Planar Ka-Band High Temperature Superconducting Filters For Space Applications

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Abstract — **The impressive explosion of the satellite communication systems during the last few years has led to new constraints in regards to filtering requirements. The development of multimedia satellites and the saturation of the operational frequency bands, necessitates an increase in frequency coverage [1]-[2]. This paper presents the design of High Temperature Superconducting (HTS) preselect receive filters for communication satellites. Attention has been focused on obtaining low insertion loss and small dimensions, at frequencies of 4 GHz and 30 GHz.**

I. Introduction

The future geo-stationary orbit satellite communication systems will use Ka-band because the traditionally used C- and Ku-bands are saturated. The availability of wide bands around 30 GHz should allow the development of new services in particular in the field of multimedia. In a receiving system a preselect filter is placed just after the antenna in order to select the wanted signal. This wide band filter removes the spurious emission and the out-of-band noise to avoid the saturation of the Low-Noise Amplifier (LNA). To not damage the receiver system noise, the preselect filter should present very low loss. High temperature superconducting preselect filters are desirable in the wireless and satellite communication due to their lower insertion loss and their relative small size and weight, compared to cavity or dielectric resonators [3]. A cooling system is necessary for HTS components and it has been demonstrated that amplifiers exhibit improved performances at low temperature [4]. So an additionally advantage of using HTS technology can be found in combining the HTS filter with the cryogenically cooled LNA in order to decrease the noise factor of the receiver front-end system. The association of these two cooled elements can provide a very-high performance front-end receiver.

At low frequency, high temperature superconducting thin films are very attractive due to their extremely low RF surface resistance compared to normal metals at cryogenic temperatures. Despite the rapid increase of the surface resistance with frequency, the great improvement of the HTS thin films quality, during these last years, allows us to consider realizing filters at higher frequency. So our objective is to show that at 30 GHz the gain on the surface resistance, in using HTS thin films, is functionally profitable. Furthermore, the progress of the processing and patterning techniques (tolerances) allows, at present, the realization of Ka-band HTS filters.

Before we study a front-end filter at 29.1 GHz we have realized and tested several filtering devices at lower frequency, which have allowed to validate our design tools and the simulation of the HTS thin film characteristics. We begin this article by the presentation of the measured results of a four-pole elliptic function filter realized with double sided superconductor at 4 GHz, then we will present the study of a four-pole Chebyshev function filter at 29.1 GHz. The different constraints induced by the realization of a filter at this frequency will be presented.

II. Results For A 4-Pole Filter Double-Sided TBCCO At 4 GHz

Previous studies on filtering devices have allowed us to analyze and design several superconductor microwave filters at 4 GHz [5]-[6].

The main problem for experimental measurements at very low temperature is the relative small size of the usuable place in cryocoolers. And at low frequency even planar devices are quite large. Therefore in order to realize a compact narrow-band four-pole elliptic function filter, we have used a new class of single-mode cross shaped open-loop planar resonators developed in [7]. The configuration of the filter can be seen from Fig. 1. 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 independently of the others, on a few simple structures. It is assumed that couplings between non-adjacent resonators are negligible. The cross-shape favours this assumption.

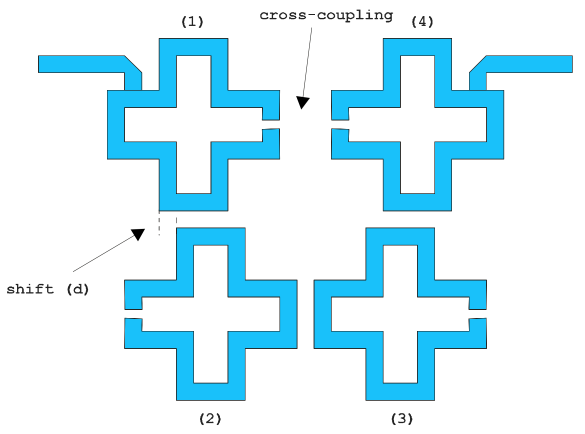

Fig. 1. Layout of a 4-pole elliptic function bandpass filter

The filter was designed to meet the following specifications (on table I) :

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

This circuit has been studied by electromagnetic simulations with several softwares like Sonnet (em), Momentum (HP-EEsof) or Finite Element Method developed in our laboratory.

The filter was fabricated on double sided thin film $Tl_2Ba_2CaCu_2O_8$ (TBCCO), on lanthanum aluminate substrate with a relative dielectric constant of 23.6 and a thickness of 0.500 mm. Theoretical and experimental results are reported in Fig. 2. The size of this circuit is about 12 mm x 12 mm.

There is a very good agreement between the two responses. The measured S_{11} parameter presents an 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.

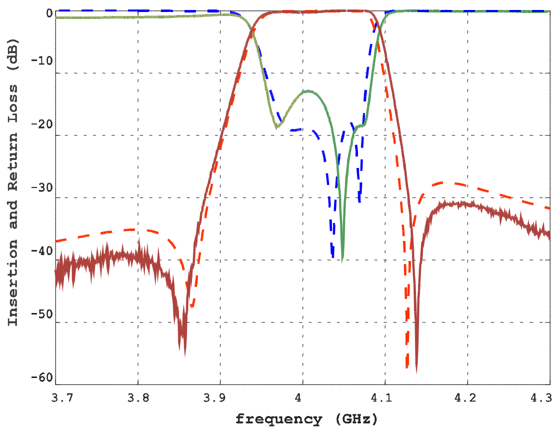

Fig. 2. Simulated (dashed lines) and measured (solid lines) performances of the 4-pole filter double-sided TBCCO on $LaAlO_3$ substrate (ε_r = 23.6 ; h = 0.5 mm).

We have shown that the design methods employed permits to conceive a narrow-band HTS filter with very low insertion loss (0.35 dB) at 4 GHz. Comparisons of High Temperature Superconductor and metal based filters have shown the performance gap between the both at 4 GHz.

II. Study Of A Front-End Filter At Ka-Band

A four-pole HTS band-pass pre-select filter has been designed for use at 29.1 GHz in order to be placed in the front-end receiver system of a satellite.

The increase in frequency for planar microwave devices involves some problems that need solving like for example, the rapid increase of the superconductive surface resistance with frequency, the appearance of parasitic modes, and the high sensitivity of dimensions.

A. Interest of superconductivity at Ka-band

The frequency dependence of the surface resistance, Rs, is of order $f^{1/2}$ for a normal conductor and f^2 for a superconductor . Comparisons between copper at room temperature and 77K, and YBCO at 77K are shown in Fig. 3. The YBCO dependence was deduced from data given by Dupont Superconductivity [8].

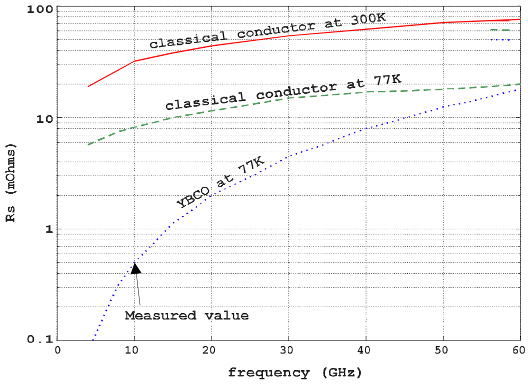

Fig. 3. Evolution of the surface resistance Rs versus frequency of a classical conductor and YBCO.

The data suggests that at 30 GHz, the surface resistance of the HTS thin film is three times better than that of cooper at the same temperature and ten times better than that of copper at room temperature. Work at this frequency would permit verification of this data and to confirm if the gain on the surface resistance Rs is profitable at 30 GHz.

B. Problem of parasitic modes

An important difficulty at Ka-band is the problem of parasitic modes coupled to the substrate and the housing. The presence of these frequency peaks disturbs the operation of planar microwave devices. In general, the higher the frequency, the greater the density of parasitic modes.

To illustrate this, Fig. 4 shows the simulated response of a microstrip resonator at 30 GHz on a magnesium oxide substrate with a thickness of 0.500 mm and a permittivity of 9.6.

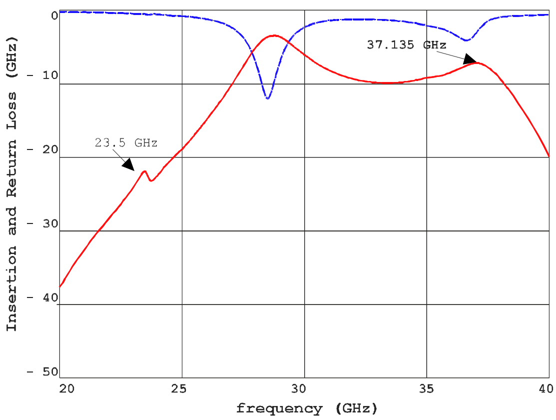

Fig. 4. Example of parasitic modes in the band 20 GHz – 40 GHz for a planar resonator on substrate with a thickness of 0.5 mm.

A solution to remove these parasitic peaks is to use a thinner substrate and to keep the housing dimensions as small as possible.

Therefore we reduced the substrate thickness to 0.250 mm. The standard thickness of a classical substrate for HTS thin films, like lanthanum aluminate ($LaAlO_3$) or magnesium oxide (MgO), is 0.500 mm [9]. It is possible to get 0.250 mm thick substrates but because of their high brittleness, the price is more expensive than for the standard one. Moreover the reduction of the substrate thickness involves a decrease of the unloaded quality factor Q_0, which means more insertion loss in the bandwidth.

C. Design of a wide band 4-pole filter at 29.1 GHz

At 30 GHz, the cross-shaped resonator composed of an half-wavelength microstripline cannot be realized without considerable damaging of its unloaded quality factor. Because the low length of the line must be compensated for the marked decrease in its width. Thus we decided to use single-mode half-wave resonators with very simple forms like “L” form resonators.

The objective of this work is not to design a very selective filter. So, we have studied a 4-pole filter wide band Chebyshev function filter which the configuration is shown in Fig. 5. The determination of the input-output couplings and inter-resonator couplings have been obtained by a classical design approach like for the first filter presented in this paper. The dimensions of the filter, 6 mm x 4 mm, are quite small.

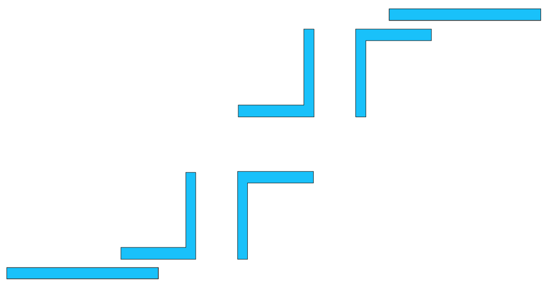

Fig. 5. Layout of a four-pole bandpass Chebyshev function filter.

A four-pole band-pass filter at 29.1 GHz has been designed to meet the specifications given in table II.

Center frequency	29.1 GHz
3 dB bandwidth	1800 MHz
Return loss in the bandwidth	< -20 dB
Rejection in the band 20 GHz-40 GHz	-60 dB

Table II

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The corresponding coupling matrix is presented in eq (1).

$$[M] = \begin{bmatrix} 0 & 1,081 & 0 & 0 \\ 1,081 & 0 & -0,794 & 0 \\ 0 & -0,794 & 0 & 1,081 \\ 0 & 0 & 1,081 & 0 \end{bmatrix} \quad (1)$$

Rin = Rout = 1.403

The study of this structure has also highlighted the high sensitivity of the dimension to the frequency. A small change of one element dimension involves a rapid variation of the coupling coefficients. So we have had problems in tuning the response of the four-pole filter. This problem has shown the necessity of implementing the use of a new method, like coupling matrix identification. In Fig. 6 we shown the response obtained by simulation with Momentum (HP-EEsof). The insertion loss are about 0.5 dB.

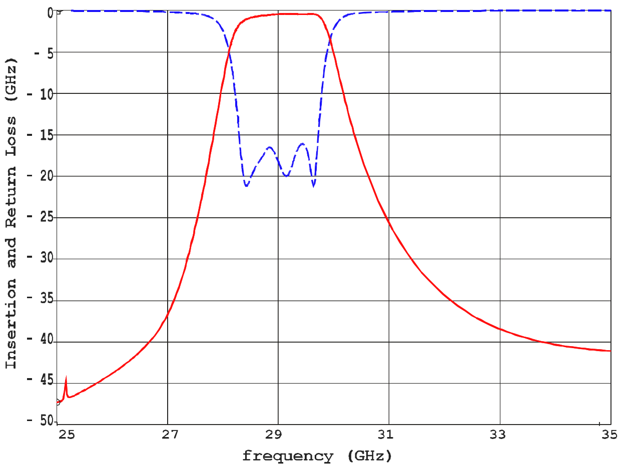

Fig. 6. Simulated response with loss of the four-pole bandpass Chebyshev function filter shown in figure 5, on lanthanum aluminate substrate ($\varepsilon_r = 23.6$; h = 0.250 mm) .

Despite the necessity to have a very high tolerance of dimensions, precisions given by different fabricants suggest that the HTS filter would work properly.

III. Conclusion

The measurements of a four-pole elliptic function filter double sided superconductor at 4 GHz has been presented.

Also, we have shown the theoretical study of a Ka-band HTS filter for a cryogenic front-end receiver for future satellite communications applications. Finally we discussed the main difficulties encountered to design a microwave device at Ka-band and the compromises necessary. The conception of the filter with YBCO thin film on lanthanum aluminate substrate of 0.250 mm thickness is now in progress.

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