NOVEL BAND-PASS FILTER UTILIZING S-SHAPED SLOT LINE RESONATORS

A. Deleniv*, A. Eriksson* and A. Khalabuhov*

* Department of Microtechnology and Nanoscience MC-2, Chalmers University of Technology
41296 Gothenburg, Sweden: anatoli@ep.chalmers.se, eriksson@ep.chalmers.se, ascry@fy.chalmers.se

Abstract **— A novel band-pass filter is designed and verified experimentally. The filter consists of five S-shaped slot-line resonators, which are aligned to form an array of coupled slots. The simulated filter pass-band is centered at 1.77 GHz with 0.6% bandwidth and with an exception of small frequency shift (20MHz) shows rather good agreement with measured data. High-temperature superconducting (YBCO) film on 1mm thick $LaAlO_3$ substrate is used to achieve low insertion loss (-0.6dB at 77K). The filter design is based on the full-wave model of coupled slots, which enables a possibility of quick and accurate circuit simulations using the duality principle.**

I. Introduction

High-quality microwave filters play extremely important role in communication systems. For some applications, the requirement of low insertion loss is crucial. In these cases, the use of high-temperature superconductors (HTS) is attractive, since it allows the design of highly selective filters. Various types of HTS filters using microstrip lines have been reported, while only few of them are available in coplanar technology. One explanation is that design and layout rules are focused mainly on keeping equipotential ground planes throughout the circuit, which is necessary to avoid undesired slot modes and standing waves. As a result it causes a frequent use of wire bonds, Yeo[1]. It is also noticed that although much work is done in development of CPW related CAD models[2-5], they are not yet well presented in most commercial circuit simulators such as HP "ADS", Ansoft "Harmonica", etc. On the other hand it is well known that due to better line-to-line isolation, CPW should enable the realization of filters with better rejection characteristics in comparison with microstrip lines and also significantly facilitates the realization of filter layouts, which require short circuit stubs, or lines. A number of attempts have been made to realize these advantages[6-9], but only few of these have a performance compatible with microstrip-based filters[8-9].

The main goal of this work is to provide design methodology and experimental verification of a novel HTS filter with CPW feed lines. We also target on demonstration of recently proposed use of magnetic current approach for circuit analysis of slot-like structures[10]. This approach is indeed a good tool to tackle slot-like circuits, specifically for those who work with microstrip circuits.

II. Filter Design

The proposed filter layout is shown in Fig.1. One uses a number of S-shaped resonators, which are aligned to form the array of coupled slots. This metallized pattern is placed on top of a finite thickness substrate. Two air-bridges (marked as black rectangles) are added to isolate the slot-mode from source (load). With an exception of coplanar feed lines this layout is dual to the one used in the filter design based on microstrip line[11].

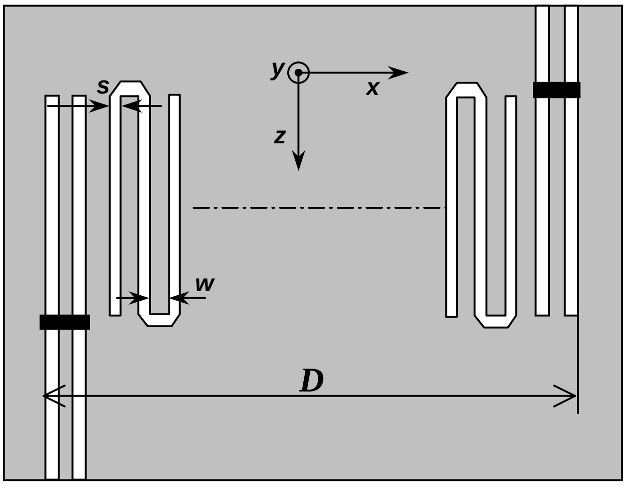
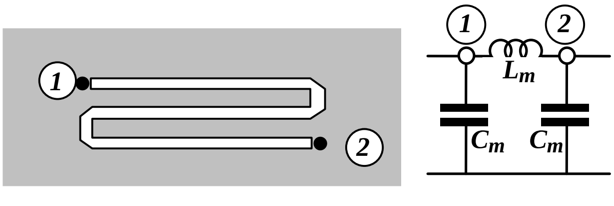


Fig.1 General layout of the filter based on the S-shaped slot resonators

The resonator (Fig.2.a) is initially designed to resonate at the center of the filter pass-band (1.775GHz) and is represented with a lumped element equivalent circuit shown in Fig.2.b (the resonator consists of three 100µm slots separated by 100µm spacing and is 9.28mm long). Subscript *m* denotes that these are elements of the equivalent circuit with magnetic current. The latter can be defined by following a few simple rules [9, 10], or using the fact, that similar layouts with either magnetic or electric current share the same equivalent circuit representation. In the next step a ladder network prototype can be assembled using lumped element representation in Fig.2.b. Then a proper spacing between



a) b)

Fig.2 Layout of the S-shaped slot-line resonator (a), and its equivalent circuit representation (b).

first resonator and a feed line is found to insure correct strength of external coupling, which is defined by Q_{ext}. For this and all other simulations we use the model of coupled slots reported in [9]. The rest of the design is essentially an iterative procedure, which is based on principle proposed by Dishal [12] and lately used by Matthaei [13]. Let us pay attention to Fig.3, where a part of the lumped prototype is shown. Resonators *k-1* and *k+1* are shorted which reflects an open circuit at nodes 7 and 10 respectively. Then the coupling between resonators *k* and *k+1* can be examined with the effects of all other resonators removed.

k-th and *k+1-th* are fed at nodes 7 and 10 using small capacitances providing week coupling. A number of iterations are then performed to find correct spacing between two resonators providing desired coupling bandwidth. Small corrections of slots/spacing in each resonator are also typically required to ensure correct positioning of the response. Finally, we simulated 5-pole filter using the equivalent circuit shown in Fig.5. The modeled response of the filter is shown in Fig.6.

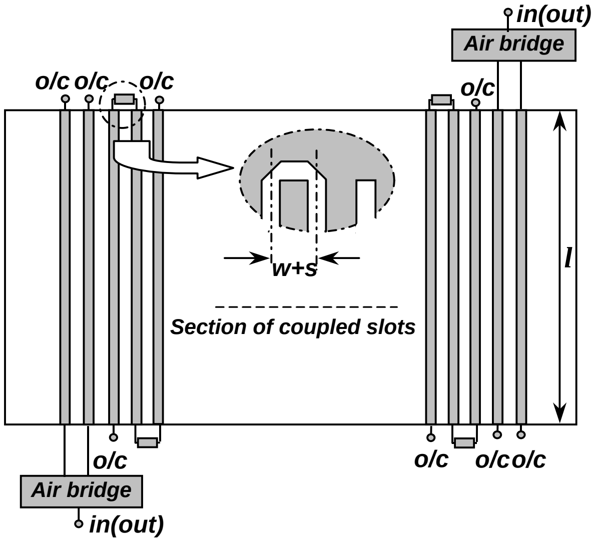


Fig.5 Equivalent circuit of the filter using the model of coupled slots.

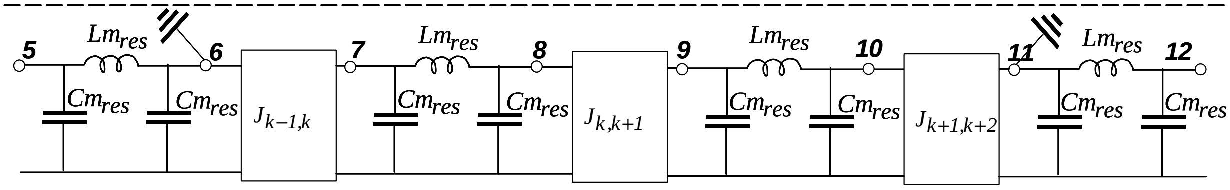


Fig.3 Circuit arrangement for observing the coupling between resonators *k* and *k+1*.

A fragment of the layout that reproduces the circuit arrangement from Fig.3 is given in Fig.4 (node numbering correspond to those in Fig. 3). Resonators

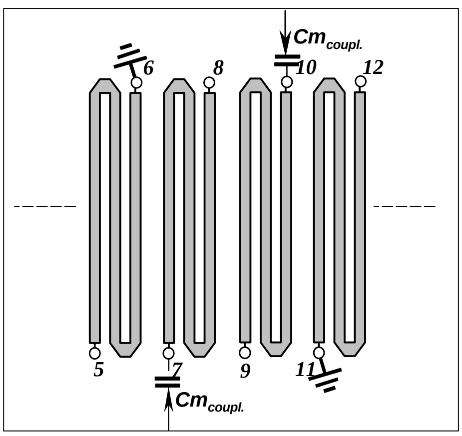


Fig.4 A fragment of the layout that reproduces the circuit arrangement in Fig.3.

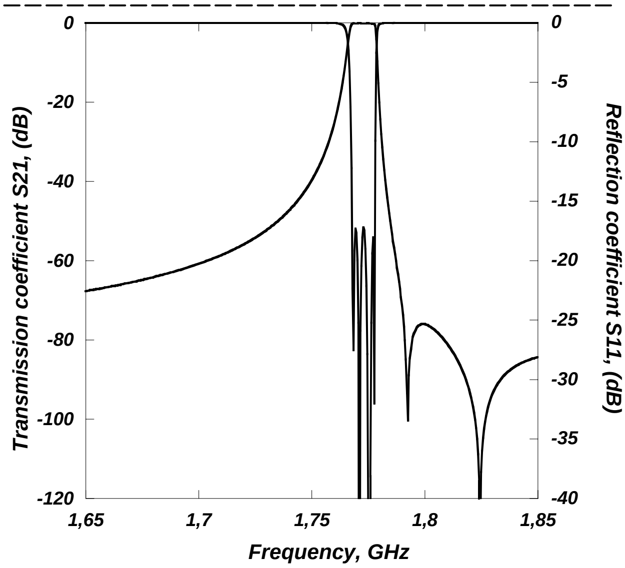


Fig.6 Simulated S-parameter response of a 5-pole filter with 0.6% bandwidth.

III. MEASURED DATA

The filter was manufactured on a 1mm thick $LaAlO_3$ substrate with $\varepsilon_r \approx 23.5$ with four years old single side YBCO film with 0.6μm thickness. A 20x20mm sample with 11.5x10mm useful circuit area was mounted in standard Wiltron test fixture as it is shown in Fig.7. The calibration is made at room temperature using standard K calibration kit at interfaces of attached to the fixture V-K adapters. Than the filter is measured in liquid nitrogen (77K) using "Wiltron 360B" network analyzer.

Fig.7 Filter mounted in standard Wiltron test fixture.

The measured wide band filter performance is presented in Fig.8. Seems important to note that second pass-band is significantly suppressed being limited below –20dB level in S21. That is quite desired feature for number of applications making this filter type rather attractive. The measured narrow band filter performance is given in Fig.9. We observe a rather good agreement between simulated and experimental data. A small frequency shift is probably due to the higher dielectric constant of the used substrate. The averaged level of the insertion losses in the pass-band is as low as –0.6 dB and matching is better than 11.5dB.

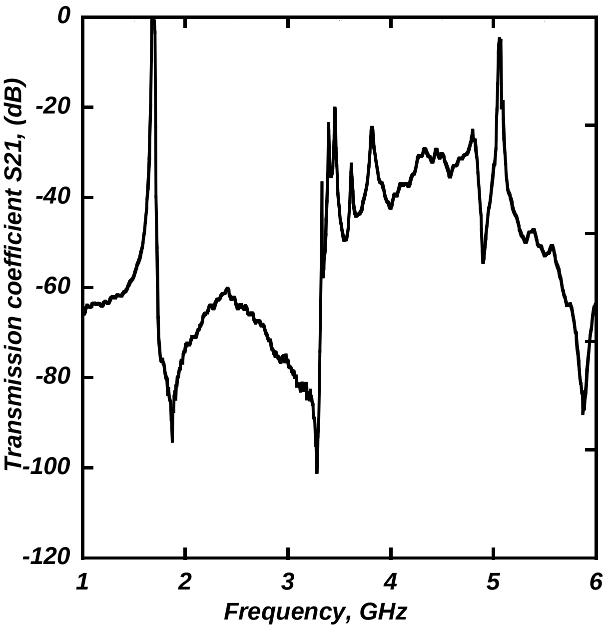


Fig.8 Measured wide band filter performance.

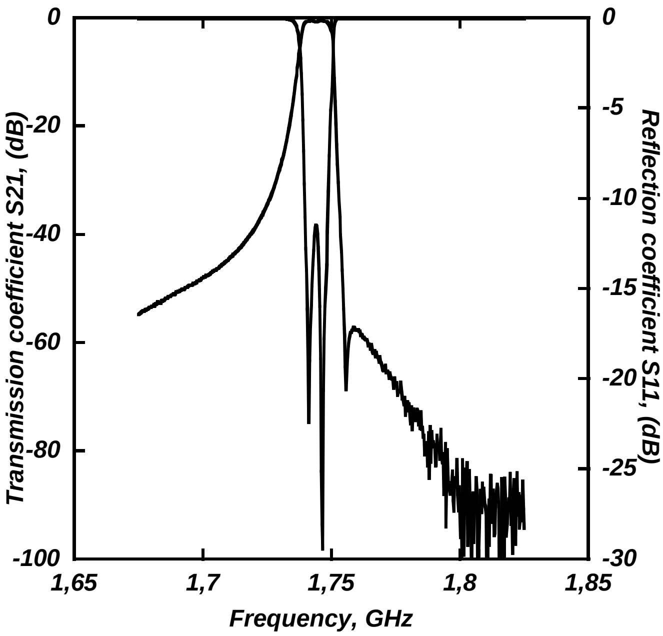


Fig.9 Measured narrow band filter performance.

CONCLUSION

A design methodology of a novel band-pass filter based on S-shaped slot line resonator is proposed and demonstrated in a 5-pole design example, which is experimentally verified.

ACKNOWLEDGEMENT

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