NEW CLASSES OF MICROSTRIP RESONATORS FOR HTS MICROWAVE FILTERS APPLICATIONS

F. ROUCHAUD - V. MADRANGEAS - M. AUBOURG - P. GUILLON
B. THERON* - M. MAIGNAN*

I.R.C.O.M - UMR CNRS 6615 - 123 Av. Thomas - 87060 Limoges Cédex - France
**ALCATEL ESPACE - 26 Av. Champollion - 31037 Toulouse Cédex - France*

ABSTRACT

The rapid growth of mobile communication means creates a great interest for the use of the superconducting technology, especially for base station and satellite communication systems. Planar devices with HTS films allow to conceive narrowband filters with very low loss and small dimensions. A novel class of cross shaped planar resonators is proposed for superconducting applications. This includes dual-mode and single-mode resonators. A four pole elliptic function filter at 4 GHz is realized and measured at room temperature. Theoretical and experimental results are presented.

INTRODUCTION

Bandpass filters are fundamental elements in the payload of a communication system. Planar filter structures offer a good solution for both volume and mass severe constraints. They also permit to combine active and passive functions. However, the insertion loss for that type of circuits are important when the bandwidth are relatively narrow. The use of high temperature superconductors (HTS) allows to eliminate these problems [1]. They can favourably replace dielectric resonator filters in satellite and even in base stations.

The development of HTS thin films is followed by the conception of various smaller and smaller planar resonators [2-5]. Filters with elliptic function response can be realized by most of these resonators to improve performances. An original class of resonators based on a cross-shape is proposed. This configuration presents a few advantages upon the classical structures like the square patch or the circular patch. After a brief presentation of the different resonators, the experimental results on a 4 pole room temperature elliptic function response filter are shown to validate theoretical expectations and to prove its feasability with superconducting material.

I - BASIC RESONATOR STRUCTURES

The first basic structure is a dual mode resonator composed of two arms of microstrip lines orthogonally placed to form a cross-shaped patch as shown in figure 1. The lines have the same length in order to obtain a pair of degenerate modes. These two resonant frequencies are coupled by a triangular perturbation put in a corner of the cross. The width of the perturbation d is responsible of the coupling coefficient between the two polarizations. So it is easy to have a two-pole filter with only one dual-mode resonator. Figure 2 shows an example of the frequency response of the circuit presented in figure 1 at 4 GHz when d≠0. The two resonant frequencies can be well observed.

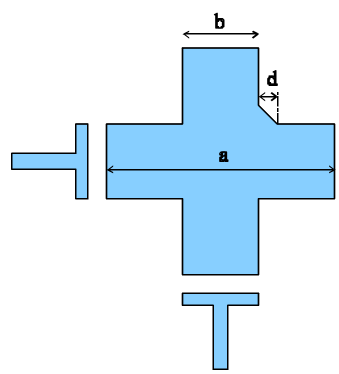

Figure 1 : Layout of two-pole dual-mode bandpass filter

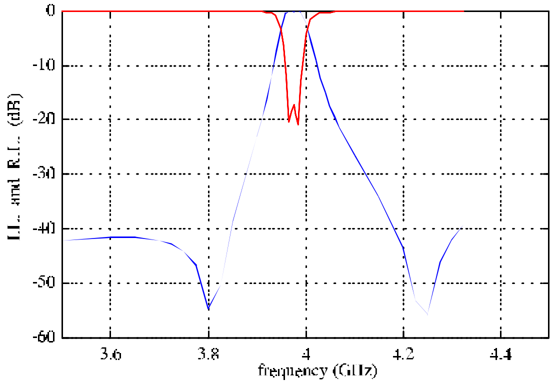

Figure 2 : Simulated response of two-pole bandpass filter shown in figure 1 (a=13.8 mm ; b=4.4 mm ; d=0.775 mm)

An advantage of this resonator is that the determination of the resonant frequency is very easy. In fact, due to the particular shape of the patch, the resonant frequency is very closed to a classical $\lambda_g/2$ microstrip resonator. The length a is only replaced by $a_{eff}=a+\frac{h}{\sqrt{\varepsilon_r}}$ (taking edge effects into account) where h is the substrate thickness [6], to have a good approximation of f_0. Moreover, for a=3b as in figure 1, the metallization surface area is about 30% less compared to a square patch resonator, at the same frequency and with an identical substrate.

Higher order filters are obtained by cascading basic dual-mode resonators. Figure 3 shows a four pole elliptic function filter made from two cross-shaped planar resonators.

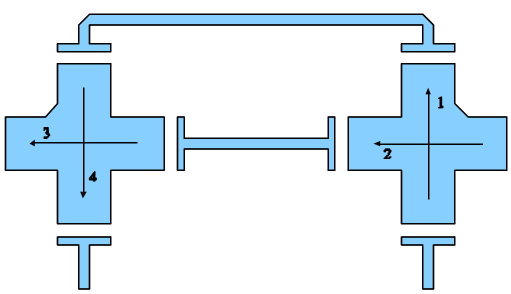

Figure 3 : Topology of a four-pole elliptic function filter using two dual-mode resonators. The cross coupling between mode 1 and mode 4 is realized by the upper microstrip line

II - OTHER CROSS-SHAPED RESONATORS

Two new cross-shaped resonators with important size reduction are presented. Although the first resonator (figure 1) has better performances (a higher unloaded Q factor, a more important maximum input power without degradation), it is desirable to conceive the smallest circuits as possible for specific applications.

1/ A cross loop resonator is shown in figure 4. The total length of the line is closed to λ_g, so the occupied surface area is approximatively $\lambda_g/4$ x $\lambda_g/4$. The existence of a pair of degenerate modes which are coupled by a perturbation in a corner, can be observed. The behaviour of this dual-mode resonator is the same as the one described in figure 1. Electromagnetic simulations show a size reduction of about 40% against the resonator presented in part I.

2/ Figure 5 presents a cross-shaped open loop resonator. To the contrary of the previous resonator, it is composed of an approximatively half-wavelength microstrip line. But it is also a single-mode resonator because of its only symmetry plane. However, the total surface area is about $\lambda_g/8$ x $\lambda_g/8$. Electromagnetic simulations show a size reduction of 66% compared to the resonator of figure 1.

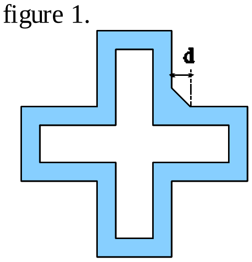

Figure 4 : Dual-mode microstrip cross loop resonator. A small perturbation in the upper right corner can be noticed

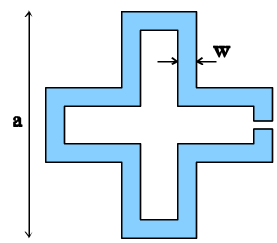

Figure 5 : Single-mode microstrip cross open-loop resonator

III - DESIGN OF A FOUR-POLE FILTER

The main problem for experimental measurements at very low temperature is the relative small size of usuable place in cryocoders. The objective is to realize a four-pole elliptic function filter at 4 GHz. For that reason, we choose to use the smallest resonator proposed in figure 5 and to employ the topology for the filter developed in [7] because of its compactness.

The configuration of the filter can be seen on figure 6. The elliptic function is realized by the coupling between first and fourth resonators on which input and output microstrip lines are connected. The synthesis method is based on the computation of each coupling coefficient independantly of the others, on a few simple structures. It is assumed that couplings between nonadjacent resonators are negligible. The cross-shape favours this assumption.

Inter-resonator coupling coefficients can be obtained by several electromagnetic simulators, either with Finite Element Method or Method of Lines which directly give the gap between two resonant frequencies or with Method of Moments [8] for very weak input coupling to isolate resonant frequencies. For each method, the coupling M_{ij} of any pair of resonators is determined by $M_{ij} = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2}$ where f_2 and f_1 are the high and low resonant frequencies of the coupled resonators.

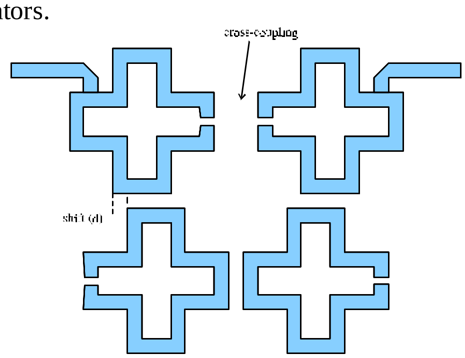

Figure 6 : Layout of a 4-pole elliptic function bandpass filter

Input and output couplings are determined by the position of the microstrip lines along the resonator from the simple structure shown in figure 7. Because of the proximity between the input line and an arm of the resonator, we can notice that the distance *l* must be taken into account. The calculation is operated on the phase of S_{11} parameter given at the junction of the line and the resonator. The external quality factor Qe is given by $Q_e = \frac{f_0}{\Delta f_{-90/90}}$ from the typical response of $\angle S_{11}$ (figure 8) where f_0 and $\Delta f_{-90/90}$ are the resonant frequency and the -90°/+90° bandwith of the input or output resonator. On figure 9 is presented the external quality factor Q_e as a function of S for different values of *l*. The important part played by *l* can be observed.

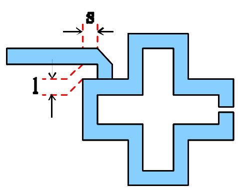

Figure 7 : Basic input and output coupling structure

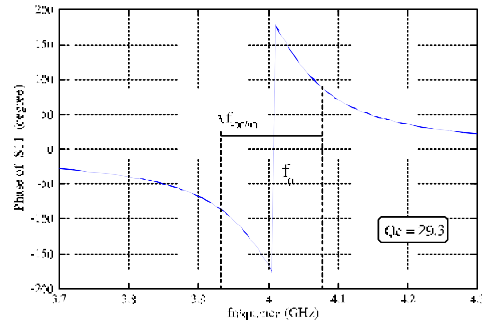

Figure 8 : Phase of S_{11} response with l=0.318 mm and S=424 µm simulated from the structure shown in figure 7

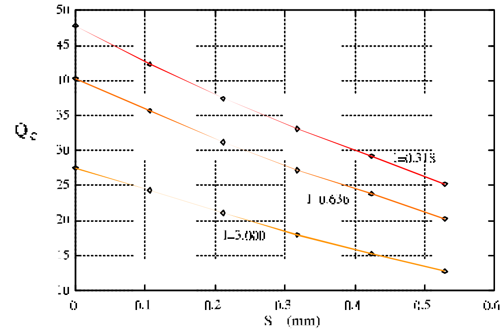

Figure 9 : Input coupling coefficient for resonators shown in figure 7 with a=5.1 mm and w=0.635 mm on aluminate substrate (h=0.635 mm) and different values of l

A four-pole bandpass filter at 4 GHz was designed to meet the following specifications (on table I). The corresponding coupling matrix is presented on table II. We can notice that the negative value of M_{14} is representative of the filter cross-coupling.

Center frequency	4 GHz
3 dB bandwidth	164 MHz
Return loss in the bandwidth	-17.5 dB
Transmission zeros / f_0	± 140 MHz

Table I

$$M = \begin{bmatrix} 0 & 0.0291 & 0 & -0.0045 \\ 0.0291 & 0 & 0.0246 & 0 \\ 0 & 0.0246 & 0 & 0.0291 \\ -0.0045 & 0 & 0.0291 & 0 \end{bmatrix}$$

$R_1 = R_N = 0.00342$

Table II

This filter was fabricated on an aluminate substrate with a relative dielectric constant of 9.8, a thickness of 0.635 mm, and with a gold metallization in a first time. Simulated and measured performances are reported on figure 10. The two transmission zeros of the elliptic function response can be observed on both curves. A shift of 20 MHz for the resonant frequency between theoretical and experimental results can be seen. The simulated 3 dB bandwidth is 155 MHz whereas measurements show a 3 dB bandwidth of 165 MHz. The four poles can be clearly observed on measured response. The losses in the bandwidth are 2.5 dB. The size of this 4 pole filter is about 11 x 10.6 mm^2.

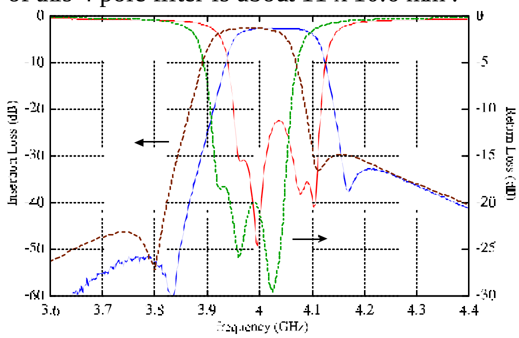

Figure 10 : Simulated and measured performances of the 4-pole filter on an aluminate substrate (ε_r=9.8 ; h=0.635 mm) with gold metallization

Unfortunately, S_{11} parameter presents unexpected rejection in the bandwidth. This can be explained by the rapid variation of the coupling coefficients in this case for strong couplings (the filter is a 4% bandwidth) and because the return loss response in the bandwidth is very sensitive to a small inaccuracy of these coefficients. To improve experimental results, four small screws were vertically placed above each inter-resonators gap. Although the electromagnetic field is highly concentrated in the aluminate substrate, a weak tuning can be introduced by the screws with the existing radiant field. Figure 11 shows experimental results of the 4-poles elliptic function filter after the adjustment. A better return loss (-15 dB) can be seen whereas the bandwidth moves to 154 MHz.

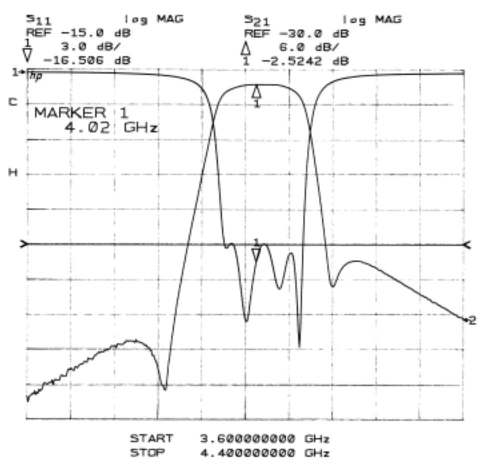

Figure 11 : Measured performances of the 4-pole 4% bandwidth filter after tuning by means of 4 screws placed at the middle of each coupling gap

CONCLUSION

A new class of single-mode and dual-mode planar resonators for filtering applications using cross shaped structures has been developed. A compact four pole elliptic function filter of 4% bandwidth at 4 GHz has been realized from one of these resonators. Good agreements with theoretical results were reported. Insertion losses mainly due to the gold metallization at ambient temperature could be practically eliminated by the use of HTS. The conception of the previous filter with a TBCCO thin film on lanthanum aluminate substrate is now in progress. Experimental results will be exposed on the Interactive Forum Paper.

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