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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 339-340
18-20 November, 2009

High Order Two-Dimensional Delta-Sigma Modulator for Ultrasound Transducer Array
超音波トランスデューサーアレイの為の高次２次元ΔΣ変調

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1. Introduction

The ΔΣ (delta-sigma) modulation is used for the high accurate AD and DA conversion of the audio band signal.
In the ultrasound band, beam forming using oversampled A/D converters was proposed.[1, 2)]

However, when the ΔΣ modulation is used in the ultrasound frequency band, there is a problem that the sampling frequency rises very high with high oversampling ratio (OSR). To solve this problem, we have proposed the method of multi dimensional ΔΣ modulator expanded to the spatio-temporal region.[3)] In this method, it has been demonstrated that high signal to noise ratio (SNR) sound field is obtained by one bit quantization at low sampling frequency.

On the other hand, operation of the 2D ΔΣ modulator becomes unstable when the sum of the orders of space and time exceeds four. Therefore, it was difficult to improve the efficiency of the modulation by adopting higher order filters in ΔΣ loop.

1.1 Design of high order 2D ΔΣ modulator

It is a difficult problem to analyze the stability of a multi-dimensional ΔΣ modulation of higher-order theoretically. However, the experimental rule on stable higher order ΔΣ modulater has been found; it is possible to stabilize the higher order modulator by limiting a gain value at outside of the signal-band of the noise transfer function.

Therefore, in this study, we designed the higher order ΔΣ modulator by the high level design technique that could limit the out of band gain of the noise transfer function (NTF). The MATLAB toolbox by R. Schreier was used for a high-level design. Designed high order ΔΣ modulator was included in the spatial filter insertion type two-dimensional modulator, which was porposed by the authors.

2. Simulation

2.1 Condition

The simulation assumed the generation of focused ultrasound field by the circular array transducer driven by 1 bit streams converted by ΔΣ modulator. Continuous sinusoidal waveform was focused to a given position, and SNR was calculated from the power spectrum density function obtained at the focus. SNR is evaluated as number of efeicient bit as,

$$\mathrm{Rbit} = (\mathrm{snr}-1.76)/6.02 \qquad (1)$$

The condtions of the simulation are as follows.

A transducer array radius	15mm
Distance to object	0.3m
Angle of focusing point	10°
Number of space channels	2048
Signal bandwidth for evaluation	7.0MHz
Over sampling ratio	1～128
The frequency of the wave	3.5MHz

We examined following (a)～(d) modulators:
(a)temporal 5th ΔΣ (T5),
(b)temporal 5th, spatial 1st ΔΣ (T5S1),
(c)temporal 5th, spatial 2nd ΔΣ (T5S2),
(d)temporal 5th, spatial 5th ΔΣ (T5S5).

Two dimension ΔΣ modulators,（a）～（d）were composed as shown in **Fig.1**. In the ΔΣ modulation only of time, one bit quantizer in which 0 level are assumed to be a threshold is used for space ΔΣ modulation block.

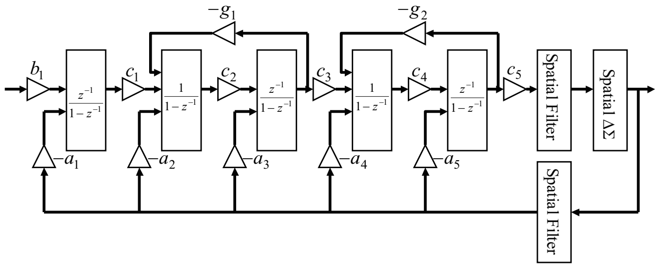


Fig.1. Block diagram of the 2D ΔΣ modulator

2.2Result

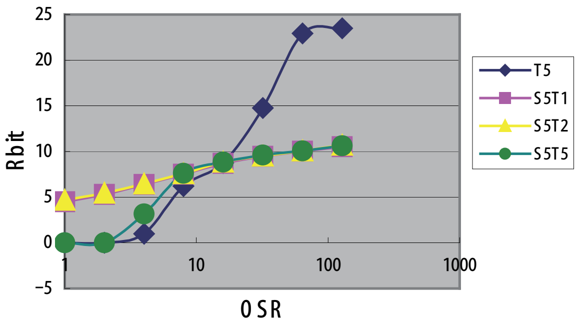


Fig2. Number of efficient bit of binary output

SNR values calculated from the power spectrum density functions for 1bit output are shown in **Fig.2**. SNR obtained by the two-Dimensional ΔΣ modulator is higher than the temporal only ΔΣ (T5) at low OSR region, but lowers in high OSR condtion.

The signal to noise ratio after 1bit output is processed with the spatial filter is shown in **Fig.3**. SNR by two-dimensional ΔΣ modulator is higher than ones by the temporal only modulator at wide range of OSR.

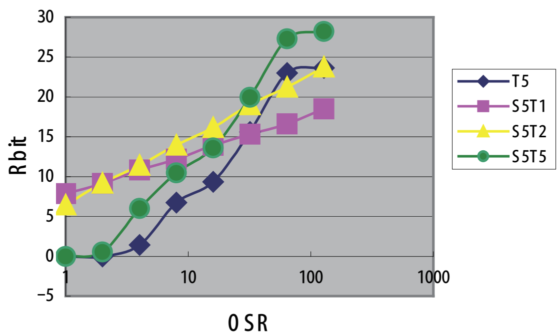
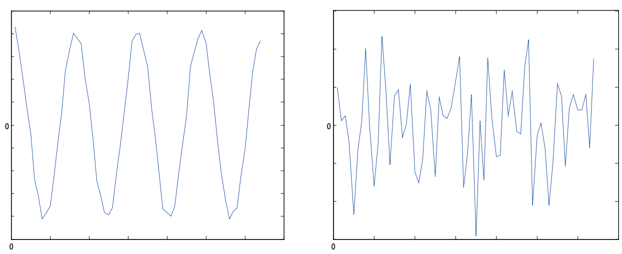


Fig3 Number of efficient bit of binary output(with the spatial filter)

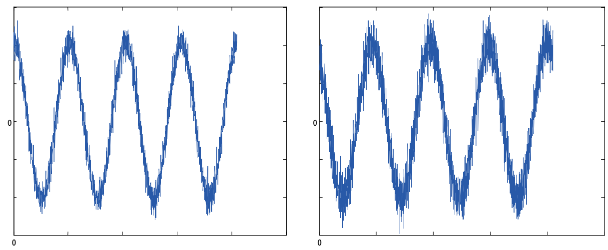
Fig. 4 shows that the waveform at the focus of 5th spatial 2nd ΔΣ modulator or temporal only ΔΣ modulator in case of OSR is 4.



(a) 2D (T5S2) (b) temporal only

Fig4 waveform in the focus (OSR=4)

Fig. 5 shows that the waveform at the focus of 5th spatial 2nd ΔΣ modulator or Time-domain ΔΣ modulator in case of OSR is 128.



(a) 2D (T5S2) (b) Time-domain

Fig5 waveform in the focus (OSR=128)

This result shows that temporal only ΔΣ modulator do not operate stably in case of low OSR.

3. Conclusion

We designed the higher order ΔΣ modulator by the high level design technique that could limit the out of band gain of the noise transfer function (NTF). Designed high order ΔΣ modulator was included in the spatial filter insertion type two-dimensional modulator.

The simulation results showed that high SNR was obtained using the designed modulator with an appropriate band-limiting spatial filter even in the low sampling frequency. In DA conversion application, the band-limiting spatial filters should be analog ones. Thus, the design of the appropriate analog spatial filter is the subject for future study.

References

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