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RF MEMS-Based Tunable Filter for X-Band Applications

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Abstract: This study presents the application of RF MEMS based switches in tunable bandpass filter operating in the wireless X-band. The filter is designed on 635 μm-thick high-resistivity silicon substrate which is compatible with the new SiGe process. The design and simulation are performed using 3D full wave electromagnetic simulator IE3D. Tuning is achieved by the Metal-Air-Metal (MAM) based fixed-fixed beam shunt switches, which present variable capacitances along the lines of a parallel coupled bandpass filter, thereby tuning the filter center frequency by 3% between 9.8 to 10.1 GHz. The simulated filter occupies a chip area of 11.8×4.2 mm^2 and achieved an insertion loss of only 0.7 dB over the frequency range of 8-11.4 GHz and return loss of less than -10 dB throughout the operation band. This filter is widely used today in radar, satellite and terrestrial communications and electronic countermeasure applications, both militarily and commercially.

Key words: Microelectromechanical system, MAM, microwave tunable filter, parallel-coupled microstrip

INTRODUCTION

A Micro-Electro-Mechanical-System (MEMS) is a miniature device or an array of devices combining electrical and mechanical components, fabricated with Integrated Circuit (IC) batch-processing techniques. By leveraging existing state-of-the-art of IC fabrication technologies, MEMS technology exhibits many advantages indigenous to IC technologies such as cost, size and weight reduction. These advantageous characteristics have positioned MEMS as a wining technology in many application areas, including accelerometers, pressure sensors, micro-optics and ink-jet nozzles. In this study we are concerned with Radio Frequency (RF) applications of MEMS specifically with wireless communications. As is well known, this area is expanding at an incredible pace for applications ranging from mobile phones to satellite and terrestrial broadband communications and RF MEMS technologies are going to be central to many parts of this expansion (Mezzanotte and Sorrentino, 2002). New developments in satellite communications as well as advances in the area of millimeter-wave multimedia services require high performance components and RF MEMS can fulfill that need by providing critical reductions in power consumption and signal loss, thereby extending battery life or reducing weight. Parallel-coupled Band Pass Filters (BPFs) are more favorable to be used for planar microstrip filters in modern microwave and wireless communication system, due to its weightless, low cost and easy integration (Wu *et al*., 2006). In this context, a novel reconfigurable parallel coupled BPF in microstrip platform with tunable bandwidth at the passband is presented. Tuning is achieved by the surface micromachined MAM shunt switches with electrostatic actuation. The proposed filter differs from the reported MEMS filters in that the bandwidth tunability is obtained by shunt capacitance variation across the resonating stub rather than the conventional length switching. Performance of the presented tunable filter is characterized by using the Electro-Magnetic (EM) simulations (Zeland Software, 2007).

MATERIALS AND METHODS

Design of X-band tunable BPF

Basic BPF topology: In order to design the tunable BPF, a 4th order parallel coupled BPF has been designed on a microstrip platform using coupled half-wave resonators to give a maximally flat response. Microstrip technology has been used for simplicity and ease of fabrication (Edwards and Steer, 2000). Although miniaturized end coupled bandpass filters are widely used for tunable applications, owing to the loose coupling of their resonators they account for high insertion losses and poor performance. This bandpass filter is designed by following the design procedure based on the even- and odd-mode impedances of the coupled lines (Pozar, 1998) and is further optimized using IE3D.

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The filter is designed on silicon substrate (ε_r=11.7) of height 635 μm using Polygon-Based Layout Editor MGRID. With this, the filter requires even- and odd-mode characteristic impedances (Zoe, Zoo) of 90 Ω and 26 Ω, respectively, for the first coupled line section, which translates to a line width of 300 μm and line gap of 30 μm on a 635 μm silicon substrate. The next coupled line section requires Zoe and Zoo of 62 Ω and 22 Ω, respectively, yielding a line width of 600 μm and line gap of 30 μm. The last two coupled line sections are symmetrical to the first two, thus they have the same dimensions as stated earlier. All the quarter-wave coupled lines have lengths of 2500 μm at 16 GHz. The dimensions of the I/O ports are corresponding to a 50 Ω microstrip line which could be consider as subminiature version A (SMA) adapter. Figure 1 and Table 1 show the top view and various design parameters along with the amount of impedances of the filter structure, respectively.

Tuning principle: The concept of tunability is incorporated into the basic filter design by a set of low loss RF MEMS switched capacitors as shown in Fig. 2. A wide variety of shunt and series switches have been successfully designed and fabricated in the past both in coplanar waveguide and microstrip configurations (Jeremy and Rebeiz, 2000). The CPW has invariably become the basic transmission line for MEMS where the shunt switches are directly connected to the ground plane using anchors. They can also be realized on microstrip platform by connecting the anchors to the ground plane using either via holes or quarter wave open stub.

The MAM switch (Panaitov *et al*., 2006) consists of a movable metallic membrane, suspended over the posts placed on either side of the coupled sections of the parallel coupled BPF. The suspended membrane is movable in the vertical direction normal to the substrate.

Table 1: Dimensions of the filter structure with the impedances

Parameters	Section 1	Section 2	Section 3	Section 4
Width (μm)	300	600	600	300
Spacing (μm)	30	30	30	30
Length (μm)	2500	2500	2500	2500
Even-mode Impedances (Ω)	90	62	62	90
Odd-mode Impedances (Ω)	26	22	22	26
Port impedances (Ω)	50	-	-	50

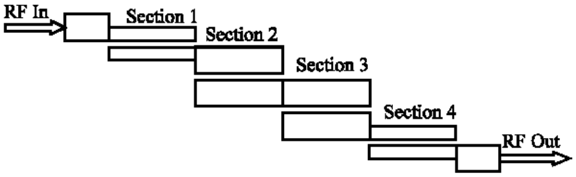

Fig. 1: Top view of the simulated BPF structure

When electric field is applied to a parallel plate system, controlling the height of the movable membrane, applying an external dc bias and thus results in a capacitance given by Eq. 1 (Jeremy and Rebeiz, 2000).

$$C=\left(\frac{\varepsilon_0 A}{g+t_d}\right) \tag{1}$$

Where:
A = Effective area of bridge
g = The gap of the bridge
t_d = The thickness of dielectric

An external dc bias alters the actuation voltage until the plate pulls down itself to 2/3 rd of its initial height beyond which the membrane sticks on to the conductor plate. The pull down voltage of the bridge is given by Eq. 2 (Jeremy and Rebeiz, 2000).

$$Vp=\sqrt{\frac{8kg_0^3}{27\varepsilon_0 W_W}} \tag{2}$$

Where:
k = The effective spring constant of the membrane
W = The width of fixed conductor
w = The membrane width
ε_0 = The permitivity of free space
g_0 = The nominal gap height

The overall filter structure is shown in Fig. 3.

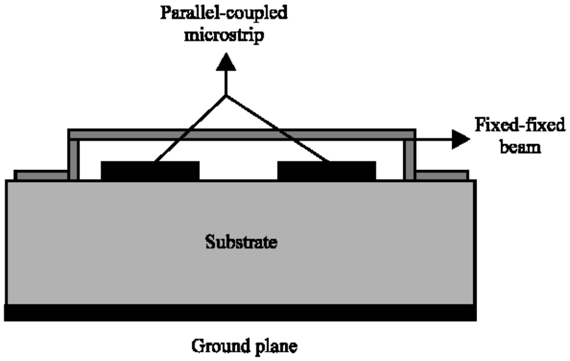

Fig. 2: Cross-section configuration of the tunable filter

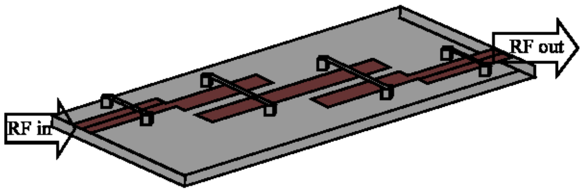

Fig. 3: The 3-D view of the tunable filter

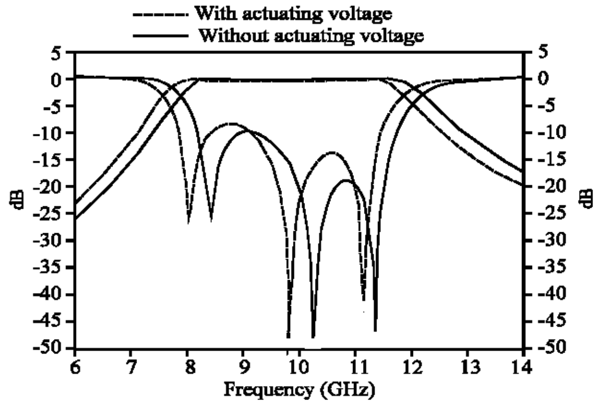

Fig. 4: Simulated S-parameters for the tunable filter

RESULTS AND DISCUSSION

The filter was simulated in the layout window of IE3D-2007. The insertion loss and return loss parameters of the tunable filter are shown in the Fig. 4. Initially, when the bridges are at a height of 36 μm the filter has a center frequency of 10.1 GHz with a 3 dB bandwidth of about 40%. As the actuation voltage is applied to the gold bridges, they start deflecting towards the conductor and consequently the bandwidth starts tuning towards the left side of the initial response. At the minimum height of 12 μm the center frequency shifts to a value of about 9.8 GHz with a 3 dB bandwidth of about 43%.

The bandwidth tuning is almost complete over the entire band of operation. The simulated filter occupies a chip area of 11.8×4.2 mm^2 and achieved an insertion loss of only 0.7 dB over the frequency range of 8-11.4 GHz and return loss of less than -10 dB throughout the operation band. A small frequency shift is encountered when compared to the initial center frequency due to the phase delay introduced by the air bridges and can be rectified by adding a small incremental length to the original length of the resonator. The 3 dB bandwidth of the filter tunes towards the left side of the response from 40 to 43% for corresponding variations in the height of the bridge being controlled by the actuation voltage. This filter is widely used today in radar, satellite and terrestrial communications and electronic countermeasure applications, both militarily and commercially.

CONCLUSION

An RF MEMS based tunable filter for X-band application has been successfully demonstrated using microstrip technology. The filter design was simulated using the IE3D-2007 and the results are studied. The simulated filter occupies a chip area of 11.8×4.2 mm^2 and achieved an insertion loss of only 0.7 dB over the frequency range of 8-11.4 GHz and return loss of less than -10 dB throughout the operation band. The filter is designed on high-resistivity silicon substrate which is compatible with the new SiGe process. Alternatively, the filter could be fabricated on ceramic substrate (ε_r= 10) for even lower loss response. The basic idea can be used to develop tunable filters in various other configurations. The fabrication feasibility of the filter has to be discussed and explored in the future.

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