RF Band-pass Filters using FBAR with Fractal Electrodes

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Abstract — **In this paper, we have proposed the fractal electrodes in Film Bulk Acoustic Resonator (FBAR) and its applications in different filter configurations. The filter performance has been compared with the FBAR filters with simple conventional planar electrodes. To study the effects of fractal geometries on the performance of FBAR filters, the FEM analysis has been carried out using commercially available CoventorWare™ tool. In our analysis, we have observed that the quality factor of FBAR have been significantly enhanced by introducing specific fractal geometries in electrode. And hence, the enhancement of quality factor had led to improvement in the performance of the different filters. The extracted equivalent circuit parameters of FBAR have been used to design and simulate the filters using Agilent ADS commercial software. In this paper, the three types of different filter configurations analyzed and their response were studied.**

Index Terms — Fractal electrodes, FBAR, RF Filters

I. INTRODUCTION

RF filters are key component of any commmunication system. We need theses filters to slelect or reject a frequency band of our interest. Today most of the suitable frequency bands are compeletly occupied by televisions, mobile phones, cordless phones, bluetooth, wireless local area networks (WLANs) as well as industrial and millitary applications. In order to avoid the interference between these applications, highly selective filters are very essential, which maintains the safety margin between two adjacent bands. To achieve such performance using lumped elements, dielectric or surface acoustic wave based front end RF filter above 1 GHz is very difficult. In particular, such filters also have limitations like large size and weight to achieve low insertion loss.

The film Bulk acosutic wave (FBAR) filter offers advantages of low insertion loss and smaller in size compared to lumped elements and dielectric resoantor based filters.

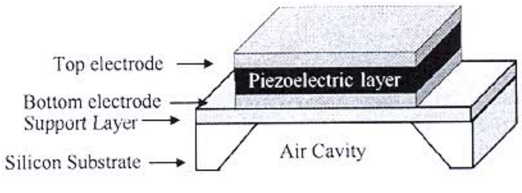

Figure 1: Typical FBAR structure

Apart from it , these kind of filters are compatible with CMOS technology, therefore they can be intergrated with active circuitary. Primarily, FBAR consists of a thin-film piezoelectric layer, which is sandwiched between top and bottom electrodes and is the heart of the device. The AlN and ZnO are commonly used piezoelectric materials. A cross section view of FBAR is shown in Figure 1. Conventionally, top and bottom electrodes are simple planar electrodes. In our previous study [1], we have proposed fractal electrodes in FBAR as shown in Figure 2. It has been seen that using specific fractal geometries in electrodes there is a significant increase in quality factor. In our case, quality factor of FBAR has been increased by 27% using 3rd order Hilbert fractal geometry.

In this paper, we propose different bandpass filter configurations using fractal FBARs and studied their filter responses. We have considered three types of filter topologies namely, ladder, lattice and mixed as shown in Figure 3. It has been found that using fractal FBAR, the insertion loss, group delay and selectivity have been significantly improved.

II. DESIGN AND SIMULATION

To study the fractal electrodes based FBAR filters, the following three different RF filter configurations, namely ladder, lattice and mixed filter have been designed, simulated and studied . In order to realize the FBAR based bandpass filter, we need to have two pairs of FBAR resonators, whose paraellel resonance frequency of one pair must be equal to series resonance frequency of the other pair.

Ladder filter used for both single-ended and balanced signals. However, single-ended configuration is most popular. In ladder topology,

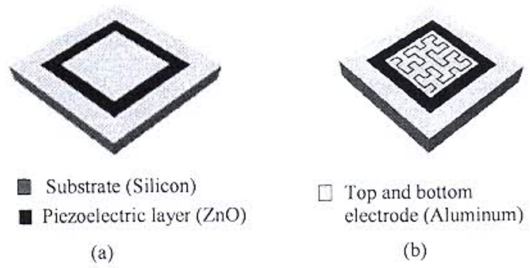

Figure 2: FBAR (a) planar electrode (b) Hilbert 3 electrode geometry

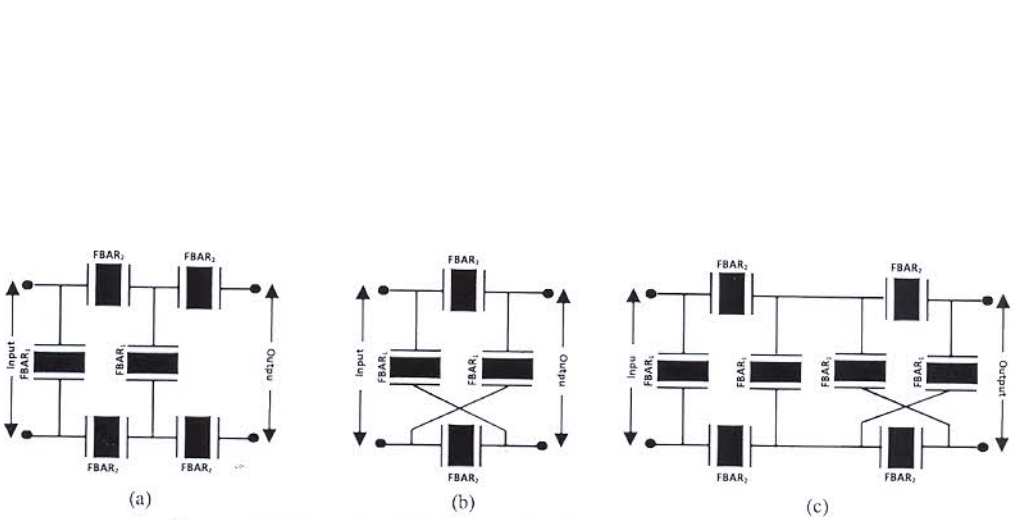

Figure 3. Three filter configurations (a) Ladder filter (b) Lattice filter (c) Mixed filter

Table 1: Extracted Circuit parameters of different resonators used for Filters [1]

Filter		F_r (GHz)	F_a (GHz)	R_m (Ohm)	L_m (nH)	C_m (fF)	C_0 (fF)	Q_r	Q_a
Without Fractal	$FBAR_1$	1.683	1.740	23.81	693.81	12.87	190.5	308	302
	$FBAR_2$	1.950	2.032	15.89	355.8	18.7	231.3	274	269
Fractal	$FBAR_1$	1.697	1.782	12.42	468.57	18.75	184.9	402	368
	$FBAR_2$	1.974	2.054	12.46	356.29	18.24	220.6	354	321

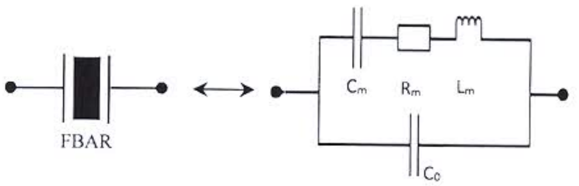

Figure 4: Equivalent BVD circuit Model of FBAR

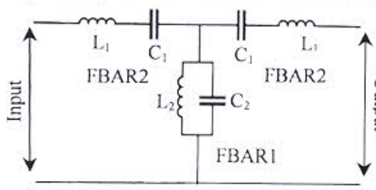

Figure 5: Typical Band-pass filter circuit

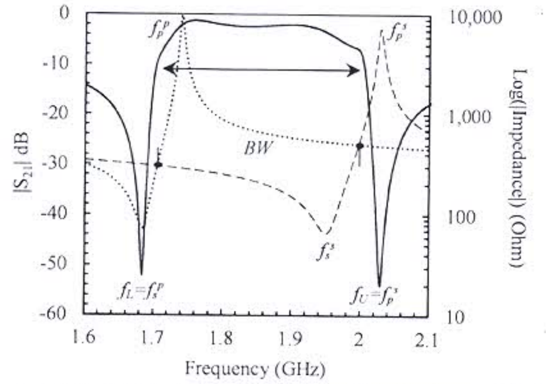

Figure 6: Dotted and Dashed lines represents the impedance of shunt and series FBAR resonators while solid line represent insertion loss of filter

two resoantors are periodically connected in series and in shunt configuration as shown in figure 3(a). The series resoantor has resonance frequency (f_s), where the electrical impedance is minimum (Z_{min}) and shunt resonator has resonance frequency (f_p), where the electrical impedance is maximum (Z_{max}). At frequency below from the series resonance frequency and above the parallel resonance frequency, the resonator behaves as pure capacitor (C_0). At frequency between series resonance frequency (f_s) and anti-resonance frequency (f_p), it behaves as pure inductor. The ladder-type filter gives a steep roll-off but poor out-of-band (OoB) rejection characteristics. A better out of band rejection can be achieved by cascading more section to the filter, however, the insertion loss has to be traded with number of the section of the filter. The group delay of the filter is poor due to ripples present in the pass band. The parallel resoanance frequency of series resoantor decides higher cutoff and the parallel resonance frequency of series resoantor decides lower cutoff of the filter. The bandwidth is decided by the cross over frequencies of the imedance curve as shown in figure 6.

The lattice filter is used when both filter ports are balanced. Lattice filter cotains bridge types of structures with four resoantors as shown in figure 3(b). The series resoantor of the filter must be equal to parallel frequency of the shunt resonator to form the passband of the filter. In lattice configuration, one branch behaves as a inductor and other branch behave as a capacitiance. When all branch have equal impedance, the transmission zero forms. The lattice filter gives poor roll-off but better Out of Band rejection (OoB) characteristics. It also gives flat group delay compared to ladder filter. The group delat is flat in the passband due to minimum ripple present in the passnband.

The mixed filter is a combination of both ladder and lattice type filter as shown in figure 3(c). The one section of the filter is

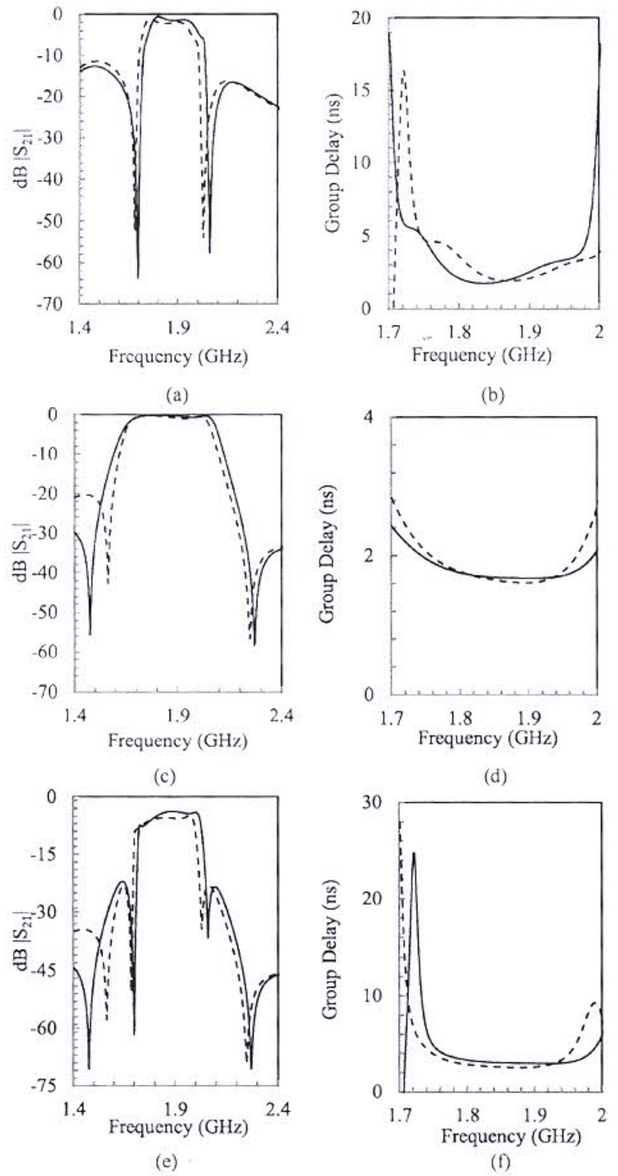

Figure 7 Dashed lines represents planar electrode filter and solid lines represents fractal electrode filter. Ladder Filter (a) Insertion Loss (b) Group Delay, Lattice filter (c) Insertion Loss (d) Group Delay, Mixed Filter (e) Insertion Loss (f) Group Delay

lattice filter and it is conncected in series to the ladder filter. It exhibits properties of both ladder and lattice type filters. It has good roll-off as well as out-of-band rejection characteristics. The group delay is poorer than lattice filter but better than ladder filter. To compare the performance of filter with fractal FBAR with conventional FBAR filter, the two filters have been realized and simulated using Agilent ADS software tool. We have studied $|S_{21}|$ and group delay. In order to construct the filter, two different thickness of the FBAR has been considered, one FBAR contains thickness of 1.24 μm ($FBAR_1$) and other contains thickness of 1.50 μm ($FBAR_2$). The characteristics of the both FBARs are given in table 1. The equivalent circuit of the both FBARs is imported in ADS and ordered as figure 4 in order to construct the filter and the typical band pass filter and its realization in terms of FBAR series and shunt resonators is shown on figure 5.

III. Results and Discussion

The $|S_{21}|$ and corresponding group delay have been plotted in Figure 5. It has been seen that filter performance like insertion loss, group delay and selectivity has been improved with the use of fractal electrodes as compared to normal planar electrodes. This improvement is directly related to quality factor of FBAR. The dotted curve corresponds to responses of filters with FBAR with normal electrodes while continuous curve corresponds to FBAR with fractal electrodes. The results show that insertion loss in pass band is improved by -0.964 dB in fractal FBAR filter as compared to -1.65dB in simple electrode FBAR filter. While the maximum rejection goes to ~-40 dB in the case of FBAR with simple planar electrodes while the maximum rejection goes to ~-50 dB in the case of FBAR with fractal electrodes which is 10 dB higher. The group delay behavior is shown in Figure 12. It can be seen from the results that the group delay is more uniform in fractal FBAR than without fractal. Within the pass band, the group delay of the fractal FBAR is found to be 1.76ns, while the group delay was found to be 1.80ns in case of without fractal FBAR.

V CONCLUSION

We have presented various fractal FBAR filter configurations and studied the effect of fractal electrodes in different types of filter. It is found that filters with fractal electrodes have better performance as compared to the normal FBAR filters. The proposed fitters can lead to new types of filter with improved performance.

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