The analysis of the influence of the auxiliary components on FBAR response

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ABSTRACT

The future trend for wireless portable products is towards integration, size and cost reduction. With MEMS technologies, the thin film bulk acoustic wave resonator (FBAR) filters have the potentials to help fulfill these goals. To further improve the performance of FBAR devices, auxiliary components such as inductors and capacitors are often used. This paper will discuss the effects of such components on the resonance frequency of FBAR and discuss the design of FBAR filters from a circuit viewpoint systematically.

Based on ladder type filer and possible number and placements of auxiliary component, the impedance and S-parameter frequency responses can also be analyzed. The simulation results can help optimize the performance of filter or duplexer. The discussion and conclusion would be very helpful to the implementation of FBAR filter and duplexer.

Keywords: thin film bulk acoustic wave resonator, wireless, filter

1 INTRODUCTION

In recent years, we have witnessed the explosive growth of wireless communication services. Besides cellular phone, Bluetooth, Global Positional System (GPS), and Wireless LAN are emerging wireless communication applications. The trend for these wireless portable products is towards integration, size and cost reduction. With micro electromechanic system (MEMS) technologies, the thin film bulk acoustic wave resonator (FBAR), as shown in Fig 1, has the potentials to be realized on semiconductor chips to help fulfill these goals. In the filter applications, FBAR has many advantages, such as size, power handling, integration, and loss issues, over Surface Acoustic Wave (SAW) devices. To further reshape the response of FBAR devices, auxiliary components such as inductors or capacitors are often used. For example, the narrow bandwidth and rejection isolation of AlN FBAR filters are often improved by adding such auxiliary components.

There are quite a few studies on FBAR filter design and modeling [1-6]. However, systematic methods and studies to implement such auxiliary components are rare. This paper will discuss the effects of such components on the resonance frequency and the influences on the design of FBAR filters from a circuit viewpoint. The discussion and conclusions would be very helpful to the implementation of FBAR filter and duplexer.

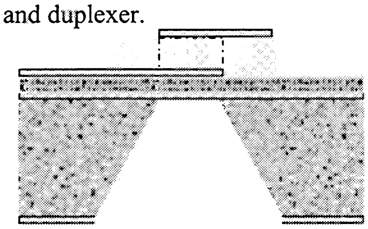

Fig. 1 Typical FBAR structure

2 EFFECTS OF AUXILIARY COMPONENTS

A typical FBAR is mainly composed of top/bottom electrodes and piezoelectric layers (e.g., PZT, AlN and ZnO) in between. Sometimes, a supporting or temperature compensation layer is also used. Piezoelectric layers are used here to make transduction between the electrical signal and acoustic wave. In order to effectively trap the energy inside the resonator, some special structure is made to reflect the elastic wave by means of the impedance difference. The special structure is usually an air cavity underneath the FBAR structure made by MEMS techniques. As appropriate RF signals are applied on the FBAR devices, the devices will exhibit resonance. The imaginary impedance frequency response, as shown in Fig. 2, will have minimum at the resonance frequency (f_r). As it occurs the whole device looks like a short circuit. But the imaginary impedance frequency response will have maximum at the anti-resonance frequency (f_a). The difference between these two frequencies, Δf, is of importance in filter design. It is determined by the electrode and piezoelectric materials and their thickness used. These effects are discussed by authors in another paper [7]. Based on the resonance characteristics of FBAR, a BVD equivalent circuit model around the resonance can be developed as shown in Fig. 3.

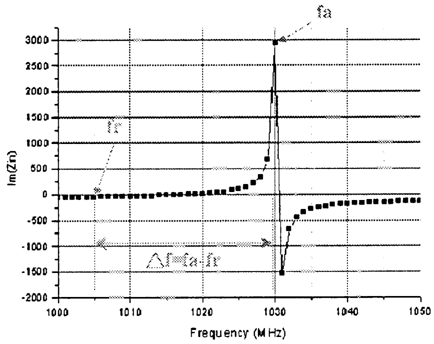

Fig. 2 FBAR impedance frequency response

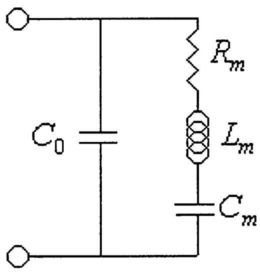

Fig. 3 BVD model of FBAR

As a FBAR is connected with a series inductor, the impedance response of whole circuit will have new zeros (due to the addition of the impedance response of a FBAR and that of a series inductor). There exist two new f_rs and they will emerge at both the lower and higher frequency sides, as shown in Fig. 4. The new zero locations are decided by the values of inductors. However, f_a still remains in the same position. If a FBAR is connected with a parallel inductor, similar phenomena will be expected (due to the addition of the admittance response of a FBAR and that of a parallel inductor). But this time new f_as will emerge at both sides and f_r will remain in the same position instead. By using this, the Δf can be widened and the wider bandwidth for filter can then be obtained. As shown in Fig. 5, a series capacitor is connected with a FBAR, but this time only one new and larger f_r is obtained. The resulted bandwidth will be narrowed instead. Therefore a FBAR device using a high electromechanical coupling material can be modified using auxiliary capacitors.

Meanwhile, area sizes used for FBARs have also significant influences. As shown in Fig. 6, when a FBAR connects with a series inductor, f_r will move to a lower frequency. The larger the FBAR area is, the farther the f_r will move to. However, when a FBAR connects with a parallel inductor, f_a will move to a lower frequency from the original f_a. The larger the area is, the closer the f_a will move to. This characteristic can also be used for widening the passband bandwidth or adjusting the isolation at the stopband.

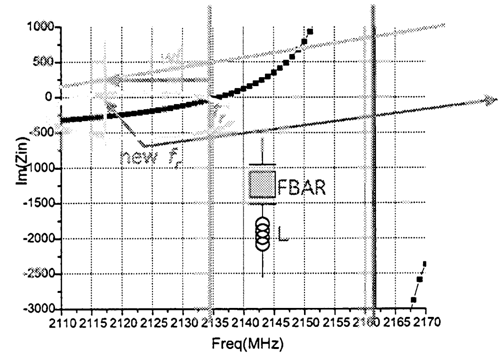

Fig. 4 a FBAR connected with a series inductor

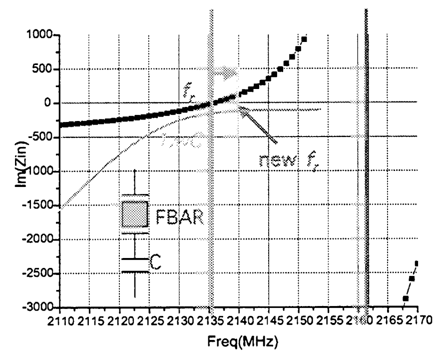

Fig. 5 The effect of different areas to f_a variation

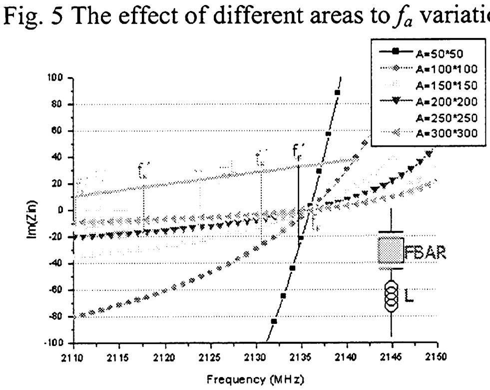

Fig. 6 The effect of different areas to f_r variation

It is also found that the value of inductor can be related with the area size used for FBAR filter. From the derived equivalent circuit model, the relations between the auxiliary inductor and BVD circuit parameters can be first obtained. Let w be equal to w_x (new series resonance frequency) and set $Im(Z_{in})=0$, the relation between series inductor and FBAR is

$$L_s = \frac{(1-w_x^2 L_m C_m)(C_o - w_x^2 C_o L_m C_m) + w_x^2 C_o C_m^2 R_m^2}{w_x^2 (C_o - w_x^2 C_o L_m C_m)^2 + w_x^4 C_o^2 C_m^2 R_m^2} \quad (1)$$

Similarly let w be equal to w_y (new antiresonance frequency) and set $Im(Y_{in})=0$, the relation between parallel inductor and FBAR is

$$L_p = \frac{1}{w_x(w_x C_o + \frac{w_x C_m (1 - w_x^2 L_m C_m)}{(1 - w_x^2 L_m C_m)^2 + w_m^2 R_m^2 C_m^2})} \quad (2)$$

With the help of Eq. (1) and (2), the required values of series and parallel inductors can be obtained for the given resonance and antiresonance frequency through the manipulation of the four parameters of BVD model. These parameters are somehow related with FBAR area sizes. After the resonance frequencies of FBAR filters are set according to the filter specifications, the required value of auxiliary components can be decided through the circuit parameters and calculations. To implement such auxiliary components in filter appropriately, a systematic method is further developed to help design.

3 FILTER DESIGN

If FBARs are mutually interconnected by series and parallel connections, as shown in Fig. 7, a bandpass filter or band rejection filter can be formed like a traditional LC filter. Usually two different resonance frequencies are used in such a configuration: all series FBAR devices share an identical frequency and all shunt FBAR devices share another identical but lower frequency. Therefore, two different thicknesses of FBAR are required. As the frequency of the applied RF signal is lower or higher than the stopband frequencies, the whole filter performs like a capacitor. As the applied frequency approaches f_r of shunt FBAR, the filter performs like a short circuit and most of the signals will be reflected, causing an attenuation pole. With a higher frequency close to f_a of shunt FBAR and f_r of series FBAR, then all shunt FBARs have high impedance and all series FBARs have low impedance. The insertion loss of whole filter is very low for this range of frequency and is used for passband. As frequency increases and gets close to f_a of the series FBAR, the filter looks like a short circuit again, causing another attenuation pole. FBAR usually is capable to provide a better and sharper attenuation profile.

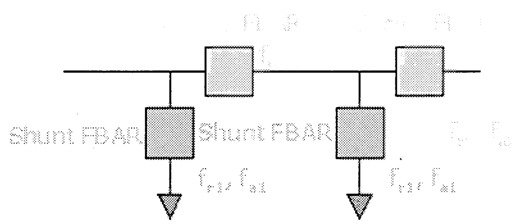

Fig. 7 Ladder type FBAR filter

3.1 Effects of placements of inductors

Different placements and numbers of auxiliary components used may change the behavior of filter. In addition to the change of S-parameter frequency response, the impedance response will be influenced too. These two responses should be considered at the same time to make an optimal filter or duplexer. For a typical 2-1/2 ladder type filer, the possible number and placements of auxiliary inductors are as shown in Fig. 8. The impedance and S-parameter frequency responses for the configuration of the case I are shown in Fig. 9. The results will be analyzed as an example. As shown in Fig. 10, the resonance frequency f_{r1} of a shunt FBAR will shift to f_{r1}', when it connects with a series inductor. The other resonance frequencies will remain at the original values. From the above discussion, it is known that the whole filter performs like a capacitor, as shown in Fig. 11(a), and has a low equivalent impedance at f_{r1}'. At frequency f_{r1}, the final impedance is dependent on the values of equivalent inductors and capacitors, as shown in Fig. 11(b), and could be very different. Between f_{a1} and f_{r2}, the input impedance is equivalent to 50Ω, as shown in Fig. 11(c). As frequency is approaching f_{a2}, the series FBARs perform like very large inductors, and the filter will exhibit high impedance status, as shown in Fig. 11(d). The addition of capacitors would not produce high impedance responses as inductors do since they can only change the location of f_r.

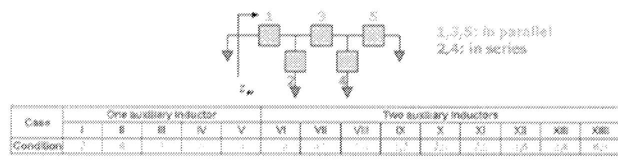

Fig. 8 Possible number and locations of inductors

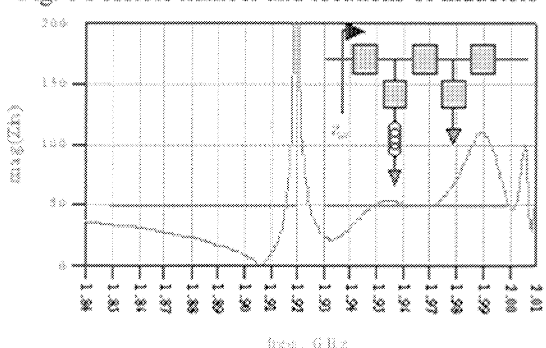

Fig. 9 Impedance response of case I

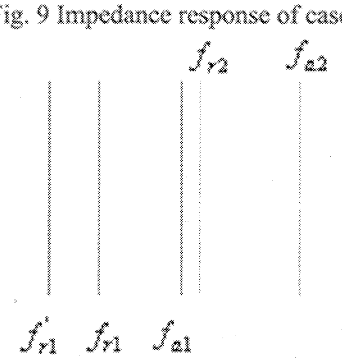

Fig. 10 Frequency distribution in FBAR filter

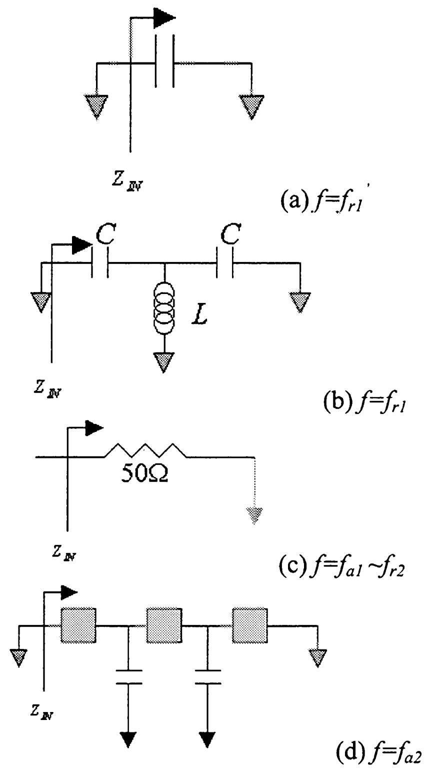

Fig.11 The equivalent circuits at different frequencies

The analysis methodology can be used to further help optimize the performance of filter or duplexer on S-parameter and impedance frequency response simultaneously.

4 CONCLUSION

In order to further improve the performance of FBAR devices, auxiliary components such as inductors or capacitors are often used. For example, a narrow bandwidth and rejection isolation of an AlN FBAR filter can be improved by adding such auxiliary components. In this paper, systematic methods to implement such components in the design of FBAR filters from a circuit viewpoint are proposed. The effects of such components on the resonance frequencies of a FBAR are also studied. Based on these analyses, the appropriate choice of auxiliary components and FBAR area sizes for FBAR filter design can be made. The discussion and conclusion could be very helpful to the implementation of FBAR filter and future duplexer.

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