A 5kHz Bandwidth Low Noise Chopper-Stabilized Dual-Band Selective Filter SoC

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***Abstract* - In this paper, various blocks and structures applied to the low-noise 2 band selection band pass filter are described. In the proposed band pass filter when the frequency is input through the buffer, one of Band 1 or Band 2 can be selected using the switch, and the output goes through the buffer after the selected switch among Band 1 and Band 2. After the pre-amplifier, the low frequency band pass filter is used to secure -3 dB or more at 29.5 kHz (5 kHz range) and is used to secure -1 dB or more at 39.5 kHz (5 kHz range). The aim is to remove the interference between bands by -20 dB or more at the interference frequencies of 29.5 Hz and 39.5 Hz, which are the center frequencies of each band. Chopper structure was used to reduce noise, and it was designed to drop more than -21dB/√Hz in Band1,2.**

***Keywords*—Band pass filter, Chopper structure, SoC**

I. INTRODUCTION

Sonar systems have been widely used to measure distances between objects in the ocean and have been actively studied from various perspectives, including sensor modeling and signal processing of ultrasonic signals. There are many sources of noise in aquatic environments, and in transmission and reception communications, they are exposed to all aquatic environment noise sources. In an aquatic environment, the performance of incoming and outgoing communications deteriorates due to the influence of all underwater environmental noise sources. Therefore, in an underwater system environment, a low noise transmission and reception system is required, and input noise (IR) noise must be lowered to improve signal-to-noise ratio (SNR) and receiver sensitivity.

On the other hand, in the underwater transmission and reception communication system, as the distance between the object and the receiving equipment is shortened, the input signal level of the receiver increases, which causes nonlinear harmonic distortion in the receiver. To solve the problem, it is necessary to design a custom analog circuit, including a filter function that effectively removes inter-band interference in a very small space in a multi-band receiver of dual bands.

In this paper, we propose a band pass filter that can control band and gain through digital control and a filter with dual bands, Band1 and Band2, that can attenuate signals except for the desired band using RLC circuit [1].

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II. DESIGN METHODOLOGY

A. Main block diagram

Fig. 1. shows the structure of the dual-band selective band pass filter proposed structure. SPI used to control the band pass frequency. Band1,2 and gain in each band can be controlled by SPI.

Once the frequency is input through the buffer, you can select either Band 1 or Band 2 using the switch, and the output passes through the buffer after the selected switch between Band 1 and Band 2, Band 1 and 2 control frequencies using capacitor and resistance arrays, respectively. The bandwidth of each signal is approximately -3 dB relative to the center frequencies of band 1 and band 2, respectively [2].

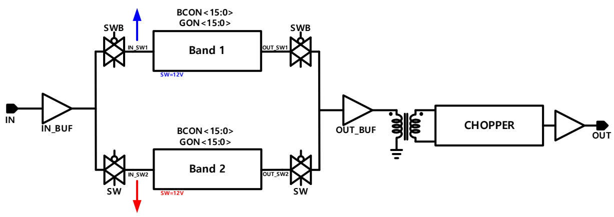


Fig. 1. Block Diagram of Band Pass Filter.

B. Active filter using Op-Amp

In order to configure a dual-band pass filter inside the SoC, rather than using a passive filter, an active filter using an OP-Amp will be designed. Since the active filter has a low output impedance, it protects the filter from the influence of the load when the filter is driven. Fig. 2 is a circuit diagram of a basic band pass filter using OP-Amp.

Compared to the passive band pass filter, since the amplifier enters, the current of the amplifier is additionally generated, but resistance and capacitor values can be relatively small, the area can be gained, and the ripple in the

BW can be effectively reduced. -We want to adopt the structure of RC band pass filter [3].

In addition, the Active-RC band pass filter can take a large order of the filter, which is advantageous for changing attenuation characteristics.

Active filters using OP-Amp require a DC power source, which has the disadvantage of having power consumption rather than passive filters but have the advantage of being able to design an accurate filter that meets the requirements due to the small dispersion of required gain or attenuation characteristics.

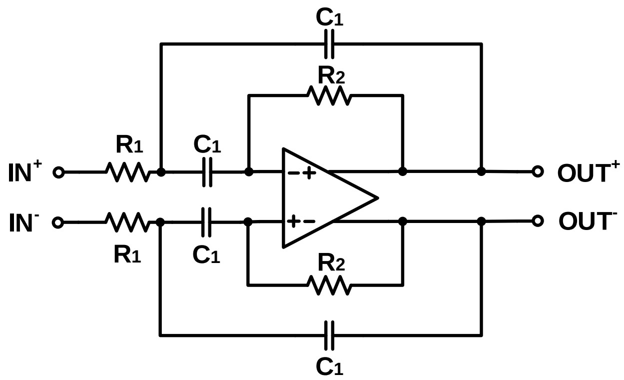


Fig. 2. Circuit diagram of active band pass filter.

C. Butterworth filter

Active filters are classified into Chebyshev, Butterworth, and elliptic types according to ripple and attenuation characteristics.

In order to efficiently eliminate interference between bands, a stable, low ripple Butterworth type 2 active filter is used.

The Butterworth type 2 filter has no ripple compared to other types of filters, so it is stable and obtains a stable waveform even when used at a low order, and the BW band is not anxious when using a high order, it is efficient in terms of area.

Fig. 3 shows the frequency response of the Butterworth type 2 band pass filter to check the ripple and attenuation characteristics. The Chebyshev type 2 filter can be designed more stably when it has the same damping characteristics. Therefore, it is efficient when designing in terms of area.

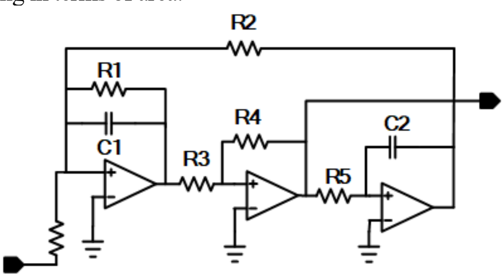


Fig. 3. Circuit diagram of butter worth type 2 active band pass filter.

Since the analog filter easily changes the frequency characteristics according to the changes of R and C, it is necessary to block a desired frequency characteristic through an automatic filter control method.

In the case of using a voltage control filter, it is designed in such a way that the loop proceeds until the desired frequency comes out and the desired phase comes out.

Since an additional circuit such as a phase-locked loop is not required, a voltage-controlled filter tuning method is used in consideration of area.

Fig. 4 shows the filter control circuit that automatically selects the capacitor control bit so that the bandwidth of the band pass filter remains constant using the time the capacitor is charged [4].

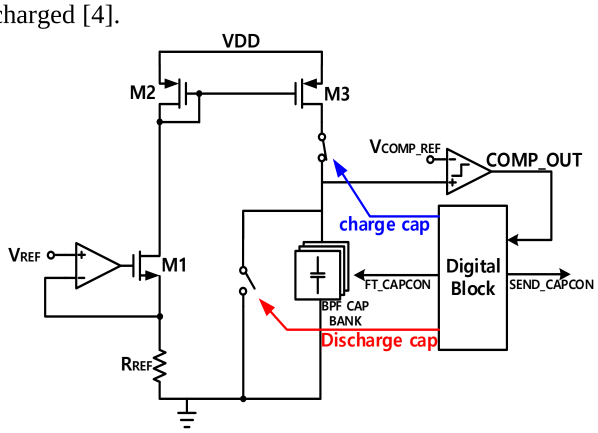
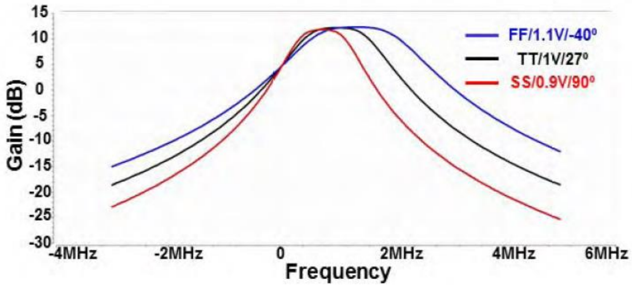


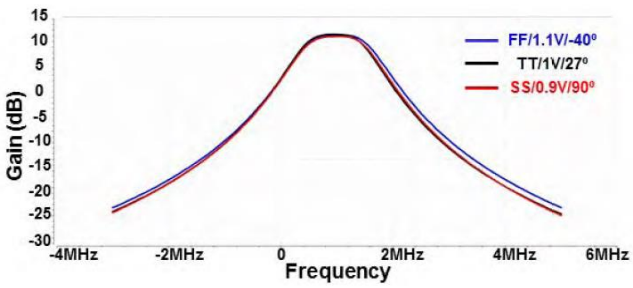
Fig. 4. Filter tunning circuit using time for charging the capacitor

In the case of Fig. 5, the simulation result is shown that reduces the error with temperature through filter tuning.

Fig. 6 shows how to adjust the center frequency of the water using cap bank and R bank [5].



(a)



(b)

Fig. 5. AC simulation result of band pass filter (a) when filter tunning is not applied, (b) when filter tunning is applied.

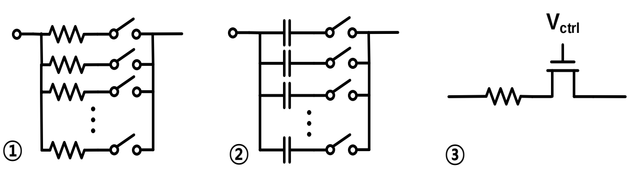


Fig. 6. How to adjust the frequency of Active-RC filter

D. Attenuation and Noise

As can be seen in Fig. 7, high attenuation can be obtained by adjusting the resistance and capacitor values, but more noise can be generated by the resistance and capacitor values that have high attenuation. Theoretically, there are Shot Noise, $i_n^2 = 2qI_D\Delta f(amperes^2)$ Thermal Noise, and Flicker Noise, and each equation is for Shot Noise, $e_n^2 = 4kTR\Delta f$ for Thermal Noise, $i_n^2 = K_f I^a / f^b \Delta f$ and for Flicker Noise. Therefore, in the case of Band 1 and Band 2 among each noise, it has been theoretically derived that thermal noise will be dominant because each band has a lower frequency. Theoretically, in the case of thermal noise, the larger the value of the resistance, the larger the value. This is because the value of 4kTR is proportional to the resistance value [6].

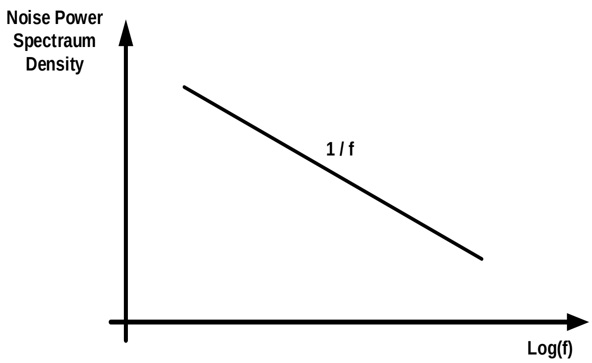


Fig. 7. Noise Power Spectrum Density.

E. Chopper technique

Chopper technique was applied as a method to improve the above noise results. As shown in Fig. 8, the chopper technique is a technique that reduces noise by converting it into a periodic pulse train to be placed using a differential signal [7].

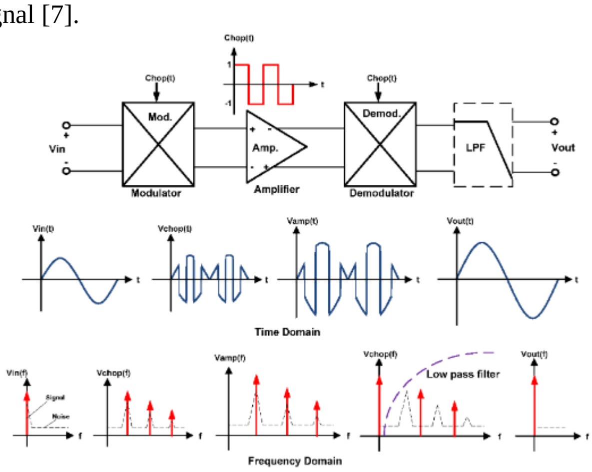


Fig. 8. Noise reduction principle using chopper.

The diagram of the chopper connected to the output of the filter can be seen in Fig. 9. After making a differential signal to two inputs to one using Balun, the signal is converted into a periodic pulse stream by passing through a chopper, and the signal from the chopper is again combined into a signal through an AMP [8].

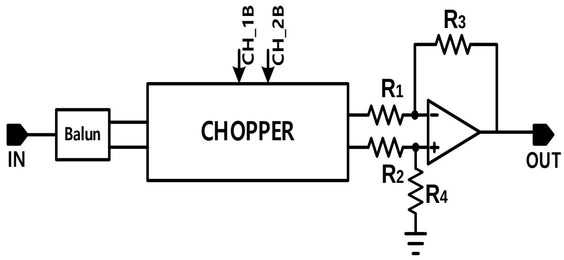


Fig. 9. Noise reduction block diagram using chopper.

III. RESULTS AND DISCUSSION

A. Band Pass Filter Top Layout

Fig. 10. shows the top layout of the dual-band pass filter. The chip area is 4,000 x 4,000um and using 180nm CMOS process.

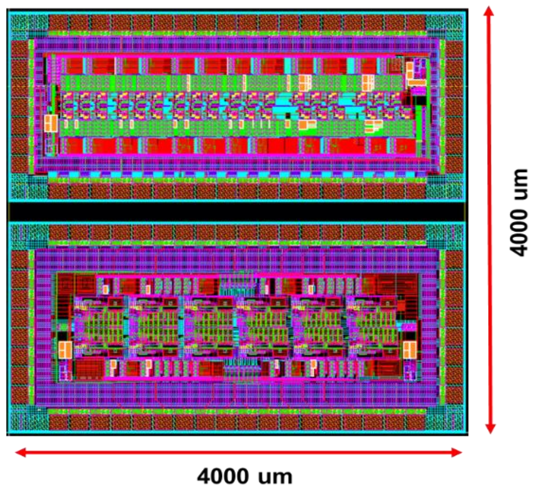


Fig. 10. Band pass filter top layout.

B. Simulation Results

Fig. 11 shows noise reduction by using chopper. It can be seen that the gain of the previous contrast is 2dB different, and that the noise is more than -21 $\boldsymbol{dB/\sqrt{Hz}}$ apart.

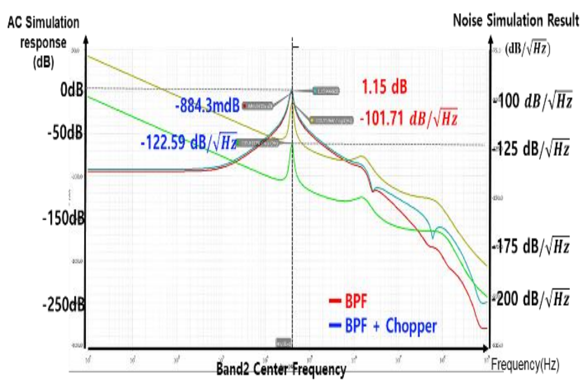
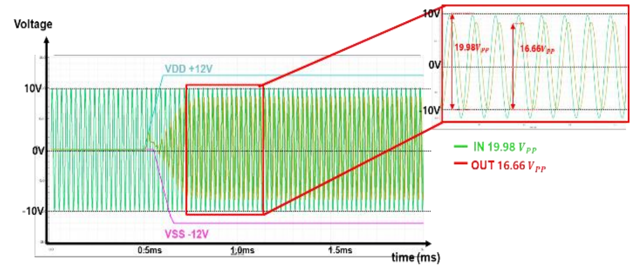
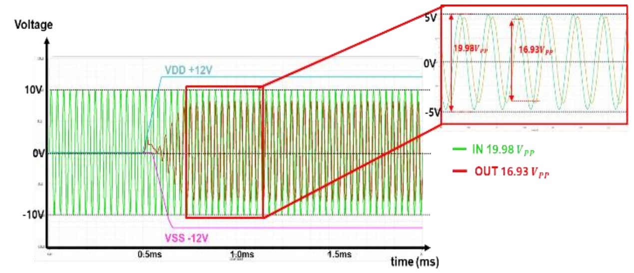


Fig. 11. Noise attenuation AC simulation with chopper.

Fig. 12 shows the BPF passing fc_B1 in Band 1 BPF and fc_B2 in Band 2 BPF.



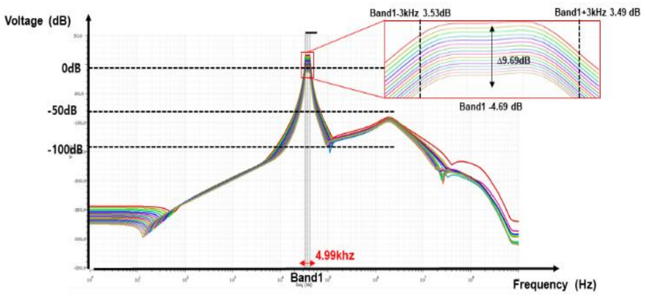
(a)



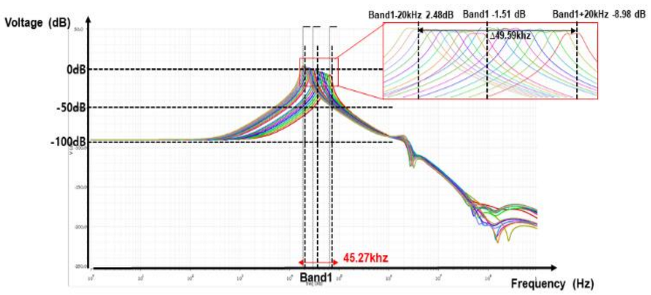
(b)

Fig. 12. Band 1 Tran Simulation of band pass filter (a), Band2 tran Simulation of band pass filter(b).

Fig. 13. shows the results of Band Control and Frequency Control. The interference cancellation ratio between bands is -20 ± 5 dB or more at a frequency fc_B1 of the BPF band.



(a)



(b)

Fig. 13. AC Simulation gain control of band pass filter (a), AC simulation band control of band pass filter (b).

Fig. 14 shows the BPF AC Simulation PVT Variation. It was designed to have an inter-band interference cancellation ratio of -20 ± 5 dB or more and a space of 5 kHz or more between bands at a frequency fc_B2 of the BPF band.

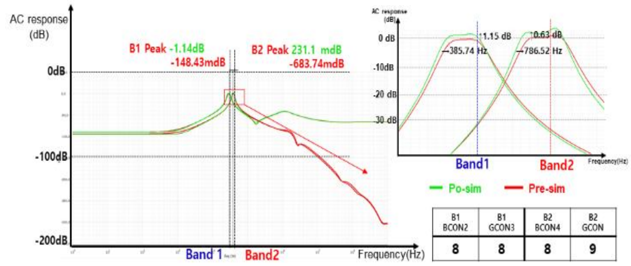
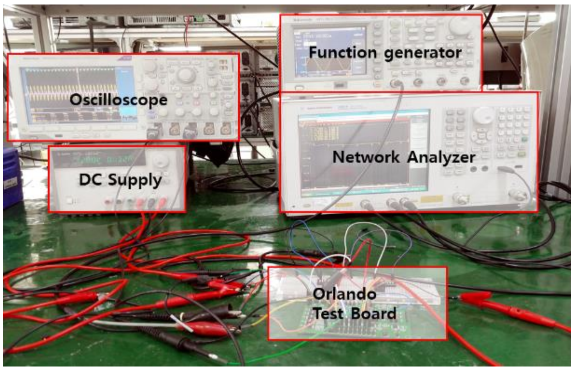


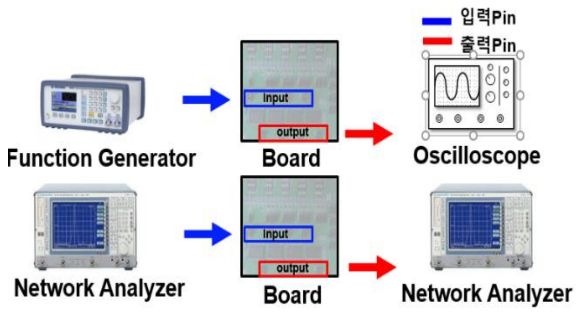
Fig. 14. AC Simulation PVT Variation of Band pass Filter

C. Measurement Results

Fig. 15 shows the measurement environment and measurement process. External SW Mode Setting, SW = 'Low', Band 1 operation, Input Signal (10 uVpp ~ 10 Vpp), B1_GCON <15: 0> = “LLLL”, B1_BCON <15: 0> = “LLLL”, Signal is Linear Make sure it comes out. , Pass Band and Gain measurement according to Bit Control.



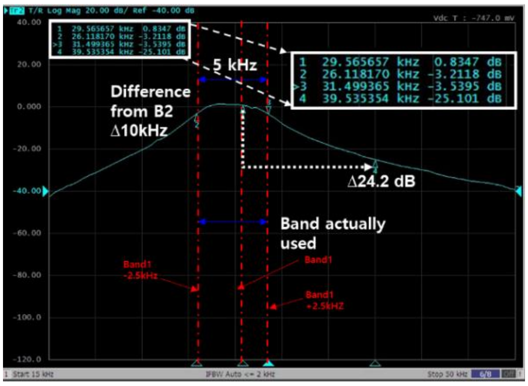
(a)



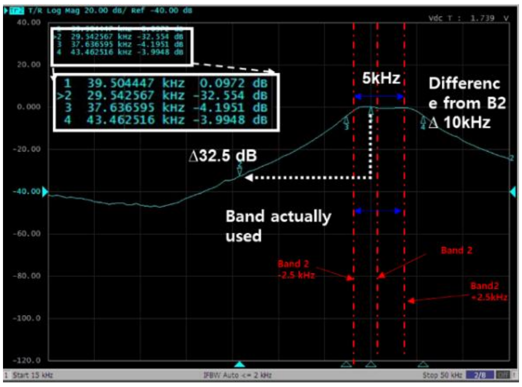
(b)

Fig. 15. Experimental measurement environment (a), AC experimental measurement process (b).

Fig. 16. shows the result of Network Analyzer measurement. Attenuation corresponding to Band 1 is -24.2dB and -24 dB difference. Attenuation corresponding to Band 2 is -32.5 dB and -33 dB difference. BW was measured based on the section corresponding to –3dB at the highest point, and the first tense has BW at about 7kHz, and the second tense has BW at about 5kHz. The band pass section is more prominent in the secondary sample compared to the primary sample.



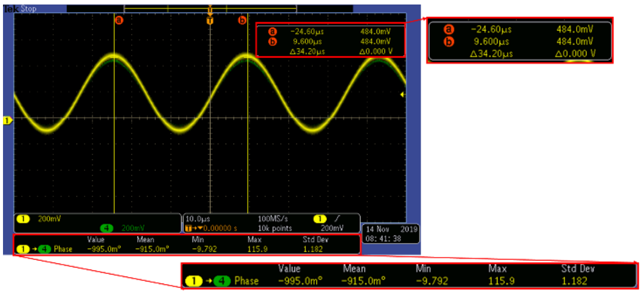
(a)



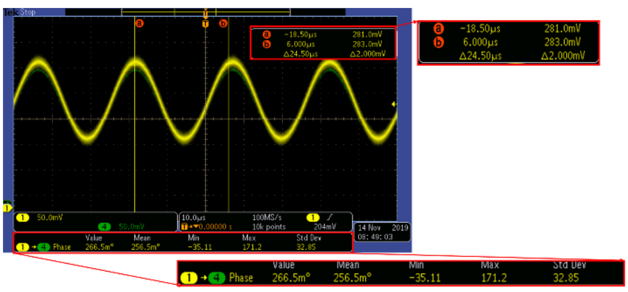
(b)

Fig. 16. Band 1 band pass filter network analyzer result (a), Band 2 band pass filter network analyzer result (b).

Fig. 17 shows the result of measuring the phase error for each band. As a result of measurement at the center frequencies of bands 1 and 2, there is a phase error within ± 1 degree between channels.



(a)



(b)

Fig. 17. Band 1 Phase Error Measurement Result (a), Band 2 Phase Error Measurement Result (b)

TABLE I. Dual-Band Pass Filter Basic Specifications

Basic Specification Table	
Input signal	5kHz~60kHz Band Analog
Output signal	Band1, Band2
Frequency Range	Band1: About 25kHz Band2: About 35kHz
Inter-band interface	At the center frequencies of 29.5kHz and 39.5kHz of each band, the inter-band interference rejection ratio is more than 20dB
Source	≥12V
Gain error of filter	±1dB within 5kHz bandwidth of the frequency band

.

IV. CONCLUSIONS

In this paper, the SoC of the 2-band selective band pass filter circuit is described. At 29.5 kHz and 39.5 kHz (5 kHz range), -3 dB or more should be secured, and the band-to-band interference rejection ratio should be 20 dB or more. In addition, the gain error of the filter was within ± 1 dB within 5 kHz, and the phase error was successful within ± 1 °.

As a specific method to achieve this, an active filter utilizing Op-Amp was used to effectively reduce the gain and ripple in BW in terms of area, and a stable BPF design was performed using a BPF structure in Butterworth Type 2. Also, it is designed to be able to compensate for errors by adjusting BW (Band Width) and Center Frequency as shown in Fig. 13 using Cap Bank among filter tuning techniques that can compensate for errors.

Through the Butterworth type 2 implemented in the actual sample, the band-to-band interference ratio of -24 dB and -33 dB was achieved, and the pass error within 5 kHz and phase error of ± 0.3 ° in CH 1 and ± 0.3 ° in CH 1 It was confirmed in the measurement.

ACKNOWLEDGMENT

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