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SHF Band Filters Configured with Air-gap Type Thin Film Bulk Acoustic Resonators

エアギャップ型圧電薄膜共振子を用いた SHF 帯フィルタの開発

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1. Introduction

Today, the mobile phone market is expanding rapidly, and a lot of wireless specifications are proposed in GHz band. For the effective frequency use, systems operating in several ten GHz should be discussed[1]. Filters for X to K band, which are using thin film bulk acoustic resonators (FBARs) have been already reported from our group[2,3].

In this paper, the development of the first K to Ka band FBAR filters if the world is reported.

2. Design

2-1. Loss estimation

In the FBAR filter design, a modified Butterworth-Van-Dyke (MBVD) equivalent circuit, where loss elements are added to the BVD equivalent circuit as shown in Fig. 1, is adopted generally[4].

All reactance elements on the MBVD equivalent circuit can be determined by structural constants of the FBAR, such as the thickness of films or the size of the active area. In contrast to that, loss elements have to be determined experimentally. It is impossible to design the filter without trial production. FBARs operating above K band, however, have not been reported before.

The impedance of the FBAR at resonance is calculated theoretically as[5]

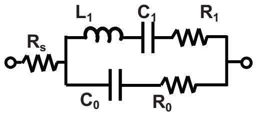
$$R_r = \frac{\pi}{2}\frac{Z_0}{jk_t^2}\cot\left(\frac{\pi}{2}(1+j\alpha)\right) \approx \left(\frac{\pi}{2}\right)^2\frac{\alpha Z_0}{k_t^2} \qquad (1)$$

where k_t^2, α, and Z_0 are the coupling coefficient, attenuation constant and characteristic impedance, respectively.

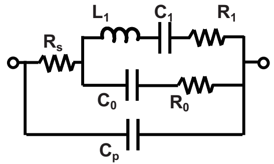
α is proportional to the resonant frequency ω_r. k_t^2 is inversely proportional to the capacitance ratio γ. Therefore, defining the normalized loss

$$R_{r\_norm} = \frac{R_r}{Z_0} \propto \omega_r\gamma \quad , \qquad (2)$$

it is proportional to the $\omega_r\gamma$.



(a) MBVD equivalent circuit



(b) MBVD equivalent circuit including parasitic capacitance

Fig. 1 Equivalent circuits based on the BVD model

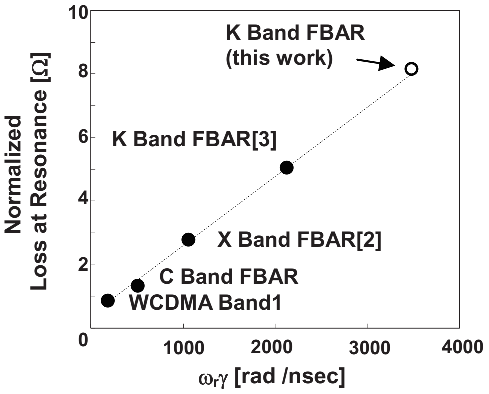


Fig.2 Relationship between the loss at resonance and $\omega r\gamma$

Filled circles in Fig. 2 indicated the relationship between the normalized loss and $\omega_r\gamma$ in the FBARs we developed[2,3]. It can be confirmed from Fig. 1 that plotted points are aligned on a line.

By using this relation, the loss elements can be estimated for a wide frequency range.

2-2. The effect of the parasitic elements

In frequency bands at several ten GHz, the result calculated using the MBVD model is not corresponding enough to the measured data within the attenuation band. This disagreement is caused by lead patterns on the chip, which are parasitic elements as well. The influence of the parasitic

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elements can be calculated using an electro-magnetic (EM) simulation based on the finite element method (FEM). However, the EM simulation needs long calculation time and is not very flexible.

Among the parasitic elements, the parallel capacitance C_p is the most crucial element within the attenuation band. By using the equivalent circuit as shown in Fig. 1 (b), the attenuation level can be estimated.

3. Verification

3-1. K band filter

The open circle in Fig. 2 indicates the loss element derived from measured data of the K band FBAR, which is fabricated on the same wafer as the filter. It is aligned on the expected line. It could be confirmed that the loss can be estimated by the relation indicated in Eqn(2).

The K band FBAR filter was designed using the MBVD model substituted the loss elements derived from Fig. 2. Figure 3 shows the topology of the filter, which was 4-stages ladder type filter. The simulation result is shown in Fig. 4 as the thin solid line.

The characteristics of the fabricated K band filter were shown in Fig. 4 as the solid line. The measurement and the simulation were matching well within the pass-band. Center frequency, fractional bandwidth and minimum insertion loss in the K band filter were 23.8 GHz, 3.4% and -3.8 dB, respectively.

The dotted line in Fig. 4 indicates the simulation results using the MBVD model with C_p as shown in Fig. 1 (b), where C_p was determined experimentally[2,3]. The simulation agrees with the measurement data well in the attenuation band without the EM simulation.

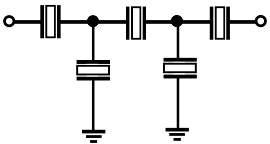

Fig. 3 Topology of the K band filter

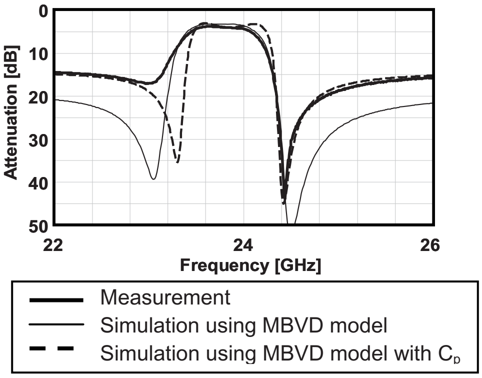

Fig. 4 The characteristics of the K band filter

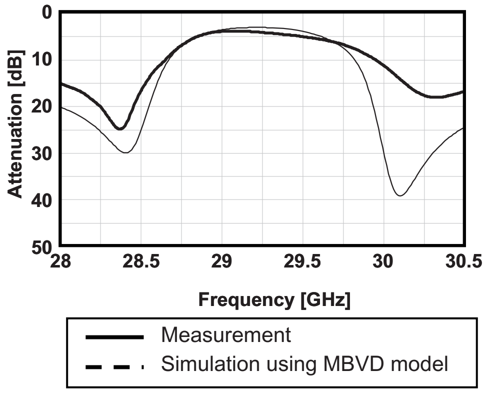

Fig. 5 The characteristics of the Ka band filter

3-2. Ka band filter

As a feasibly study, the Ka band FBAR filter was fabricated. It was designed by usage of the same technique as for the K band filter. The filter characteristics are shown in Fig. 5. Center frequency, fractional bandwidth and minimum insertion loss of the fabricated Ka band filter were 29.2 GHz, 3.4% and -3.8 dB, respectively.

4. Conclusion

In this study, the first K and Ka band filters of the world using thin film bulk acoustic resonators (FBARs) were developed. The filters were ladder type filter configured with the air-gap type FBARs and designed using an equivalent circuit based on a Butterworth-Van-Dyke (BVD) model.

A center frequency, a fractional bandwidth, a minimum insertion loss and suppression in attenuation band were 23.8 GHz, 3.4%, -3.8 dB and -13 dB in the K band filter, and were 29.2 GHz, 3.4%, -3.8 dB and -11 dB in the Ka band filter, respectively.

Acknowledgment

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