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Nonlinear Distortion of Acoustic Devices for Radio-Frequency Front-End and Its Suppression

RF フロントエンド弾性波デバイスの非線形歪みとその抑圧

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1. Introduction

Requirements being placed on acoustic devices for mobile communication systems are becoming more and more stringent every year. In addition to very low insertion loss and steep cutoff characteristics, it is vital to reduce the inter-modulation distortion (IMD) or so-called triple-beat (TB) products, so that they can be used in the wideband code division multiple access (WCDMA) or third-generation systems [1,3].

This paper clarifies nonlinearities on surface acoustic wave (SAW) and bulk acoustic wave (BAW) resonators and indicates the importance to suppress the even-order nonlinearity of BAW resonators. Then, we demonstrate the further effectiveness of our proposed method [4] using several types BAW duplexers and present how to reduce nonlinearities.

2. Nonlinear products of SAW and BAW resonators

It is empirically known in industries that duplexers employing RF BAW technologies such as a film bulk acoustic resonator (FBAR) and solidly mounted resonator (SMR) offer somewhat better TB than those employing SAW technologies. This can be explained by the difference in the stored energy density in the resonators. Since piezoelectric materials ($LiTaO_3$, $LiNbO_3$) for used in the substrates of RF SAW devices have about four times more permittivity than the AlN used in RF BAW devices, the electrode area of BAW resonators is larger than that of SAW.

In contrast, it is also known that SAW duplexers offer a 2nd order nonlinearity suppression that is roughly a few tens of dB better 2nd-order nonlinearity suppression than that offered by RF BAW duplexers. Then, we experimentally measured the second- and third-order harmonics in both an AlN- base FBAR [2] and a $LiTaO_3$ SAW one-port resonator for an input power of 26 dBm, where both resonators have almost the same static capacitance.

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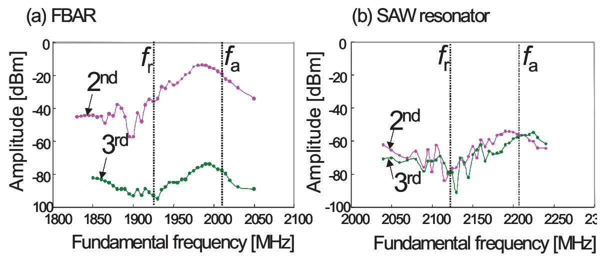

Fig. 1 2nd and 3rd nonlinear harmonics caused by FBAR (a) and SAW (b) resonators.

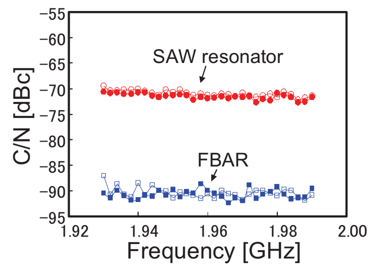

Fig. 2 Triple-beat caused by FBAR and SAW resonators

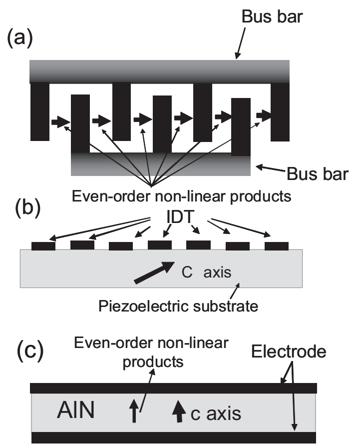

Fig. 3 Even-order nonlinear products for SAW (a), (b) and BAW (c).

The third-order distortion of FBAR was about 15 dB better than that of SAW, while the second-order distortion of FBAR was about 30 dB worse than that of SAW (see Fig. 1). We also investigated TB products on SAW resonator and FBAR, where SAW or FBAR with about 2.2-GHz resonant frequencies. As a result, BAW resonators indicate better performance than SAW resonators shown in Fig. 2. Let us consider the electric field distribution in the SAW transducer (see Fig.3). Since it is essential to have structural asymmetry to produce piezoelectricity, a piezoelectric substrate inherently produces an even-order distortion as well as the odd-order distortion that is produced by the applied electric field. It should be noted that the polarity of the even-order distortion is determined by the direction of the crystal axis and is independent of the polarity of the electric field. Therefore the generated even-order distortion will not be detected by the SAW transducer due to the alternate polarity of the electrode geometry. We understand it is important to cancel out the IMD products to suppress the even-order distortion.

3. Simulation and experimental results of BAW nonlinearities

We demonstrate the proposed way [4] using 2.1-GHz band 1 air-gap type FBAR duplexers [2] with Tx filter topologies shown in Fig. 4, and compared the simulation with the experimental results. Leftmost portion of the filter in Fig. 4 is consists of topology (1)-(4), and arrows attached to resonators symbol indicate the polarity of AlN *c*-axis. Here, Rx filter was connected to Port 1 which was common terminal as an antenna port. A sinusoidal signal $f=f_a$ was applied to the Tx port (Port2). A power amplifier was added to increase the output level from the antenna port (Port 1) to 21 dBm. Another sinusoidal signal $f=f_b$ (-15 dBm) was also supplied to the port 1, and the IMD2 with $f=f_b-f_a$ was detected at the Rx port by a spectrum analyzer.

Since f_a and f_b were scanned simultaneously from 1.92 to 1.98 GHz and 4.03 to 4.15 GHz, respectively, the IMD2 signal with $f=f_b-f_a$ appeared in the Rx band (2.11 to 2.17 GHz). The simulation was performed for the IMD2 characteristics of these FBAR duplexers. Figure 5 shows a comparison of the simulated and measured IMD2 products as a function of f_b-f_a. Except for a slight shift in the IMD2 minimum frequency, they agreed fairly well. Structure (3) and (4) have about 20 dB smaller than that of structure (1). This is because in structures (3) and (4), two identical resonators are connected in polarity-inversion set-up, and this causes the IMD products caused by two resonators to cancel out.

4. Conclusions

We discussed the difference in nonlinear performance between SAW and BAW resonators, and were able to evaluate the accuracy and efficiency of the proposed simulation technique on BAW devices by comparison our simulation with the experimental data. We also indicated how to reduce even-order nonlinearity.

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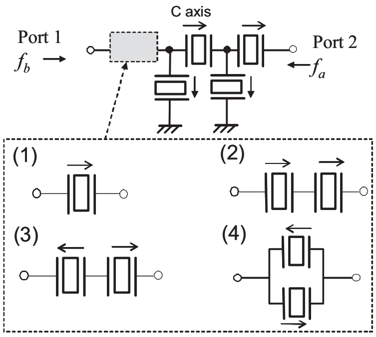

Fig. 4 Filter topology.

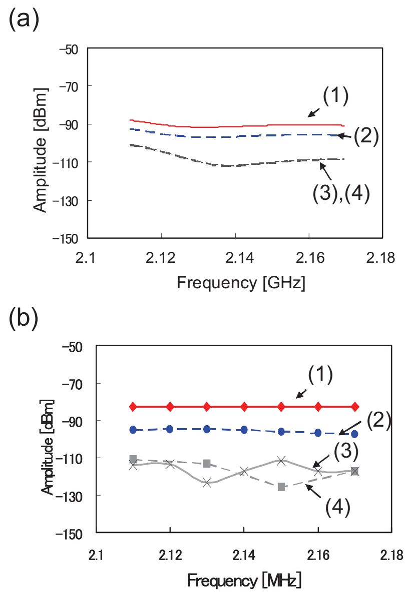

Fig. 5 FBAR IMD products, (a) simulated results, (b) experimental results.

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