A Novel Thin Film Bulk Acoustic Resonator (FBAR) Duplexer for Wireless Applications

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Abstract

A duplexer comprising transmitter (Tx) filter and receiver (Rx) filter using thin film bulk acoustic resonators (FBARs) for use in 1900 MHz PCS band is presented. The typical minimum rejection specifications for Rx filter are > 50 dB in the band of 1850−1910 MHz and for Tx filter are > 40 dB in the band of 1930−1990 MHz. The duplexer requires filters to pose very steep roll-off characteristic because of the very narrow guard band. In the meanwhile, the input impedance must have high impedance in the stopband of each filter to guarantee the receiving signal will go to the Rx filter and the transmitting signal will go to the antenna only. This paper proposes a systematic methodology to design a duplexer to meet all the above requirements using FBARs with minimum auxiliary devices.

Key Words: FBAR, Duplexer, Filter

1. Introduction

A duplexer is a three-port device, in Figure 1, having a transmitting port, a receiving port and an antenna port. It provides the necessary connection while prevents the modulated transmitting signal generated by the transmitter from being reflected from the antenna back to the input of the receiver and overloading the receiver. A time switching system uses switches to select between the Rx bands and the Tx bands and provides good connections and attenuation properties. For a frequency division multiplexing structure, a duplexer instead a switch is used. Usually, the specification of the duplexer demands that the guard band between the transmitting signal and the receiving signal is about 1% of the carrier frequency and the bandwidth assigned to the transmitting and the receiving signal are about 3% of the carrier frequency. This means that the Rx filter and Tx filter are required to have an extremely sharp roll-off. Although ceramic filter is able to meet these requirements, its large size and high cost make it in competitive. As for surface acoustic wave (SAW) filter [1], its performance as a duplexer is not very good though it has the advantage of low cost and small size. FBAR duplexer can overcome these problems [2−5]. Nevertheless a quarter-wave transmission line is usually used between antenna and Rx filter as the phase shifter and this may cause unnecessary parasitic effects and enlarge the device size.

This paper proposes a novel design of a duplexer using FBARs with minimum auxiliary devices and requires no additional quart-wave transmission line.

2. Conventional FBAR Duplexers

The duplexer proposed by Agilent shown in
Figure 2 consists of Tx filter and Rx filter; both are ladder type filters. One port of the Tx filter is connected to the transmitter section and the other is connected to the antenna. The Rx filter is connected to the antenna through a quarter-wave transmission line. Each filter has resonators with two frequencies wherein the shunt FBARs all have the same resonant frequency and series FBARs all have the same resonant frequency that is a few percent higher than shunt FBARs. The auxiliary inductors can be used to increase the bandwidth in the passband and enlarge the attenuation at stopband as shown in Figure 3. It should be noted that if these two bandpass filters are connected directly to the antenna, the performance of Tx filter would degrade as in Figure 4. This is because the input impedance of Rx filter is not high enough in its lower stopband (the passband of Tx filter). The method proposed by Agilent [2,3] is to use the phase shifter that may be composed of lumped inductors and capacitors or a quarter-wave transmission line and this can transform the impedance into high impedance as in Figure 5 and improve the performance of duplexer as in Figure 6. However, this additional phase shifter may introduce parasitic effects and increase the size of the duplexer.

3. A Novel FBAR Duplexer

To overcome the problems discussed above, a new strategy of designing duplexers is proposed. Similar to a conventional FBAR duplexer, a ladder-type filter structure is adopted. The auxiliary inductors are used to tune the passband bandwidth, sharper the roll-off in the guard band, and increase the attenuation in the stopband for each bandpass filter. The inductors can be connected to the shunt FBARs in series or to the
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3.1 Limited $\Delta f$ of FBAR

Since the bandwidth of the filter is related to $\Delta f (= f_a - f_r)$ of FBAR which is the material property of the piezoelectric film, we can only tune $\Delta f$ by changing the thickness ratio of piezoelectric layer to electrode layer or by using auxiliary components such as inductor or capacitor [6]. Here, the auxiliary inductor is used to enlarge the value of $\Delta f$. As shown in Figure 8, the original $\Delta f$ is expanded to $\Delta f'$, and correspondingly the bandwidth of the filter will become larger.

3.2 The Roll-off in the Guard Band and the Attenuation in the Stopband

One way to increase the roll-off in the guard band and the attenuation in the stopband is to use multiple FBAR thicknesses. It will allow more choices on possible zeros. From fabrication consideration, it is not practical. Through the manipulations of the auxiliary inductors, however, the resonant frequency and dip phenomena of FBAR filter can be changed. Hence the roll-off in the guard band and the attenuation in the stopband can be modified by choosing the number and positions of dips as in Figure 9.

As shown in Figure 9, the $f_1$ of shunt FBAR causes one dip and the other two dips are contributed by the two auxiliary inductors. By further tuning the position of these dips, the roll-off in the guard band and the attenuation in the stopband
Figure 10. The impedance of the FBAR filter without auxiliary inductors.

Figure 11. The impedance of the FBAR filter with auxiliary inductors.

can meet the specification of PCS duplexer.

3.3 Impedance Matching

Beside the two issues mentioned above, we must make sure the impedance in the stopband for each filter is high enough. Since the Tx filter already has high impedance, it is not necessary to do anything. As for Rx filter, it has very low impedance below the passband as in Figure 10. This will cause the transmitting signal to mix with the receiving signal at the receive port and may overload the low-noise amplifier. Therefore the performance of the duplexer may degrade as shown in Figure 4. Unlike the method adopted by Agilent, through appropriate arrangement of auxiliary inductors, the impedance of Rx filter can be pulled up to high impedance region as shown in Figure 11. The effect is the same as the phase shifter used between the antenna and the Rx filter with no additional transmission line required. This is good for parasitic effects elimination and size reduction. However, from the study it is concluded that the position of the inductor must connect with the first series FBAR in parallel and there should be no shunt FBARs connected in front of this FBAR.

4. Simulation Results

Based on the proposed method, a duplexer used for PCS system can be designed easily and effectively. An example is given as in Figure 12, wherein a series FBAR in the Tx filter is connected with an inductor in parallel (Tx band: 1850–1910 MHz) and series FBARs in the Rx filter are connected with two inductors in parallel (Rx band: 1930–1990 MHz). Ten FBARs are used in the duplexer totally. All specifications are met. The auxiliary inductors play multiple roles here such as enlarging $\Delta f$, adjusting roll-off in the guard band and attenuation in the stopband, and also acting as the phase shifter.

5. Conclusion

In this paper, a new ladder-type FBAR duplexer without additional phase shifter has been proposed. The obtained frequency characteristic shows low insertion loss, high attenuation at stopband, and sharper roll-off. They meet all the required duplexer specifications for PCS system. In addition, the elimination of auxiliary phase shifter device is effective to remove unnecessary parasitic effects and reduce the size of the duplexer.

References


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