

## Novel Band-Pass Filter Utilizing S-shaped Slot Line Resonators

A. Deleniv, M. Gashinova, A. Eriksson, A. Khalabuhov

Department of Microelectronics MC-2, Chalmers University of Technology  
41296 Gothenburg, Sweden

**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 0.5% 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  $\text{LaAlO}_3$  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, and also provides new design ideas.

### 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].

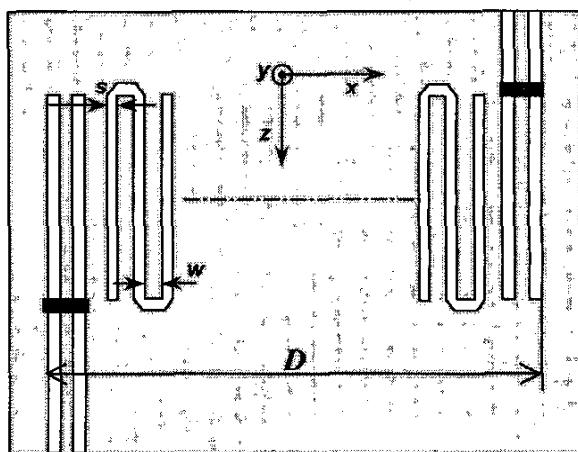


Fig.1 General layout of the filter based on the S-shaped slot resonators

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 100 $\mu\text{m}$  slots separated by 100 $\mu\text{m}$  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

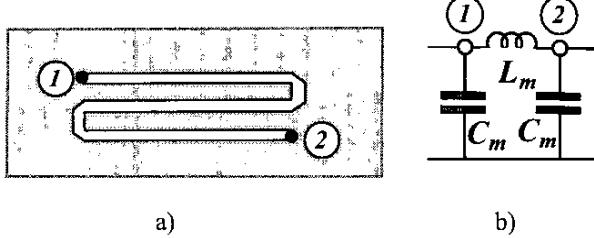


Fig.2 Layout of S-shaped slot-line resonator (a), and its equivalent circuit representation (b).

representation in Fig.2.b. Then a proper spacing between 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.5, 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.

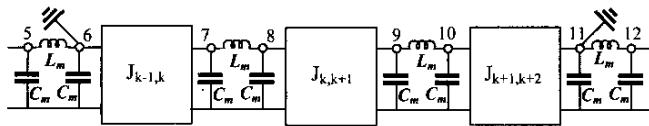


Fig.3 Circuit arrangement for observing the coupling between resonators  $k$  and  $k+1$ .

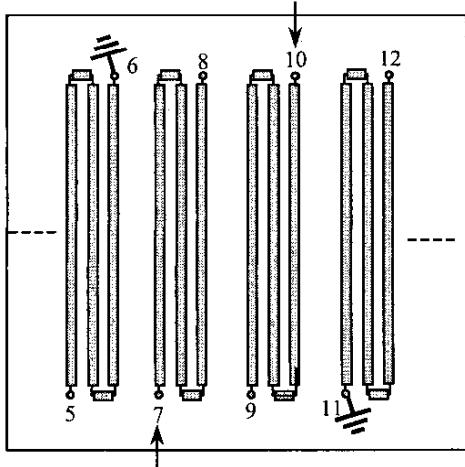


Fig.4 A fragment of the layout that reproduces the circuit arrangement in Fig.3

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  $k$ -th and  $k+1$ -th are fed at nodes 7 and 10 using small capacitances providing weak 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.4.

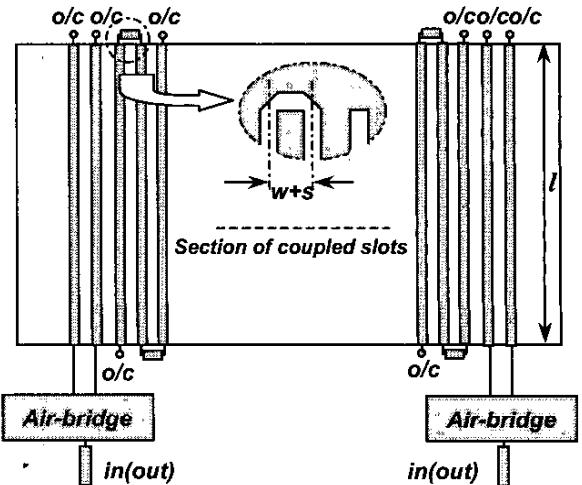


Fig.4 Equivalent circuit of the filter using the model of coupled slots.

The modeled response of the filter is shown in Fig.5.

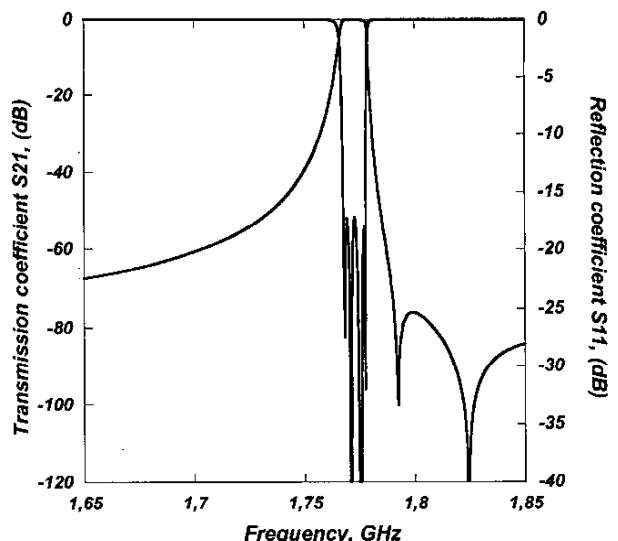


Fig.5 Simulated S-parameter response of a 5-pole filter with 0.5% bandwidth.

### III. MEASURED DATA

The filter was manufactured on a 1mm thick  $\text{LaAlO}_3$  substrate with  $\epsilon_r=23.5$  with four years old single side YBCO film with  $0.6\mu\text{m}$  thickness. A 20x20mm sample with  $11.5 \times 10\text{mm}$  useful circuit area was measured using standard Wiltron test fixture in liquid nitrogen (77K) using Wiltron "360B" network analyzer. Experimental data are presented in Fig.7. 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  $-0.6\text{dB}$  and matching is better than  $-11.5\text{dB}$ .

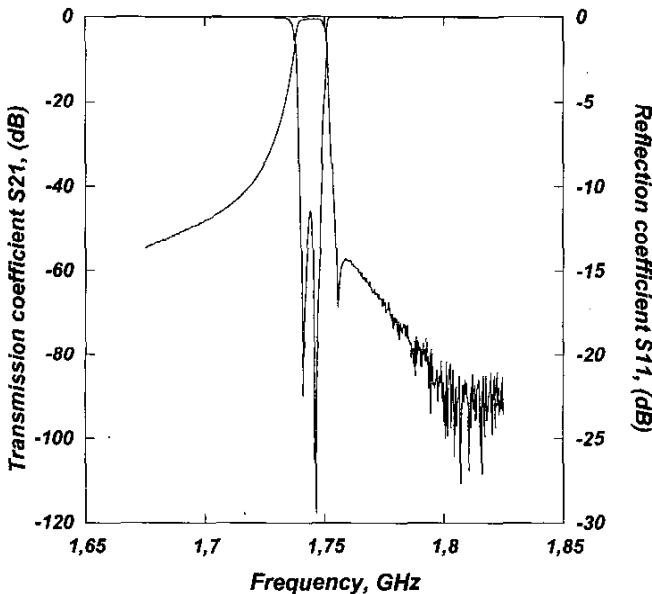


Fig.7 Measured response of the 5-pole filter.

### 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

Support for this work was provided by Swedish Science Foundation (Vetenskapsrådet) and CHACH. S.Gevorgian is acknowledged for useful discussions.

### REFERENCES

- [1] Yeo, M, "Practical Applications of CPW in Radar and Electronic Warfare Sub Systems", Analysis, Design and Application of Coplanar Waveguides, IEE Colloquium on, 1993, pp.12/1-12/3.
- [2] Th. Becks, B. Hopf, D. Köther, R.Kulke, P.Pogatzki, M. Rittweger, Th. Spokmann, M. Werthen, I. Wolff, "Activities on Coplanar Waveguide Structures at the IMST", Analysis, Design and Application of Coplanar Waveguides, IEE Colloquium on, 1993, pp.5/1-5/10.
- [3] P. Pogatzki, R.Kulke, Th. Spokmann, D. Köther, R. Tempel, I. Wolff, "A comprehensive evaluation of quasi-static 3D-FD calculations for more than 14 CPW structures-lines, discontinuities and lumped elements", Microwave Symposium Digest, 1994, IEEE MTT-S International, vol. 2, pp.1289-1292.
- [4] A. Deleniv, I.Vendik, and S.Gevorgian, "Modeling Gap Discontinuity in Coplanar Waveguide Using Quasistatic Spectral Domain Method", Int. J. RF. Microwave Computer-Aided Eng. 3, May 2000.
- [5] S.Gevorgian, T. Martinsson, P.Linner, E. Kollberg, "CAD models for multilayered substrate interdigital capacitors", IEEE Trans. Microwave Theory Tech., vol.44, pp.896-904, June 1996.
- [6] Vogt A and Jutzi W., "An HTS narrow bandwidth coplanar shunt inductively coupled microwave band-pass filter on  $\text{LaAlO}_3$ ", IEEE Trans. Microwave Theory Tech., vol.45, pp.492-497, April 1997.
- [7] R.Weigel, N.Nalezinski, A. A.Valenzuela, P.Russer, "Narrow-band YBCO Superconducting Parallel-Coupled Coplanar Waveguide Band-Pass Filters at 10GHz", Microwave Symposium Digest, 1993, IEEE MTT-S International, pp.1285-1288.
- [8] K.Yoshida, K.Sashiyama, S.Nishioka, H.Shimakage and Z.Wang, "Design and Performance of Minituarized Superconducting Coplanar Waveguide Filters", IEEE Trans. Appl. Supercond., vol.9, pp.3905-3908, June 1999.
- [9] A.Deleniv, M.Gashinova, I. Vendik and A.Eriksson, "Design of an Interdigital Hairpin Band-Pass Filter Utilizing a Model of Coupled Slots", IEEE Trans. Microwave Theory Tech., vol.50, pp.2153-2158, Sept 2002.
- [10] A.Deleniv, M.Gashinova and A. Eriksson, "On the Application of Duality Principle for Analysis of Slot-Like Structures", Proceedings of EuMC 2002 (Milan, Italy), pp.9-12.
- [11] Vendik I.B., Deleniv A.N., Sherman V.O., Svischnev A.A., Kondratiev V.V., Kholodniak D.V., Yudin P.N., Min B.-C., Choi Y.H., Oh B., "Narrowband  $Y\text{-Ba}\text{-Cu}\text{-O}$  filter with quasi-elliptic characteristic", IEEE Trans. Appl. Supercond., vol.11, pp.477-480, march 2001.

[12] M.Dishal, "Alignment and adjustment of synchronously tuned multiple-resonant-circuit filters", Proc. IRE, vol. 39, pp.1448-1455.

[13] G.Matthaei, G. Hey-Shinton, "Novel Staggered Resonator Array Superconducting 2.3 GHz Bandpass Filter", IEEE Trans. Microwave Theory Tech., vol.41, pp.2345-2352, Dec. 1993.