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Low Insertion Loss Hexaplexer for Band 1+3+7 Using Spurious-Suppressed I.H.P. SAW Devices

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1. Introduction

In recent years, the miniaturization of filters has been increasingly demanded due to the positive utilization of carrier aggregation, which transmits and receives simultaneously in multiple bands, and the increasing complexity of RF front-end designs. As a solution, compact multiplexers with low insertion loss that integrate multiple filters within a single package with internally connected antenna terminals are increasingly desired.

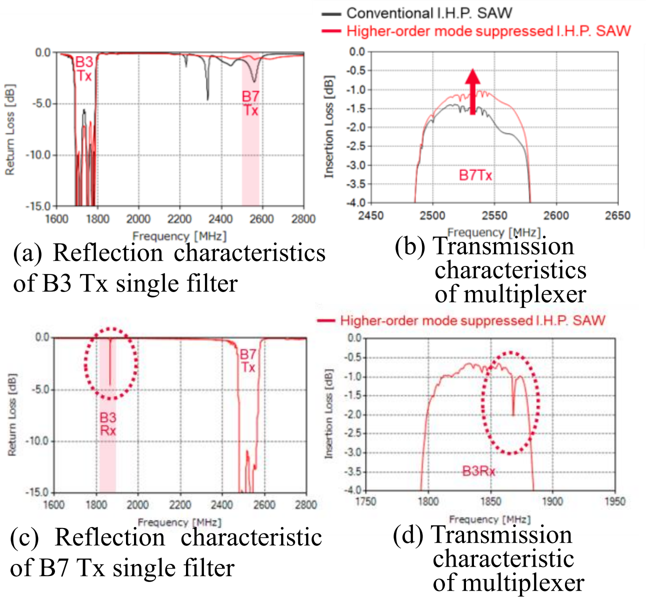
Incredible high-performance (I.H.P.) SAW device was reported in 2016.[1)] Subsequently, a structure for suppressing higher-order modes in I.H.P. SAW devices was reported.[2)] By utilizing this SAW device, it becomes possible to fabricate low-loss multiplexers without degrading the characteristics of counterpart filters that have passbands corresponding to higher-order mode frequencies.

2. Rayleigh Mode Spurious and Their Suppression

Fig. 1(a) shows the reflection characteristics at the antenna terminal in a single filter configuration for Band 3 Tx using a higher-order mode suppressed I.H.P. SAW. **Fig. 1(b)** shows the transmission characteristics of the Band 7 Tx when connected to the Band 3 Tx filter at the antenna terminal. In these figures, it is confirmed that the suppression of higher-order mode responses contributes to a reduction in the degradation of loss characteristics of the Band 7 Tx.

On the other hand, **Fig. 1(c)** shows the reflection characteristics at the antenna terminal in a single filter configuration for Band 7 Tx using a higher-order mode suppressed I.H.P. SAW. A strong response is observed around 1900 MHz, which is induced by the Rayleigh wave mode. Therefore, when the Band 7 Tx filter and Band 3 Rx filter are connected to the antenna terminal, as shown in **Fig. 1(d)**, a sharp spurious response appears in the transmission characteristics of the Band 3 Rx.

From these results, it has become clear that to fabricate a multiplexer with favorable characteristics for this band combination, additional suppression of Rayleigh wave response occurring on the lower side of the passband is necessary. Therefore, we attempted to investigate parameters for suppressing



(a) Reflection characteristics of B3 Tx single filter

(b) Transmission characteristics of multiplexer

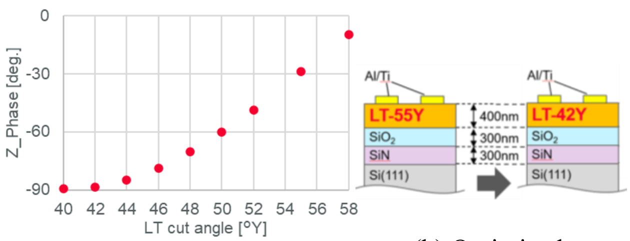
(c) Reflection characteristic of B7 Tx single filter

(d) Transmission characteristic of multiplexer

Fig. 1 Simulated characteristics of single filter state and multiplexer State.

Rayleigh wave response based on higher-order mode suppressed I.H.P. structure using 2D FEM simulations.

Fig. 2(a) shows dependence of intensity of Rayleigh wave response on LT cut angle. Here, the maximum impedance phase is used as the index value to evaluate the intensity of the response. From this figure, it can be confirmed that reducing the cut angle decreases intensity of Rayleigh wave response; at a cut angle of 42°Y, intensity almost disappears. Additionally, variations in the intensity of higher-order modes and the relative bandwidth of the main mode were also examined under these conditions. The intensity of higher-order modes remains almost constant. On the other hand, the relative bandwidth



(a) Impedance phase of Rayleigh wave response

(b) Optimized parameter

Fig. 2 Variation of intensity of Rayleigh wave response on LT cut angle and the optimized parameter.

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of the main mode increases from 3.9% to 4.7% when reducing the cut angle from 55°Y to 42°Y. However, it is considered feasible for Band 7 Tx/Rx filter design. Thus, an LT cut angle of 42°Y is selected in this study, as shown in **Fig 2(b)**.

3. Antenna Matching Circuit Design for Hexaplexer

In the design of hexaplexer, it is necessary to simultaneously achieve suppression of signal energy leakage losses among filters and match the impedance at the antenna terminal to 50 ohms across all six filters.

The Band 7 Tx/Rx operate at frequencies approximately 500 MHz higher than the Band 1 Tx/Rx and Band 3 Tx/Rx. Consequently, when the Band 1 Tx/Rx and Band 3 Tx/Rx filters are connected to their antenna terminals, the susceptance value corresponding to frequencies of Band 7 Tx/Rx becomes large. In other words, their impedance trajectories on a Smith chart are positioned much closer to a short-circuit region, as indicated by symbol (i) in **Fig. 3**.

In this configuration, connecting the Band 7 Tx/Rx filters results in a significant capacitive drop in the impedance of the Band 7 Tx/Rx filter's passband at the antenna terminal, thereby increasing mismatch losses. This significantly degrades the transmission characteristics of the Band 7 Tx/Rx.

Therefore, in this hexaplexer, a series inductor is added after connecting the Band 1 Tx/Rx and Band 3 Tx/Rx filters to set the impedance trajectories in their own bands and the counterpart band of Band 7 Tx/Rx into an inductive region, as indicated by symbol (ii) and (iii) in Fig. 3. This establishes a complex conjugate relationship with the impedance at the antenna terminals of the Band 7 Tx/Rx, as indicated by symbol (iv) and (v) in Fig. 3, thereby enabling matching the impedance at the antenna terminal to 50 ohms for all filters, as indicated by the symbol (vi) in Fig. 3.

In this case, adding a series inductor with a relatively small inductance value allows for setting the impedance trajectory to the desired position. This

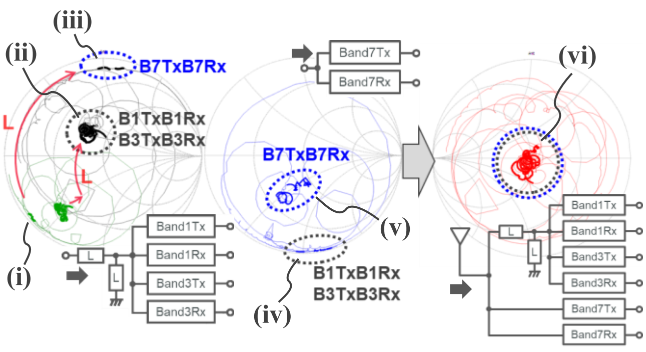
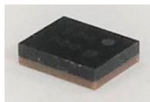
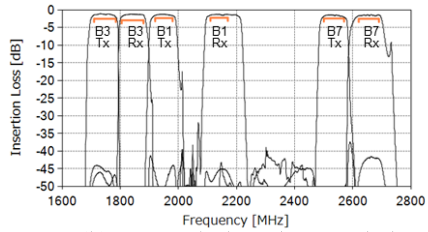


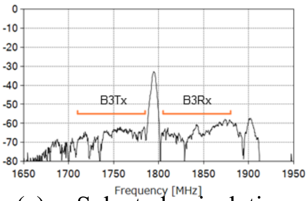
Fig. 3 Antenna matching circuit for hexaplexer.



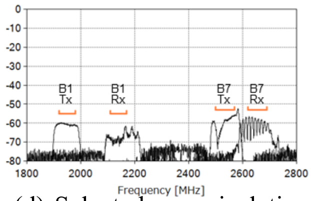
(a) External view



(b) Transmission characteristics



(c) Selected isolation characteristic



(d) Selected cross isolation characteristics

Fig. 4 External view and measured characteristics of fabricated hexaplexer.

contributes to reducing losses caused by the inductor itself.

4. Fabrication of Hexaplexer

Using these configurations, the hexaplexer was fabricated as shown in **Fig. 4(a)**. The size is 2.50 × 2.00 × 0.65 mm^3. The measured electrical characteristics are shown in **Fig. 4(b), (c) and (d)**. The peak insertion loss in the passband of all filters was successfully achieved at less than 1.5 dB without any degradation due to mismatch losses or spurious effects from other filters. Additionally, good isolation characteristics were also obtained. The impedance for each filter in the passband at the antenna terminal has been internally matched to 50 ohms, as the inductors of the matching circuit are formed within the package substrate.

5. Conclusions

We have addressed the issue of Rayleigh wave response in multiplexers using higher-order mode suppressed I.H.P. SAW. Using FEM simulation, we investigated and identified the optimal parameter for suppression. Additionally, we determined the optimal matching circuit configuration. As a result, we successfully fabricated a Band 1+3+7 hexaplexer exhibiting favorable characteristics.

References

1) T. Takai, H. Iwamoto, Y. Takamine, H. Yamazaki, T. Fuyutsume, H. Kyoya, T. Nakao, H. Kando, M. Hiramoto, T. Toi, M. Koshino and N. Nakajima, 2016 IEEE Int. Ultrason. Symp., 2016, ISBN 978-1-4673-9897-8.
2) R. Nakagawa, M. Ozasa, H. Iwamoto and A. Michigami, Jpn. J. Appl. Phys. **63** 02SP70 (2024).