FOUR-POLE TUNABLE BAND-PASS FILTER BASED ON TWO DUAL MODE $SrTiO_3$ DISC RESONATORS

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Abstract — **A four-pole tuneable band-pass filter based on two STO disc resonators (0.5mm thick, 7.0 mm in diameter) is designed and characterized experimentally. The filter with a center frequency about 0.5 GHz and bandwidth less than 2.0 % is utilised on two degenerate TM_{110} modes of parallel-plate resonators to operate at temperature 60K. The change in center frequency under DC bias 500V is about 8%.**

INTRODUCTION

Parallel-plate circular disc resonators based on single crystals of SrTiO3 (STO) and KTaO3, (KTO) are promising for high power tunable filter applications, Vendik et al (1), Gevorgian et al (2), Eriksson et al (3). To get a DC field dependent dielectric permittivity (tenability) these materials have to be cooled below 100 K, where the permittivity is larger than 1000. The application of a DC bias to the plates of the resonator causes a reduction of the permittivity and leads to frequency agility of the resonator. To keep the DC bias voltages low the resonator is usually made thin (also electrically), and supports only TM_{mn0} modes, Eriksson et al (4). The experience shows, (1-2), that the Q-factor of resonators made of STO (and KTO) with superconducting plates decreases drastically, typically from several thousands at zero bias to several hundred at DC field above 10 kV/cm. At high voltage it is practically defined by the loss tangent of dielectric material. The use of superconducting electrodes improves the Q factor only at low DC fields. Thus, it is reasonable to consider the use of cheaper copper electrodes instead.

In a previous work (3) an experimental two-pole tuneable filter was realized using two KTO disc resonators, where a transmission pole was introduced at the high frequency skirt making the filter useful for high power duplexer applications. The filter was designed utilizing TM_{020} modes to operate at 77 K with a pass-band 1.5% and centre frequency 0.9 GHz. In the present work we utilise the degeneracy of TM_{110} mode in STO circular disc resonators to design a four-pole filter with improved skirts.

DESIGN OF THE FILTER

The design of filters consists of several steps. In the first step the operation temperature was chosen, which was motivated by the fact that minimum of the loss in STO crystals is about 60 K, Viana et al (5). This was followed by experimental characterization of the disc resonator with copper electrodes in the range of DC bias 0-500V. In the frequency range 0.53-0.57GHz the averaged value of the slope parameter *b* is estimated to be ≈2.25S. Extracted value of the unloaded Q-factor is in the range 310-250 and the relative change in the resonant frequency (i.e. tuneability) is about 8% for mentioned above DC voltages. Using the measured resonant frequency and the sizes of the disc resonator, we extracted the dielectric permittivity of STO at 60K using HFSS simulations, which is estimated to be 2650. In the next step we designed a slit with width w and depth l, to couple two degenerate TM_{110} modes with orthogonal polarization. The field pattern for one of these modes is shown in Fig.1a. The results of simulations are summarized on Fig.1c, where the coupling bandwidth $\Delta f = f_e - f_o$ is plotted versus slit depth l for fixed width w=0.5 mm (f_o, f_e - are odd and even mode resonant frequencies respectively). The response of the dual-mode resonator for the port configuration shown in Fig.1b is identical to two coupled resonators with a capacitive coupling. Following Fig.1c one can note, that a rather wide range of coupling can be achieved with reasonable sizes of the slit.

The design procedure of this filter involves Ansoft's ADS and HFSS simulations. First, the lumped element equivalent circuit of the filter prototype is defined using measured susceptance slope parameter *b*. This circuit can be represented in two parts – one is related to

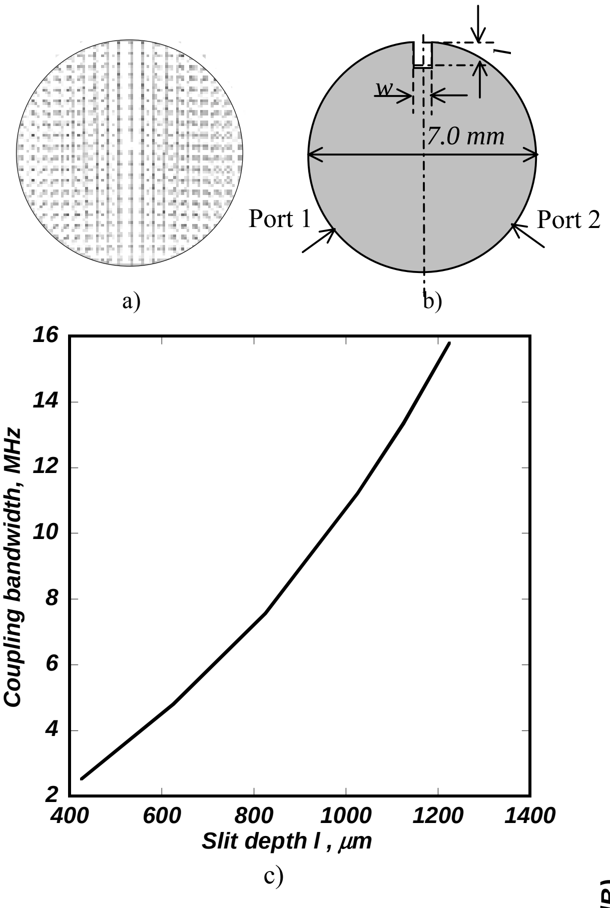


Fig.1 The magnetic (→) and electric (o and ×) field patterns of the TM_{110} mode (a), upper electrode with a perturbation slit (b), and coupling bandwidth versus slit depth *l* (c).

equivalent representation of dual mode resonators (including inter-mode coupling) while latter one provides coupling with feed lines and disc-to-disc one The second part of this circuit is translated into microstrip network in accordance to lumped element representation for a transmission line section and layout is than optimised in Momentum. In the next step we have chosen the slit depth following Fig.1c using inter-mode coupling coefficients obtained from the lumped element prototype. Finally, the S-parameters of the microstrip network from Momentum simulation, and S-parameters of the dual mode resonators from HFSS simulation are exported to ADS circuit simulator to simulate the overall filter performance.

The layout of the filter is presented in Fig.2. The 40x40mm microstrip substrate is 0.625mm thick with circular via holes to the ground plane to accommodate the STO discs. The open stub 3, section of high impedance line 2 and a capacitance borrowed from the first resonator establish a π-network, which provides coupling with feed line 1. The inter-disc or second-to-third resonator coupling is realized on the section of the transmission line 5 and capacitances borrowed from the second and third equivalent resonators.

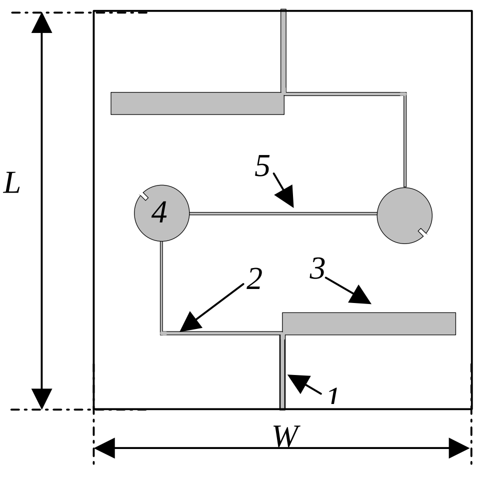


Fig.2 Layouts of the four-pole filter based on dual mode resonators.

The results of simulations, obtained after a number of simulation/optimization steps, are presented in Fig.3. The simulations show that in the range of DC voltages 0-500V the insertion losses do not exceed 5dB.

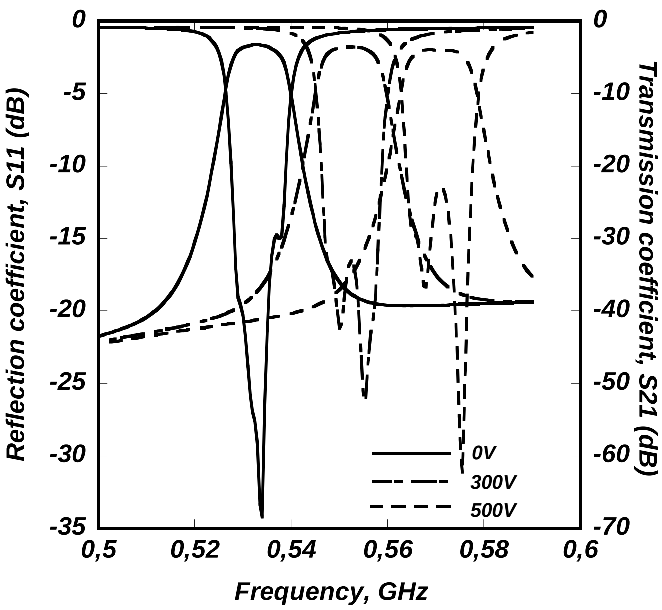
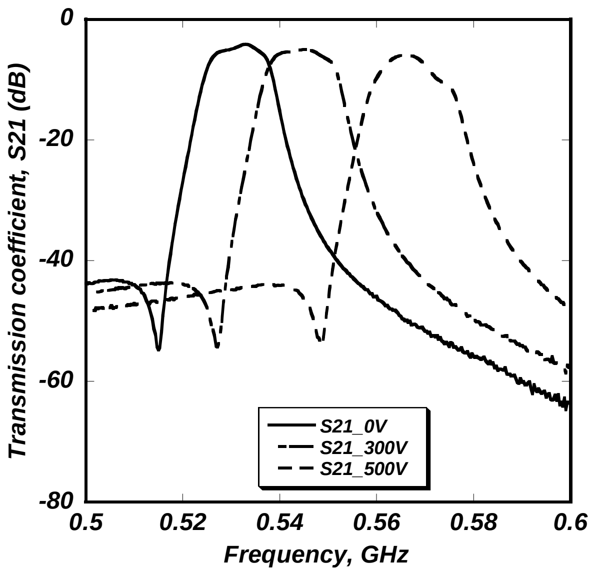
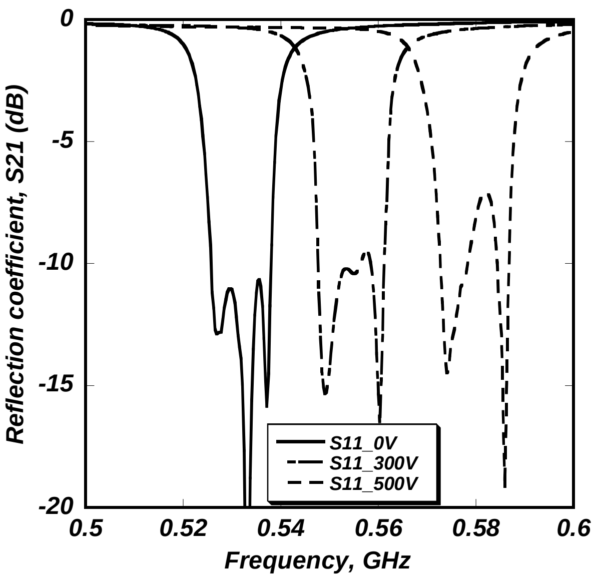


Fig.3 Simulated filter performance.

The results of the measurements are presented in Fig.4a, b. No trimmings or adjustments are used. The insertion losses are about 1 dB higher (it is in the range 4.2-5.5dB) than expected from simulations. The pole observed at the low skirt in the experiment (Fig.4a) may be explained by effect of discontinuity at ribbon-to-disc transition. The resonator is characterized by high slope parameter *b* and it is very sensitive to parasitic influence, which is not accounted for in the simulations.



a)



b)

Fig.4. Measurement data for the four-pole dual mode filter based on STO disc resonators.

CONCLUSION

Design of the tuneable band-pass filter on dual-mode parallel plate resonators based on combination of experiment, full wave and circuit analysis is presented. In general a good agreement is found between measured and simulated performance. The obtained results compare favourably with a similar commercial 4-pole filter, Pole/Zero Corp. (6), with 2% bandwidth in terms of shape factor (30dB/3dB). However, the insertion loss performance for our filter is about 4dB better. The insertion losses of the filter are limited by the losses in STO crystals, especially for large tuning ranges (voltages), smaller losses with small tuning range (<5%) may be achieved if superconducting plates are used instead of copper.

ACKNOWLEDGEMENT

Support for this work was provided by Vetenskaprådet (Swedish Science Foundation) and CHACH.

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