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Research paper

A Study on the Transmission Line in FBAR Duplexer for Industrial Wireless Communication in the Context of Industry 4.0

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Abstract

Background/Objectives: This paper designs and manufactures a transmission line with PCB stacking of 3.8mm x 3.8mm x 1.8mm for the miniaturization of FBAR duplexer.
Methods/Statistical analysis: To evaluate the performance of the fabricated transmission line, we applied it to a duplexer made up of Tx and Rx filters made of a combination of FBAR resonators and confirmed its characteristics.
Findings: In this study, a pentagonal resonator was fabricated for each filter size, and Tx and Rx filters were designed after extracting physical properties for each resonator. And we design duplexer using combined Tx/Rx filter. The characteristics of the transmission line were analyzed by using the designed duplexer.
Improvements/Applications: The line width of the transmission applied to the duplexer was 210 ㎛ and designed as a strip line having a length of 18mm.It was confirmed that the phase difference was 179.9° at 18mm.A transmission line was applied to a very small FBAR duplexer having a size of 3.8 mm×(length) 3.8 mm×(height) 1.8 mm to be applied (width) to obtain S_{11} (-5.638 dB), S_{21} (-18.296 dB), $S3_1$ 42.832dB).

Keywords: *Transmission line, FBAR, Filter, Duplexer, PCB*

1. Introduction

Recently, according to the 4th revolution, mobile and information communication devices are integrated into a single terminal, thereby increasing the number of accessories attached to the terminal[1]. And as terminals are getting smaller, integration of components, integration of functions, and broadening of bandwidth are required. The same is true for miniaturization of duplexer among wireless communication parts. First of all, the configuration of the duplexer is composed of a transmission / reception filter and a λ/4 microstripline[2]. To miniaturize the duplexer, it is important to miniaturize the size of the transmission / reception filter, but it is more important to study the miniaturization of the λ/4 microstrip line which occupies about 1/3 of the total area of the duplexer[3]. Therefore, in this study, we design a λ/4 a transmission line as a method to miniaturize microstrip line by PCB lamination. In this paper, in order to secure the reliability performance characteristics, the FBAR resonator is fabricated by area and the MBVD equivalent circuit parameters are found by extracting the property values by each resonator size[4]. We also confirmed that each resonator is fabricated to resonance frequency by size. Then, the fabricated resonators are combined by size to form an optimum filter for the characteristics of the duplexer. The inductor sensitivity analysis is a matching device to capture the duplexer characteristics, and the strip line that separates the transmission signal (1850 ~ 1910 ㎒) and the reception signal (1930 ~ 1990 ㎒). In this paper, we design a duplexer composed of Tx and Rx filters starting from fabricating the FBAR resonator for stripline application, and applying the transmission line to PCB (printed circuit board) laminate structure to evaluate its characteristics.[5,6].

2. Materials and Methods

2.1. How to Make A FBAR Resonator

In this experiment, first, a high-resistance (HRS) wafer substrate was used to fabricate a resonator having a sandwich structure of piezoelectric thin films between upper and lower electrodes[7]. Figure 1 shows the 3D modeling of the FBAR resonator tested in this paper and the material name and structure of each layer of the fabricated resonator. It is important to determine the thickness of the thin film and the resonance area so that the resonance occurs at the frequency. In this experiment, the thickness of each layer of the Tx resonator was 0.41 ㎛ for the upper electrode, 1 ㎛ for the piezoelectric body and 0.41 ㎛ for the lower electrode so that the Tx center frequency could resonate at 1880MHz. The thickness of the upper electrode, the piezoelectric body, and the lower electrode of the Rx resonator was 0.43 ㎛, 0.85 ㎛ and 0.43 ㎛, respectively, in order to match the receiving center frequency to 1960 ㎒.[8].

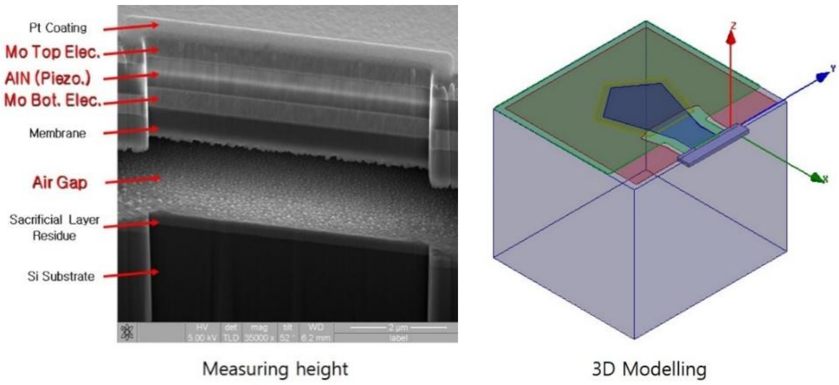

Figure 1:. 3D Modelling and SEM image of fabricated FBAR

The FBAR resonator was fabricated as shown in Figure2. AMS sputtering equipment was used as the deposition equipment and dry etcher equipment was used as the pattern removal equipment. The sacrifice layer removal was performed using HF 49% stock solution and free standing to have an air gap of 2 ㎛ height.

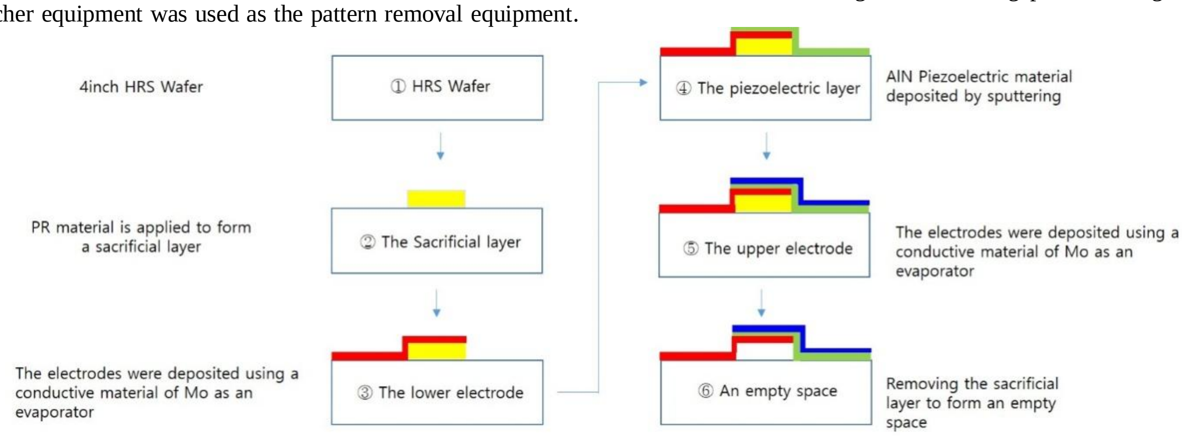

Figure 2:. Process for fabricated FBAR

The shape of the resonator is a pentagon shape that can be easily designed and manufactured and minimized errors in the process. The size of the resonator was fabricated as $10um^2$ ~ $400um^2$ and the resonance frequency was measured according to the area. Figure.3 shows the results of the series-parallel resonance frequency for each resonator measured in the wafer state[9,10].

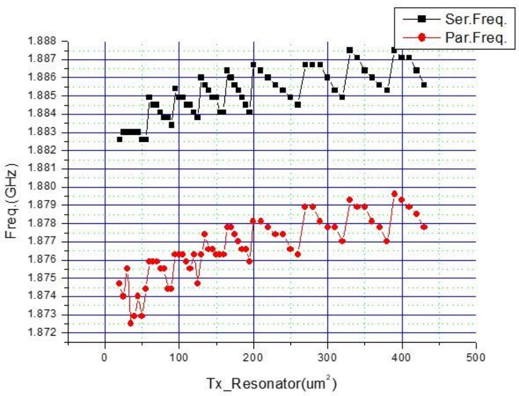

Figure 3:. Frequency deviation by resonator size

In figure3, the reason why the resonance frequency does not occur uniformly with increasing resonator area is that the sputter equipment condition is not uniformly deposited on the 4 'wafer. However, in this experiment, since it takes a considerable time to optimize the deposition conditions for the sputtering equipment, the wafer yield is not considered in large measure. Among the evaluation parameters for the fabricated resonator, the quality factor Q value was calculated through Equation (1).k^2_{eff}(effective electro- mechanical coupling constant) is calculated through equation (2) and the characteristics of each resonator are used for evaluation [11]. Table1 show the measurement result for k2eff & Q.

$$Q = \frac{\left(\frac{f_s}{f_p}\right)}{\left(1-\frac{f_s}{f_p}\right)^2}\sqrt{\frac{(1-|S_{12max}|)}{|S_{12max}|}\frac{(1-|S_{11max}|)}{S_{11max}}} \quad (1)$$

$$k^2_{eff} = \frac{\pi^2}{4}\left(\frac{f_s}{f_p}\right)\left(\frac{f_p-f_s}{f_p}\right) \quad (2)$$

Table 1: Measurement result for k^2_{eff}& Q

Item	Resonance frequency (GHz)	k^2_{eff}	Quality factor (Q)
f_s	1.853	5.997	1488
f_p	1.899		1230

Generally, the Q value and k^2_{eff}tend to be highly correlated with each other, so that if the Q value is improved, the k^2_{eff} characteristic value also becomes better. Here, k^2_{eff} is a very important parameter for determining the bandwidth of the FBAR filter, which is mainly determined by the series and parallel resonance frequencies as shown in equation (2). Based on the resonator measurement data, the parameters of the unit resonator were extracted by using circuit simulation with physical properties. The equivalent circuit modeling used in this experiment was a modified butterworth-van dyke model (MBVD). R_0 is a phenomenological resistance component including the dielectric loss of a piezoelectric thin film. C_0 represents a storage component possessed by the piezoelectric thin film as an upper dielectric body. The R_m, C_m, and L_m components are represented by dividing the oscillating component by resistance, capacitance, and inductance components, respectively, according to the AC signal of the piezoelectric thin film. The vibration component is generated by the alternating current applied to both ends of the piezoelectric thin film and the resonance phenomenon of the vibration of the piezoelectric thin film.Figure 4show MBVD Parameters for Ser.&Par. Resonators.

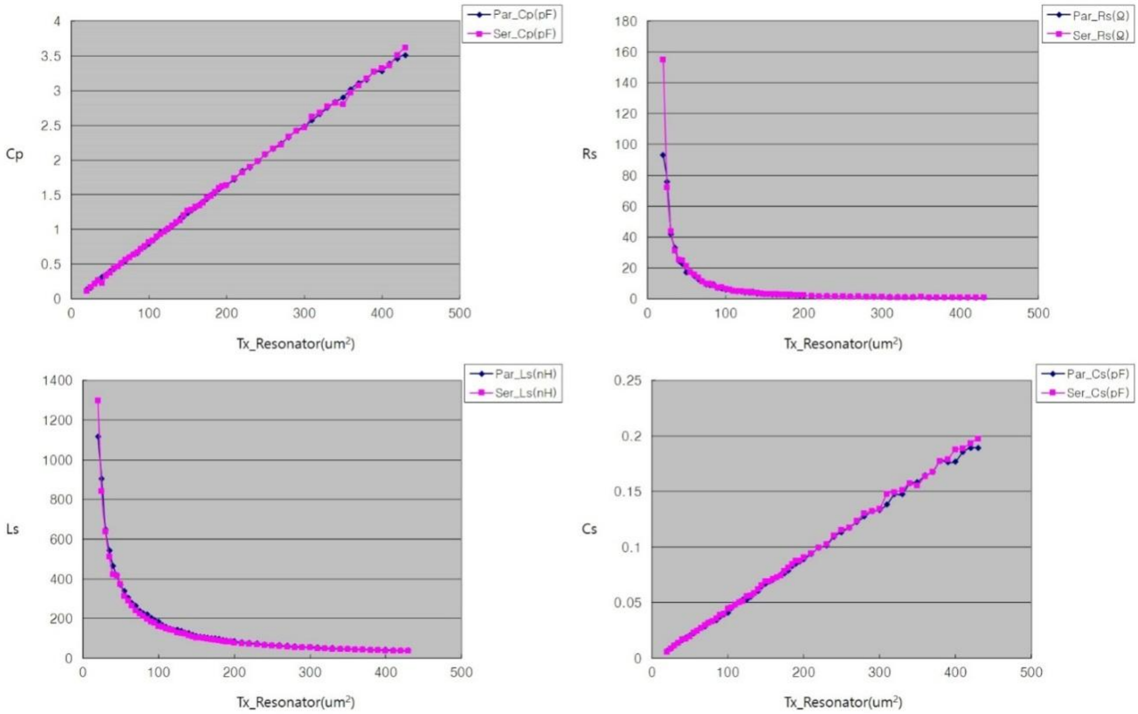

Figure 4:. MBVD Parameters for Ser.&Par. resonators

2.2. Filter Design and Manufacturing Method

This chapter can be easily applied to filter analysis and filter circuit based on FBAR resonator results. Based on the data for each extracted parameter of the resonator, ladder) [5] to form the series-parallel resonators. As shown in Fig. 5, the Tx series resonator structure is 3 × 2 and Rx is 3 × 4. The designed Tx / Rx filter is a passband filter. Figure. 5 shows the S-parameter design results for the FBAR pass band Tx / Rx filter designed in this study.Figure 6 show Results of S11 and S21 for Tx, Rx Filter.Figure 7 show Smith chart of S11 and S21 for Tx, Rx Filter.Figure 8 show Design for Tx, Rx Filters.

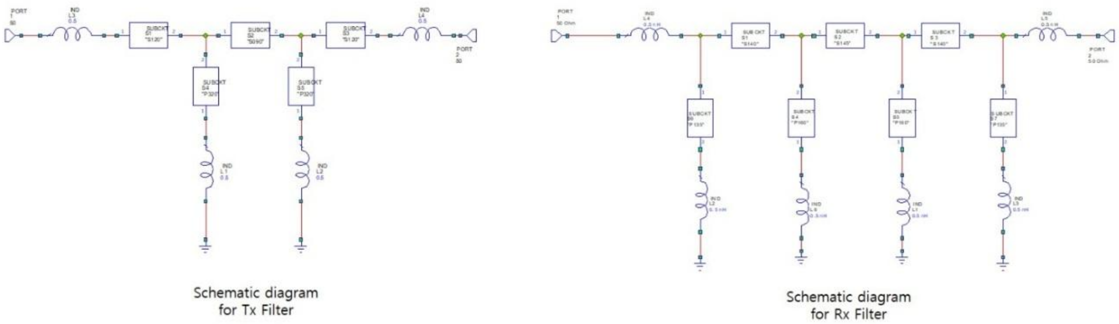

Figure 5:. Design for Tx, Rx Filters

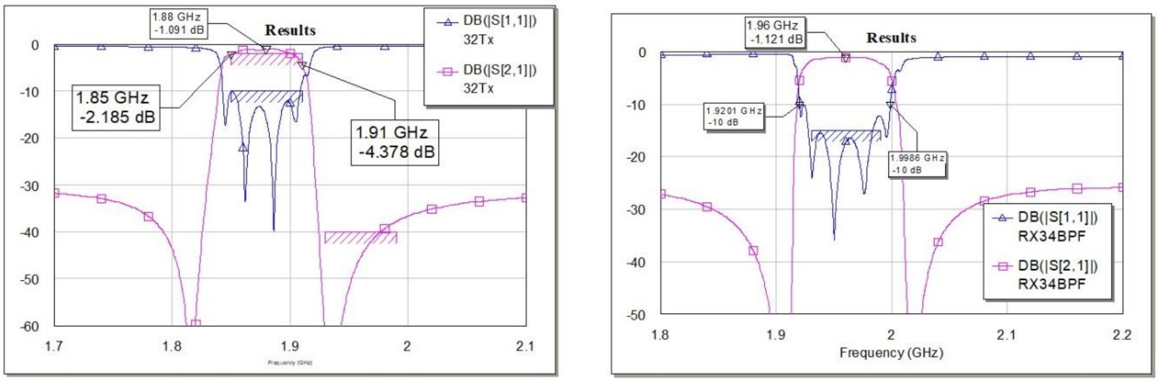

Figure 6:. Results of S11 and S21 for Tx, Rx Filter

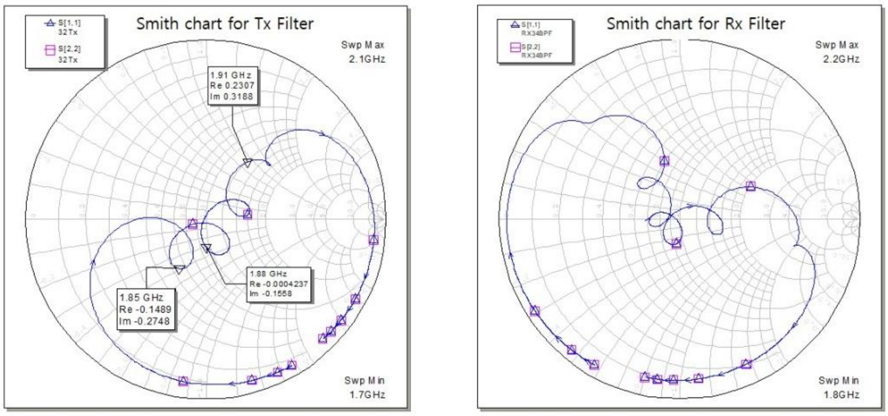

Figure 7:. Smith chart of S11 and S21 for Tx, Rx Filter

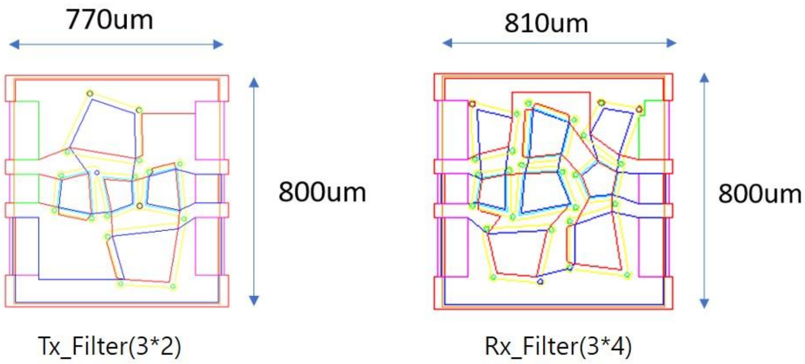

Figure 8:. Design for Tx, Rx Filters

2.3. How to Design the Transmission Line

The duplexer requires a transmission line to separate the signal from the transmit/receive filter.

In this study, the following equations were used to calculate the microstrip line length with a characteristic impedance of 50 Ω at 1.96 GHz and a phase difference of 180 °.

This equation expresses that the characteristic impedance decreases as W (line width) increases.

$$\mathrm{W} = \mathrm{bx} \tag{3}$$

$$\mathrm{x} = \frac{30\pi}{\sqrt{\varepsilon_r}} - 0.441 \tag{4}$$

$$Z_0 = \frac{30\pi}{\sqrt{\epsilon_r}} \frac{b}{W_e + 0.441b} \tag{5}$$

Here, we is the effective width of the center conductor and can be obtained by the formula (6), and the line width of the strip line can be obtained using these equations. $\sqrt{\varepsilon} Z_0 = \sqrt{3.4} \times 50\Omega = 92.19$.(W(Strip line width), b(Substrate height : 0.4mm), εr=3.4, Z0=50Ω)

$$\frac{W_e}{b} = \frac{W}{b} \begin{cases} 0 & for\ \frac{W}{b} > 0.35 \\ 0.85 - \sqrt{0.6 - x} & for\ \frac{W}{b} < 0.35 \end{cases} \tag{6}$$

Therefore, $\mathrm{x} = \frac{30\pi}{\sqrt{\varepsilon_r Z_0}} - 0.441 = \frac{30\pi}{\sqrt{3.4 \times 50}} - 0.441 = 0.5881$,W is $(\mathrm{W} = \mathrm{bx} \rightarrow 0.4\mathrm{mm} \times 0.581)0.23\mathrm{mm}$.

Check that the line width (W) matches the characteristic impedance (50Ω). It can be confirmed by the calculation method that it matches 50Ω as shown below.

$$Z_0 = \frac{30\pi}{\sqrt{\epsilon_r}} \frac{b}{W_e + 0.441b} = \frac{30\pi}{\sqrt{3.4}} \frac{0.4}{0.23 + (0.441 \times 0.4)} = 50.03\Omega \tag{7}$$

Next, in order to obtain the line length (ℓ) for obtaining the phase difference of 180°, the length is calculated to be 83 mm by the strip line wavelength formula considering the dielectric constant 3.4 of the substrate.Dividing this length by λ / 4 to produce a phase difference of 180 results in a final length of 20.75 mm.By using the 3D simulation tool with the length from the calculation formula, the trend of the pattern width was analyzed, and the line width suitable for the characteristic impedance could be obtained. Figure 9 show Design method for TL.

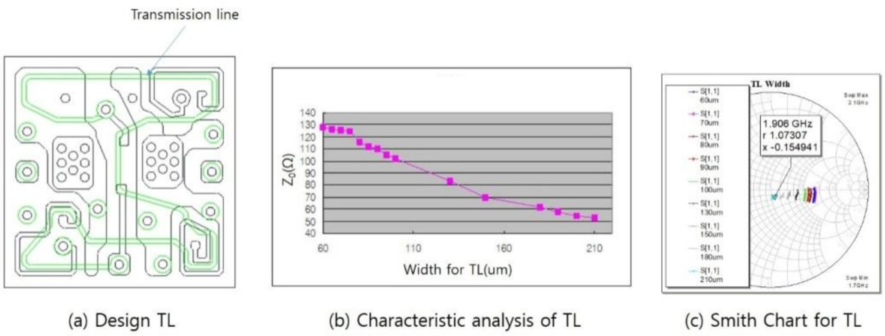

Figure 9:. Designmethod for TL

The transmission line designed for the high isolation of the transmitting and receiving end is strip-line type.

As shown in Fig. 9, a co-planar waveguide ground (CPWG) structure is formed by forming a ground via hole next to a signal line uniformly along the signal line so that the electro-magnetic mode of the electromagnetic field is uniform.In order to have uniform electromagnetic field TEM mode, they were spaced 200 ㎛ away from each other at the center of the transmission line.The spacing between the other lines, the spacing between holes, ie, the spacing between the line and hole spacing and the grounding area, was unified to a minimum technically feasible width of 75 µm.In other words, the reason for doing this is to form a uniform TEM mode by designing it to be surrounded by the ground plane, the ground hole, and the ground wall in order to prevent mutual interference.It should also be designed with care that the signal lines should not be adjacent to each other or under or over the transmission line.The characteristic impedance is important in the transmission line. First, we use the equation (3) to (7) to find the line width according to the characteristic impedance of 50 Ω. found.As shown in Fig. 14, the length of the transmission line was used as a duplexer transmission line by finding a λ / 4 length exactly 180 ° out of phase at 1880 ㎒, which is the center frequency of Tx.Figure 10 show Result for Phase shifter of TL.

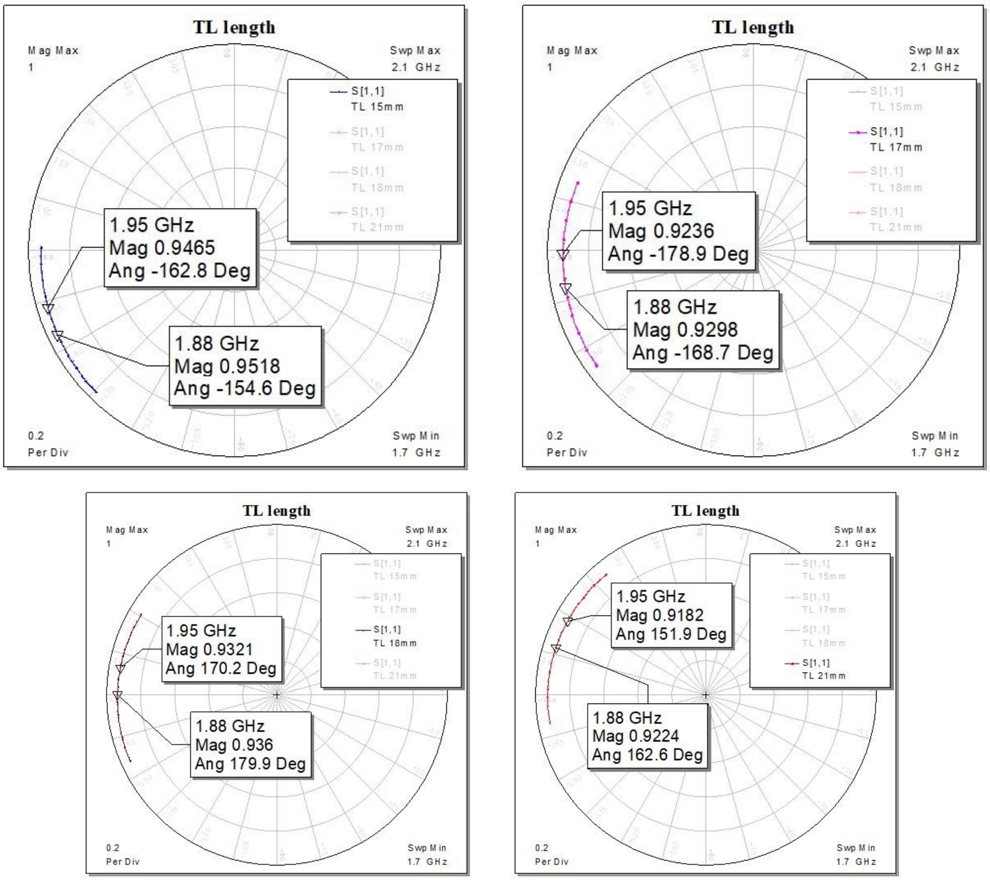

Figure 10:. Result for Phase shifter of TL

3. Results and Discussion

In this paper, we design a transmission line for a compact FBAR duplexer with 3.8 × (height) and 1.8 ㎜ (horizontal) dimensions for wireless systems. Figure 10 shows the design and 3D modeling of a duplexer using the transmission line designed through this experiment. Figure 10 shows the characteristics of the duplexer measuring the S parameters S11, S21 and S31 by performing the equipment calibration and connecting the PCB board for measurement to the network analyzer. The results show that S11 (-5.638dB), S21 (-18.296dB), and S31 (-42.832dB).

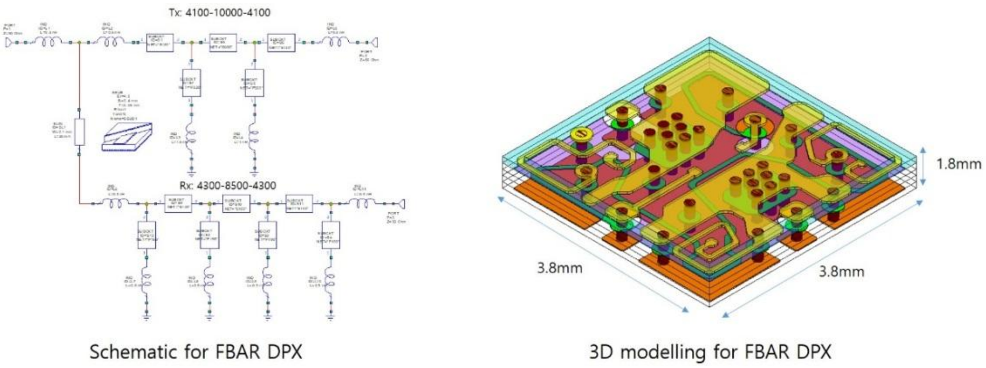

Figure 10:. Schematic and modeling based on experimental results

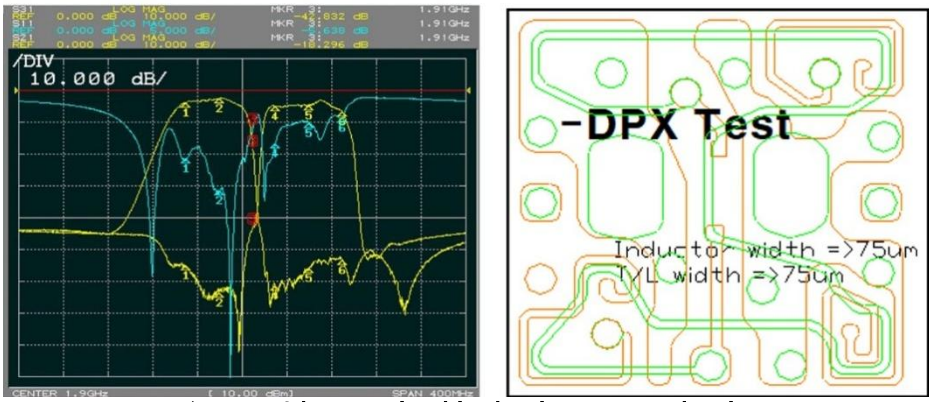

Figure 11:. Schematic and modeling based on experimental results

In order to obtain these results, a pentagonal resonator was fabricated for each filter size.The Tx and Rx filters were designed after extracting the physical properties for each resonator.And we design duplexer using combined Tx / Rx filter. Figure 11. Schematic and modeling based on experimental results. The design of the duplexer was verified using a measurement board. Tx and Rx from the wafer state. The Tx, Rx resonator quality factor (Q) from the wafer state is about 1488 and k2eff is 5.997.In this case, the Tx filter has a 3 × 2 shape and the Rx filter has a 3 × 4 shape.The transmission lines for transceiver signal separation wereimplemented with strip lines with a width of 210 ㎛ and a length of 18 ㎜.Among the characteristics of the duplexer including the matching device in this experiment, the Tx band is 1850MHz to 1910MHz and the Rx band is 1930MHz to 1990MHz.Even though the characteristics of the FBAR resonator on the wafer were excellent during the research, each of the assembled chips was packaged on the PCB and molded with wire bonding and nonconductive epoxy, and it took a considerable time to find the main cause due to some characteristic changes.During the analysis, there were changes in substrate material, inductor length, transmission line change, grounding enhancement, and number of via holes. However, in this study, it was found that if the accurate transmission line is not implemented, the transmission and reception signal separation is unstable I got it.In this study, we prove that the design of the transmission line for the separation of the transmission and reception signals can achieve the characteristics of the desired duplexer.The designed duplexer has 4 layers of PCBs as shown in Fig. 12 and an inductor and pad on the 1st layer. The second layer is inserted into the third layer.The transmission line was inserted to serve as a reflector so as not to interfere with the ground floor.On the third floor, there is a strip line type transmission line, and the bottom is packaged as a ground plate.

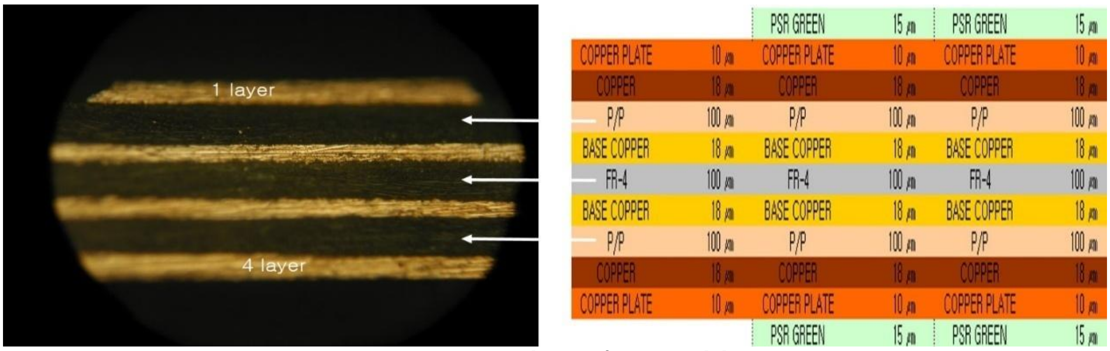

Figure 12:. Structure diagram for PCB multilayer

One of the most important manufacturing methods when packaging is to remove parasitic capacitor components in via-holes.The method used in this study was to fill the plated via holes with a nonconductive resin and cut with a cutting machine to re-apply the plating pattern to the secondary work.Since the holes are filled with non-conductive resin, the ground effect between the substrates is maximized and the thermal conductivity is improved.Thereby improving the characteristics of power handing and temperature sensitivity so that the capacitance components existing in the holes are removed.The additional consideration is that the thickness of the ground plane of the PCB should be as thick as possible and the more conductive the material is used, the better the number of vias on the ground plane.The substrate used in this study was a substrate of polypropylene resin with a dielectric constant (ε_r) of 3.4 and a loss factor of 0.002 (@ 1 ㎒).The low loss factor is chosen because the lower the loss factor of the substrate is, the less the substrate loss of the inductor and transmission line.

4. Conclusion

In this paper, we design a transmission line used in a FBAR duplexer used in a wireless system and design a transmission line according to characteristics of a transmission / reception filter. The characteristics were verified by applying it to a micro FBAR duplexer. In this study, a pentagonal resonator was fabricated for each filter size. In this paper, we design the transmission line used in the FBAR duplexer used in the wireless system and design it according to the characteristics of the transmission and reception filters. The characteristics are confirmed by applying it to the micro FBAR duplexer. In this study, a pentagonal resonator was fabricated for each filter size. In this experiment, the thickness of each layer of the Tx resonator was 0.41 ㎛ for the upper electrode, 1 ㎛ for the piezoelectric, and 0.41 ㎛ for the lower electrode so that the Tx center frequency could resonate at 1880 ㎒. The thickness of the upper electrode, the piezoelectric body, and the lower electrode of the Rx resonator was 0.43 ㎛, 0.85 ㎛ and 0.43 ㎛, respectively, in order to match the receiving center frequency to 1960 ㎒. The k2eff of the fabricated resonator was 5.997 and the quality factor (Q) was 1488 in the series and 1230 in the parallel. The resonator area for the filter combination was fabricated from 20um2 to 430um2, and the characteristics were combined to fabricate the transceiver filter. Using these resonators, the size of the 3 × 2 Tx filter was designed to be 770 µm × 800 µm, and the size of the Rx filter of 3 × 4 type was designed to be 810µm × 800µm. The insertion loss of Tx (1.88 GHz) was -1.091 dB and the insertion loss of Rx (1.96 GHz) was -1.211dB. The transmission line, which serves as a phase shifter, is designed as a strip line with a width of 210µm and a length of 18 mm. It was confirmed that the phase difference was 179.9° at 18mm. A transmission line was applied to a very small FBAR duplexer having a size of 3.8mm × (length) 3.8mm × (height) 1.8mm to be applied (width) to obtain S11 (-5.638 dB), S21 (-18.296dB), S31 42.832dB).

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