Multi-Stage Dual-Mode Cross-Slotted Superconducting Filters for Telecommunication Application

A. Cassinese[a)], M. Barra[b)], G. Panariello[c)] and R. Vaglio[a)]

[a)]INFM and Dipartimento di Scienze Fisiche Università di Napoli Federico II, Napoli, Italy

[b)]Dipartimento di Elettronica e Telecomunicazioni Università di Napoli Federico II, Napoli, Italy

[c)]D.A.E.I.M.I. Universita' di Cassino, Cassino, Italy.

***Abstract* — Dual mode high temperature superconducting (HTS) filters represent an interesting device class for telecommunication application since they combine a high power handling capability with a miniaturized size. Here we report on the design and realization of dual mode cross slotted filters presenting a more compact size if compared with the traditional dual mode patch filters. Single stage filters operating in C-band with 1% fractional bandwidth have been designed and tested at prototype level by using double sided ($YBa_2Cu_3O_{7-x}$) YBCO and $Tl_2Ba_2Ca_1Cu_2O_8$ (Tl-2212) superconducting films grown on $LaAlO_3$ substrates. The YBCO filter presents insertion losses IL=1dB and a power handling higher than 10dBm at T=77K while the Tl-2212 allows to operate at higher temperatures with comparable performances. Dual stage (four poles) and four stage (eight poles) filters with 1% fractional bandwidth operating in C–band and presenting a Chebychev or a quasi elliptical response have been analyzed. Finally, a four stage filter well fitting on a 1"x 1" substrates was designed.**

I. INTRODUCTION

In communication systems, there is currently a considerable interest for filters realized with high temperature superconductors (HTS) since they present, significantly improved performances, lower power dissipation and miniaturized size [1]. However, the properties of HTS filters degrade with increasing power due to the nonlinear nature of the surface resistance (Rs) of HTS which increases with the circulating r.f. current. This degradation is enhanced in miniaturized structures and a compromise between size and power handling has to be reached depending on the specific application [2]. In this respect, dual mode filters represent an interesting structure to exploit. In fact, since two modes are used in a single element, this gives a size advantage and the widely-spread current distribution gives a good power handling.

Here we report on the realization of cross slotted dual mode filters, [3] realized using superconducting films grown on $LaAlO_3$ substrates.

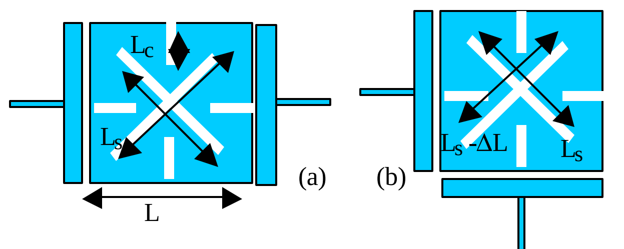

Fig. 1 Top view of the dual mode (a) resonator and (b) filter.

II SINGLE STAGE FILTER

The top view of the dual mode designed is shown in Fig 1 and described in detail in ref. 4-5. Briefly, the basic single mode resonator is a LxL square patch (fig.1 a) diagonally crossed by slots (L_S) long and by a transverse cut (L_C) on each side of the patch. Due to the cuts, the fundamental frequency is shifted downward increasing the slot length, since the r.f. current path increases accordingly. If compared with the patch resonator (L_S=L_C=0) a frequency reduction of 40% is obtained in case L_S=L and L_C=L/3. The resonator is capacitively externally coupled through two stubs. The external quality factor Q_{ext} and the insertion losses IL of the resonators are shown as a function of the gap between the stubs and the resonator in Fig. 2. The simulated response was obtained using ENSEMBLE, an EM simulator based on the 2.5 dimensional moment method. The resonators and the ground plane are assumed as perfect conductors deposited on 0.5 mm thick substrates with dielectric constant ε_r=23.4-24. The coupling between the two modes is achieved by using an adequate difference (ΔL) between the two slots and placing the feed lines at 90° (fig.1b). The transmitted power S_{21} as a function of frequency for different values of ΔL is reported in Fig 3. Ideally, there is no coupling between the two modes with ΔL=0. The simulation shows that in this case S_{21} is lower than – 30 dB, with a good isolation between the two modes.

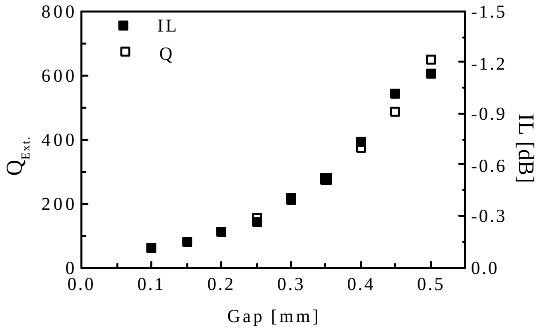

Fig. 2. External quality factor Q_{Ext} and insertion loss IL as a function of the capacitive gap for the *cross slotted* resonator.

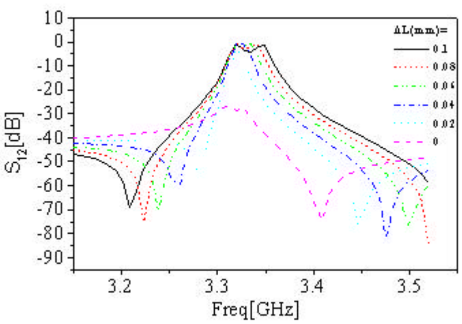

Fig. 3. Simulated frequency response (S_{12}) of the dual mode filter as a function of the parameter ΔL (see text).

Nevertheless, some weak parasitic coupling between the two modes is still present, likely to be ascribed to the asymmetrical arrangement of the two external lines. Increasing ΔL from 0 to 0.1 mm, S_{21} first moves rapidly upward to – 0.1 dB and then it splits in two visible peaks. Increasing the difference between the slots length, the resonance for one of the modes remains constant, while the other linearly drops off. The presence of transmission zero point at finite frequencies is related to the cross talk between the pads and the resonator. The possibility to change the position of the attenuation zero can be achieved by changing the dimension of the pads. C-band single stage filters have been designed and realized using high quality 360nm thick YBCO film grown by coevaporation technique and $Tl_2Ba_2Ca_1Cu_2O_8$ (Tl-2212) 1000nm thick films grown by MOCVD technique, reported in more details elsewhere [4,6].

The basic resonator is a 6x6 mm^2 squared patch, crossed with L_S= 6mm , L_e=2mm long and w=0.17mm wide. The difference between the two slots is ΔL=0.06 mm corresponding to a filter with 1% fractional bandwidth. The gap between the stubs (0.6 mm wide and 6 mm long) and the patch was 0.1mm. A typical response observed on YBCO filters at T=77K is reported in fig. 4 and compared with the simulated response. The YBCO presents at T=77K (T=4.2K) insertion losses IL=1.1 dB (0.5 dB) respectively. The coupling between the modes is temperature dependent as expected, showing in some cases an enhanced ripple. However, no tuning screws were used in order to optimize the response. The insertion losses IL as a function of the temperature are reported in fig.5 for both Tl-2212 YBCO filter. The losses of the Tl-2212 device are lower than YBCO filter for T ≥ 85 K, in good agreement with the R_s(T) behavior of the two materials measured at 87 GHz (see inset of fig.5). It should be noted that at 90 K the losses for the Tl filter are IL=3dB, still lower than those obtained in case of filter realized with 1μm gold (IL=10dB) while, at the same temperature, the YBCO filter is already in the normal state. It is worth to mention that the possibility of increasing the operation temperature of HTS devices can open the road to the development of more miniaturized and lightly closed-cycle coolers, making more attractive the realization of superconducting systems for mobile and satellite applications.

In fig. 6, IL as a function of the input power for both Tl-2212 and YBCO filters measured at T=77K and T=4.2K are reported. The Tl-2212 filter presents at both temperatures a lower power handling in respect to YBCO which can be ascribed to the granular nature of the films. However. no relevant changes have been observed on both filter response up to 5 dBm and a minor degradation have been observed up to 10 dBm.

III. MULTI STAGE DUAL MODE FILTER

The layout of the dual stages (four poles) dual mode filters analyzed is shown in fig. 7. The couplings constant K12=K34, as a function of ΔL on the single patch, and K23 evaluated as a function of the distance d between the two resonators, are reported in fig. 8. In order to refer all the couplings to the same center frequency, f_0, both slots of each patch are symmetrically changed. As is shown in fig. 7 the first and fourth slots are L+ΔL/2 long while the others are L2=L-ΔL/2 long.

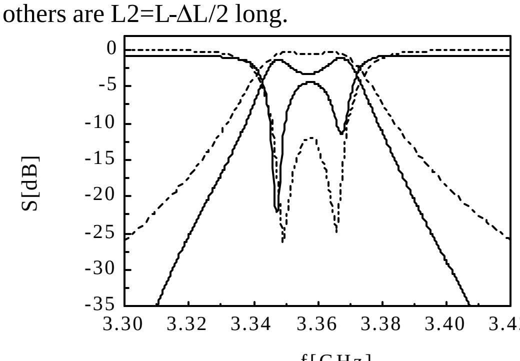

Fig.4 Experimental scattering parameters S_{11} and S_{12} (continuous curves) measured at 77 K and simulated response (dashed curves) for the single stage cross slotted YBCO filter.

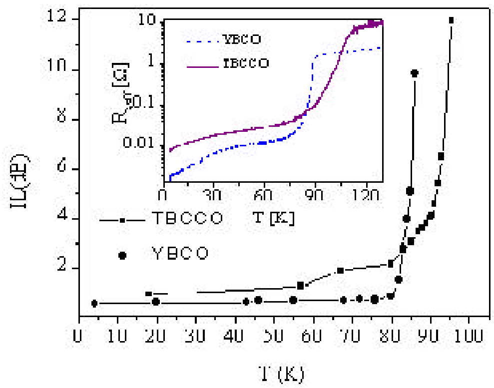

Fig. 5 Insertion losses IL as a function of the temperature for YBCO (squares) and Tl-2212 filter (circles). In the inset the Rs data measured at 87 GHz for both samples are reported.

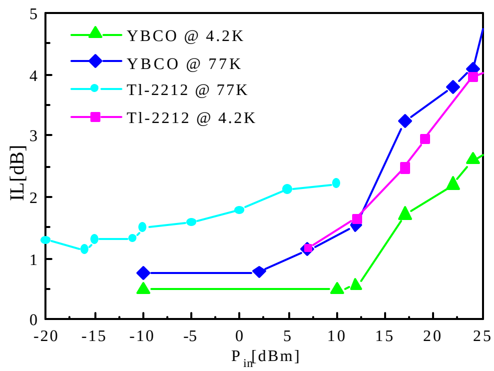

Fig. 6 Insertion losses IL as a function of the input power Pin measured at T=77K and T=4.2K on the Tl-2212 and YBCO filter

A prototype Chebyshev filter with a 1% fractional bandwidth and 0.1 dB in band ripple has been designed. The response is reported in fig.9 and was obtained considering ΔL=90μm d=9mm and Q_{Ext}=100 while all the other parameters are unchanged in respect to the single stage configuration. Since a relatively large distance is present between the two patches the couplings K13 , K24 and K14 are negligible.

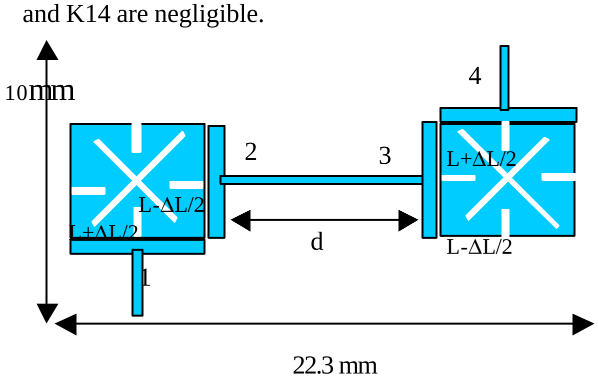

Fig. 7 Top view of the dual mode dual stage filter.

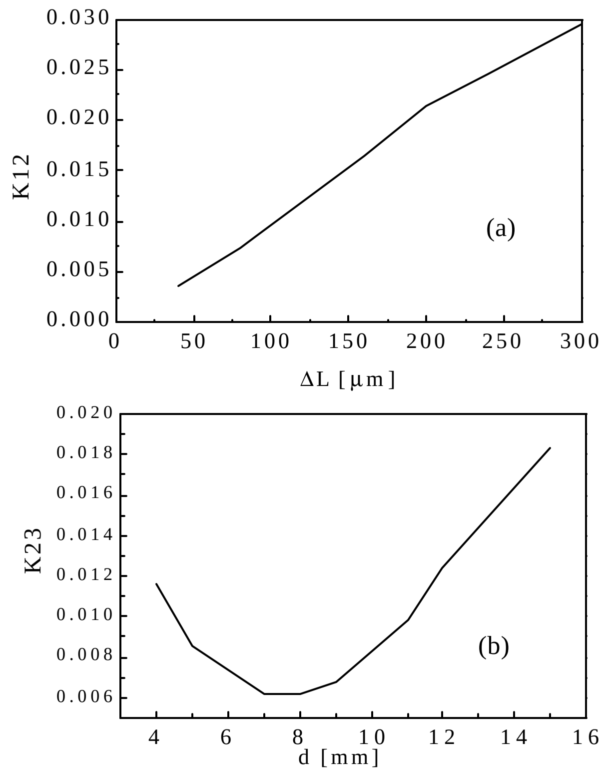

Fig. 8 (a) coefficient coupling K12 as a function of the difference length ΔL .(b) Coefficient coupling K23 as a function of the distance d between the two patches.

Note that due to the complexity of the filter structure, limited by the software, a cell size of 0.2mm was used due to software limitations. Nevertheless, the simulated response (dashed curve) obtained agrees well with the Chebychev response (continuos curve) evaluated in a conventional way by considering the lumped elements equivalent circuit [7]. The main difference is related to the lower out-band rejection due, as in the case of single stage filter (see fig. 3), to the asymmetrical arrangement of the two pads and to the IL=0.3db due to radiation effects. However, a quasi elliptical response (dotted curve) has been obtained by inverting the length of the two slots on the second patch. In this last configuration, without changes in the out band rejection, the response shows a clearly enhanced selectivity.

Finally, a four stage (eight poles) filter with a 1% fractional bandwidth and 0.1 dB in band ripple was designed and sketched in fig. 10. The filter having ΔL1=ΔL4=100μm, ΔL2=ΔL4=76μm, d12=d34=9.3mm and d23=9mm, well fits on 1"x1" substrate. In fig.11 is reported the simulated scattering response (continuos curve) evaluated by a standard Chebyshev technique compared with those obtained in the case of 2 stage filter (dotted curve). It should be observed that even in this case the presence of transmission zero further improves the selectivity of the filters. For the out-band rejection a value of 80 dB is expected limited by the cross talk between the pads. It is worth to mention that a four stage dual mode will be of extremely interest for L-band mobile communication systems since patch with L=9 mm of side could be used yielding for a total dimension less than 2"x2" for the full device

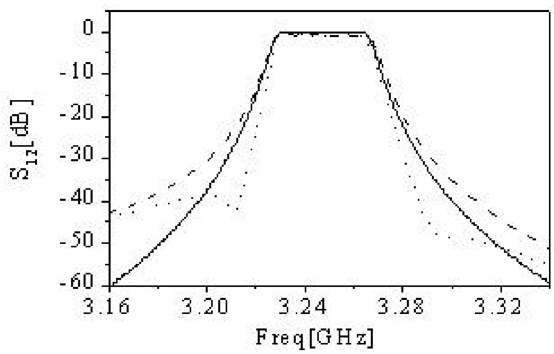

Fig. 9. Scattering parameters of the dual mode dual stage filter with Chebyshev response (dashed curve) and with quasi elliptical response (dotted curve) compared with those obtained by lumped circuit (continuos curve) .

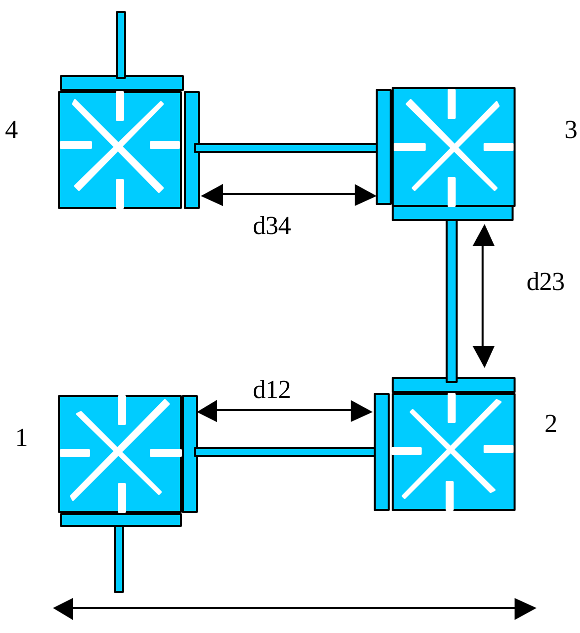

Fig. 10. Top view of the dual mode four stage filter.

Conclusions

The response of single- and multi-stage dual mode cross slotted filters have been analyzed. Measurements on C-band single stage filters realized with YBCO and Tl2212 proved the high performance of this class of filters when realized using superconducting films.

Multi stage filters have been designed and the possibility to introduce attenuation poles by varying the slot length is discussed. In particular a four stage filter operating in C-band with 1% fractional bandwidth is designed with total dimension less than 1"x1".

Acknowledgement

We thanks A. Andreone and F. Schettino for stimulating discussions. The technical support of A. Maggio and S. Marrazzo is also gratefully acknowledged. This work is funded under the I.N.F.M. Progetto Sud "Filtri Superconduttivi".

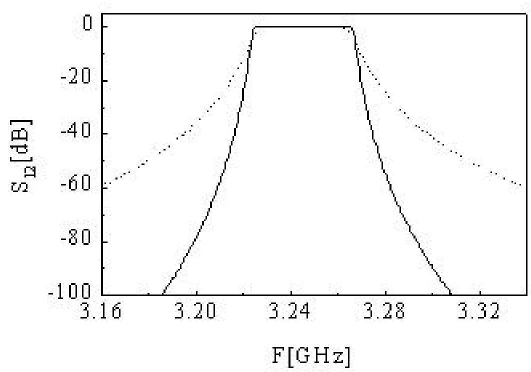

Fig.11. Scattering parameters of the four stage dual mode filter response (continuos curve) compared with the dual mode dual stage (dashed curve) response.

References

[1] M.J. Lancaster, *Passive Microwave Device Applications of HTS*, Cambridge University Press, Cambridge, 1997.
[2] H. Chaloupka, M. Jeck, B. Gurzinski and S. Kolesov. Electr. Lett. **32,**1735(1996).
[3] L. Zhu, P. M. Wecowski, and K, Wu , IEEE Trans. Microw. Theory Techn. **47**, 650 (1999).
[4] A. Cassinese, A. Andreone, F. Palomba, G. Pica, G. Panariello Appl. Phys. Lett. **77**, (2000) *in press.*
[5] A. Cassinese, A. Andreone, F. Palomba, G. Pica, R. Vaglio, G. Panariello, F. Schettino, M. Cirillo, and R. Russo, J. of Superc. **14,** 1st February 2001 *in press.*
[6] A. Cassinese, A. Andreone, G. Pica, R: Vaglio ,G. Malandrino, V. Ancarani, and I. L. Fragalà *unpublished.*
[7] G.L. Matthei, L. Young and E.M.T: Jones, *Microwave filters, impedance-matching networks and coupling structures*, Artech House Books-Dedham,Maryland, 1964.