Design and Simulation of Tunable Bandpass Filters Using Ferroelectric Films for Wireless Communication Systems

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ABSTRACT

This paper presents the simulation of Au / $Ba_xSr_{1-x}TiO_3$ (BSTO) / Magnesium oxide (MgO) multi-layered and electrically tunable band-pass filters (BPFs) by using high frequency structure simulator (HFSS). This model is a two-pole microstrip edge coupled filter. The filter was designed for a center frequency about 5.8 GHz. The tunabillity of the filter is achieved using the nonlinear dc electric-field dependence on the relative dielectric constant of BSTO ferroelectric thin film. This work seems very promising for future wireless communication systems.

KEYWORDS

Tunable bandpass filter, ferroelectric film, high frequency, HFSS, simulation

I. Introduction

Bandpass filter plays an important role in RF/MW wireless communication systems. The emerging wireless communications require RF/MW filters with even higher performance, smaller size, lighter weight, and lower cost. Recent advances in novel materials and fabrication technologies, including high-temperature superconductor (HTS), low-temperature cofired ceramic (LTCC), monolithic microwave integrated circuits (MMIC), microelectromechanic system (MEMS) and micromachining, have accelerated the development of new types of RF/MW filters. Furthermore, advances in computer-aided design (CAD) tools such as High-Frequency Structure Simulator (HFSS) has revolutionized filter design [1]. On the other hand, ferroelectrics have been studied since the early 1960s for application in microwave devices [2]. However, it is very recently that their applications are beginning to emerge [3–5]. These types of filters can be comparable with HTS filters from the standpoints of their final application and fabrication technique. The permittivity of the ferroelectric film tends to change according to the applied electric field across the film, which is the key to realize the bandpass filters with a wide range of frequency applications. This is because ferroelectrics generally exhibit spontaneous polarization. Such a crystal can be seen to contain positive and negative ions and also in a certain temperature range the positive and negative ions are displaced, resulting in a net dipole moment. The orientation of the dipole moment can shift from one state to another by an electric field. The appearance of the spontaneous polarization is highly temperaturedependent, and in general the ferroelectric crystals have phase transitions, where the crystal undergoes structure changes [6]. This transition temperature is known as the Curie temperature (T_c) at which the material properties change abruptly. Some materials were observed to have a variable permittivity with electric field [7, 8]. Both strontium titanate STO ($SrTiO_3$, STO) and barium strontium titanate BSTO ($Ba_xSr_{1-x}TiO_3$, BSTO) where x can vary from 0 to 1, are the most popular ferroelectric materials, currently being studied for the frequency-agile high frequency wireless components and circuits. The STO materials are usually applied for HTS filters at low temperature, and the BSTO materials are more suitable for filters which operate at room temperature. In this work, we have designed and simulated the electrically tunable bandpass filters based on the BSTO films on MgO substrates.

II. Layout Designs

The microstrip filter structure consists of a dielectric substrate (MgO, typically 500μm thick), a ferroelectric film layer with thickness, *t*, varied from 0.3 to 1μm, a gold thin film of 1 or 2μm thickness for the top conductor, and a 2μm – thick gold ground plane. **Fig. 1** shows a first filter layout with the following dimensions: the width and thickness of each microstrip line are w = 500μm and *t* = 1μm, respectively. The other parameters are l_1 = 2mm, l_2 = 3.24mm, l_3 = 3mm, the coupling length l_4 = 2.94, the coupling gap s_1 = 0.25mm, s_2 = 0.9mm, and s_3 = 0.3mm.

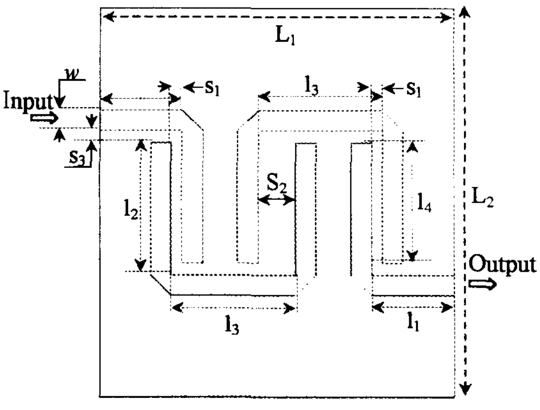


Fig.1. Layout of microstrip bandpass filter (mitered bend striplines).

Fig. 2 illustrates the other schematic layout of the bandpass filter. The width and thickness of each microstrip line are w_1 = 250 μm, w_1 = 500 μm, respectively. The other parameters are $l_1 \approx$ 2.01mm; $l_2 \approx$ 5.07mm; $l_3 \approx$ 2.94; $l_4 \approx$ 1.9mm; $l_5 \approx$ 1.4mm; $l_6 = l_9 \approx$ 5.7mm; $l_7 = l_8 \approx$ 5.6mm; The coupling gap s_1 = 0.25mm; s_2 = 0.3mm. The radius of three circles are all the same R = 0.7mm. The total area of the filter is $L_1 \times L_2$ = 20×20mm ($2cm^2$).

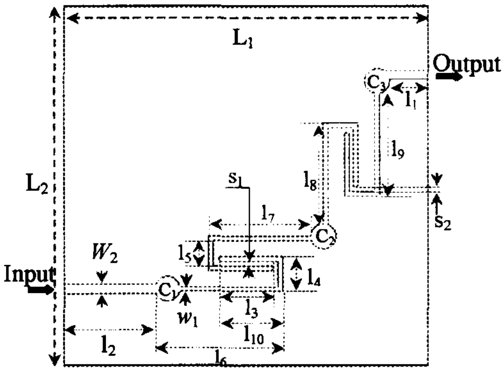
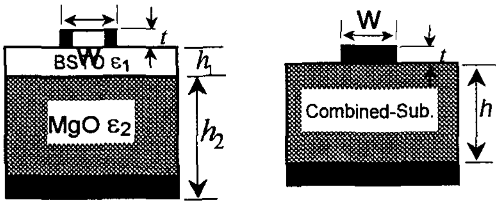


Fig. 2. Layout of microstrip bandpass filter.

III. Simulation Results

The filter performance was verified through the simulation with HFSS and ADS software tools. To facilitate the simulation, we proposed and used a formula which includes the combined permittivity, considering both the MgO substrate and BSTO films. Consequently, the four-layer structure can be converted into three-layer structure, *i.e.*, two dielectric layers now become one according to the following equation as shown in **Fig. 3** :



4 layers

3 layers

Fig. 3. Conversion from 4 layers to 3 layers structure.

$$\varepsilon_{rcom} = \frac{h_1\varepsilon_1 + \alpha h_2\varepsilon_2}{h_1 + \alpha h_2}$$

where ε_1, ε_2 are dielectric constants; and h_1, h_2 are the thickness of BSTO and MgO, respectively ($h = h_1 + h_2$), and α ($0<\alpha\leq1$) is a constant. We simulated by using HFSS for the case of the input parameters such as ε_{rcom} = 10.04; h = 500.5μm; and other parameters were given above. **Fig. 4** shows the simulated passband responses.

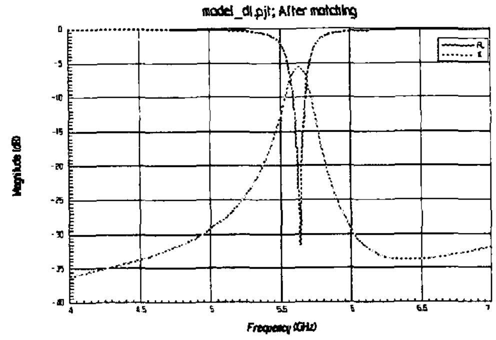


Fig. 4. Simulated passband responses of the mitered bend striplines bandpass filter.

As a result, the insertion loss IL = 5.53 dB; return loss RL = 31.61 dB; center frequency f_c = 5.635 GHz, bandwidth BW = 175 MHz. The RL factor is good enough, but the IL factor is a little larger than 5dB.

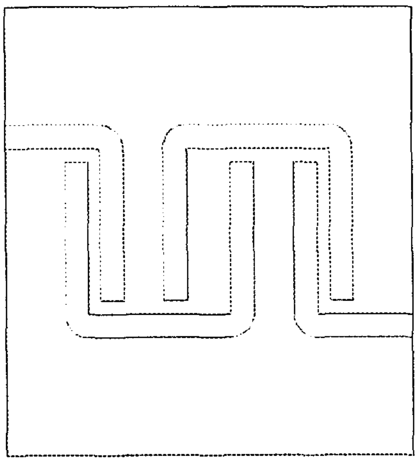


Fig. 5. Schematic layout of microstrip bandpass filter (radial bend striplines).

Thus, the layout needs to be further refined. **Fig. 5** shows a similar layout of this filter after optimization. The IL factor has been a little improved. Also with this layout, we have simulated it with various values of combined-dielectric constants, as shown in **Fig. 6 and Fig.** 7. From **Fig. 6**, the results of this filter are: IL ≤ 4.4dB; the RL in the range [24 dB, 27.5 dB]; the BW is about 148 MHz; and the center frequency f_c has been shifted from 5.425 GHz (ε_{rcom} = 10.024) to 5.14 GHz (ε_{rcom} =11.7929) or say another way, the tunable range is 285 MHz.

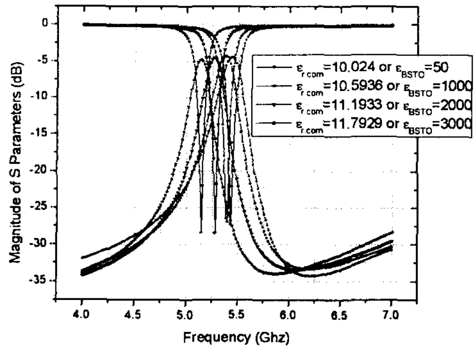


Fig. 6. Simulated passband responses of the radial bend striplines filter.

From **Fig.** 7, the results of this filter are: IL ≤ 4.9dB; the RL in the range [17dB, 42dB]; the BW is ~140 MHz; and the f_c has been shifted from 5.65 GHz (ε_{rcom} = 9.6903) to 4.81 GHz (ε_{rcom} =12.5874) or the tunable range is 840 MHz.

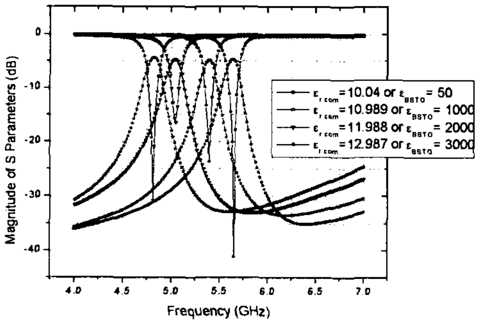


Fig. 7. Simulated passband responses of the radial bend striplines filter.

IV. Conclusion

When the relative dielectric constant of the BSTO film increases from 50 to 3000, the center frequency is reduced from ~5.6 GHz to 4.5 GHz. The smaller IL factor results in the larger bandwidth. The typical bandwidth and insertion loss are ~174 MHz, and < 3 dB, respectively. The values of RL is relatively small. Further study needs to be done.

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