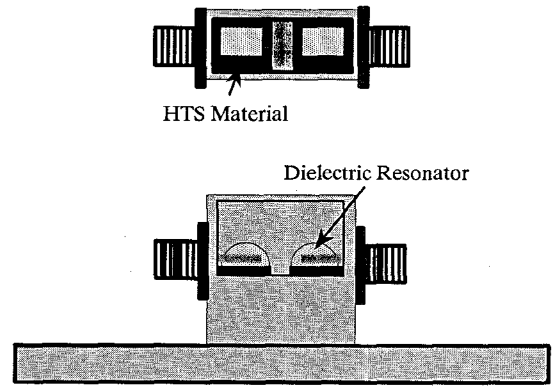

Figure 4 Single Mode Half Cut Dielectric Resonator/HTS Filter

Current waveguide and dielectric resonator designs often use dual mode (two poles per physical resonator) cavities to reduce size and weight. Figure 5 shows an HTS/Dielectric resonator hybrid design using the HE111 dielectric resonator mode(two orthogonal modes per cavity). In this case, no HTS is used between the resonators to allow interresonator coupling, although an alternate design might place a superconducting substrate with a coupling slot between the resonators to minimize size.

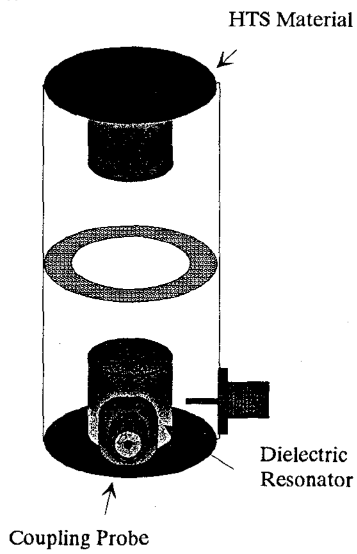

Figure 5 Dual Mode Dielectric Resonator/HTS Filter

EXPERIMENTAL RESULTS

A number of dielectric resonator filters were fabricated for the Naval Research Laboratories' High Temperature Superconductor Space Experiment(HTSSE). A three pole Chebychev design was chosen for a single mode post design. Testing took place by initially using substitute copper substrates to rough tune the filter and to size the resonators. Final tuning involved installing the HTS substrates and tuning the filter while cooled with liquid nitrogen. This technique resulted in an excellent , well tuned filter characteristic. Figure 6 shows the passband performance of the single mode dielectric resonator/HTS filter. Figure 7 depicts the flight single mode filter. Center band loss is .2 dB, with large improvements possible using better HTS films as well as with a somewhat larger cavity enclosure. A two pole half cut resonator design also demonstrated excellent performance, as shown in Figure 8. Figure 9 shows the flight half cut filter.

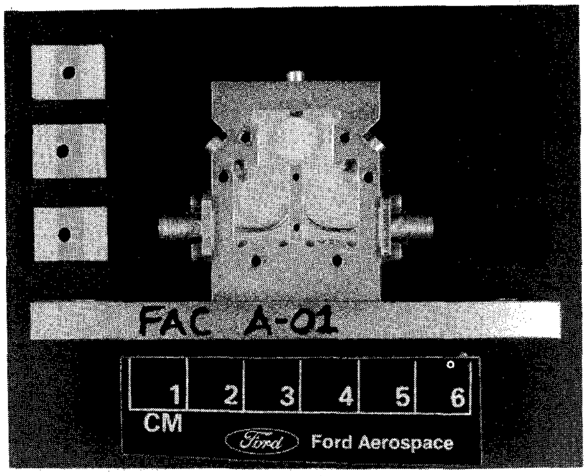

Figure 7 Flight Model Single Mode Post Dielectric Resonator/HTS Filter

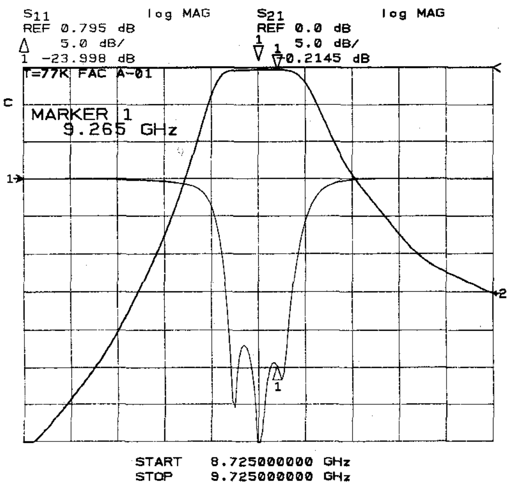

Figure 6 Measured Performance of Single Mode Post Dielectric Resonator/HTS Filter

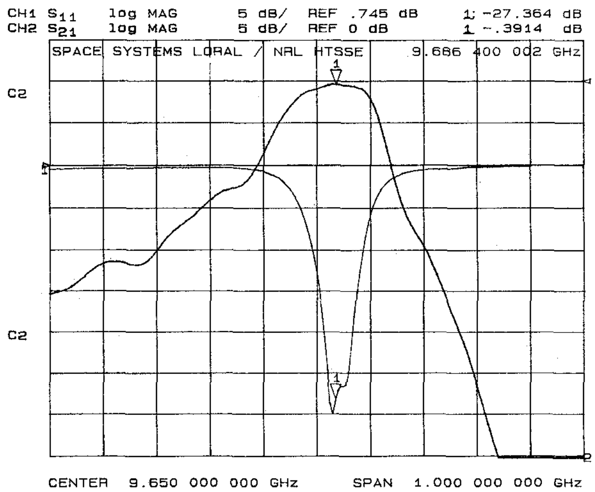

Figure 8 Measured Performance of Half Cut Dielectric Resonator/HTS Filter

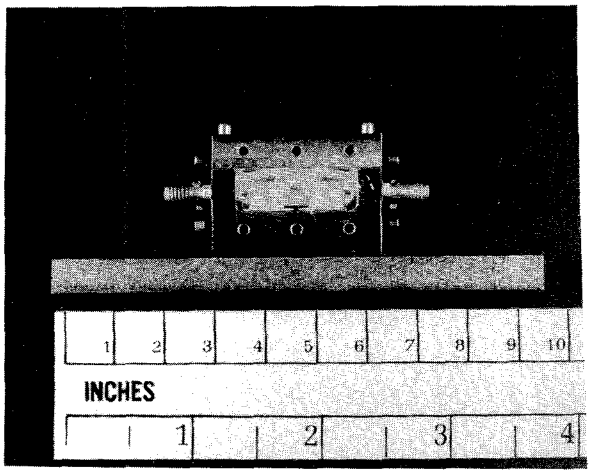

Figure 9 Flight Model Half Cut Dielectric Resonator/HTS Filter

CONCLUSION

A novel technique for realizing extremely high performance, compact filters has been demonstrated. This dielectric resonator/HTS combination offers a variety of advantages for use in narrowband filter applications, where high Q factor and precise alignment are required. Table I shows a comparison of various HTS filter techniques.

Clearly, further advances in this technology are fundamentally controlled by the development of higher Tc superconductors. In addition, processing technologies, especially for the microstrip designs is of utmost importance. The HTS/dielectric resonator filters described here offer a relatively small and low cost alternative which exhibits exceptionally high performance.

ACKNOWLEDGEMENTS

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Table I Comparison of HTS Filter Designs

Resonator Type	Size	Loss	Cost	Temperature Stability	Tunability
Microstrip	Small	Moderate	Low in quantity High in small lots	Poor	Poor
Cavity	Large	Very Low	High	Fair	Good
Dielectric Resonator	Small	Low	Moderate	Excellent	Excellent