

A Low Complexity Decimator for Communication between a Basestation and a Base Station Control System of an Underwater Acoustic Network

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ABSTRACT

Background/Objectives: We designed a decimator for a basestation-basestation controller communication of an underwater acoustic sensor network. Since it cannot be supplied with power smoothly, we focused on a low-complexity decimator.

Method/Statistical Analysis: Many underwater acoustic communication systems including decimators have been implemented using a microprocessor because acoustic wave signals are typically processed at a lower operating frequency than operating frequency of microprocessors. However, we designed a specific hardware decimator that support a low-power underwater acoustic communication system based on specifications of Hoseo University research group to reduce power consumption. We used Matlab and Verilog-HDL to simulate our algorithm and architecture.

Findings: Although a CIC filter has a simple and regular structure, it has a wide transition region and a narrow passband. So it is not suitable for underwater communication where channel spacing is narrow. We added a halfband filter for fast attenuation in the transition region and a compensation filter for passband attenuation compensation. We constructed the sampling rate conversion in three stages with an individual CIC filter. Since the last CIC filter was the most influential on the signal attenuation, the compensation filter was designed for the three-stage CIC filter. The halfband filter and the compensation filter were cascaded before and after the three-stage CIC filter, respectively, to reduce power consumption. Since the transition region of the halfband filter is located at the $1/4$ frequency of the sampling frequency of the input signal, the sampling down rate of the three-stage CIC filter is half. Therefore, the proposed decimator has a narrow frequency transition region and a flat passband suitable for underwater acoustic communication.

Improvements/Applications: Our proposed decimator makes it possible to realize a stable digital circuit in low frequency band signal processing such as sensor data processing as well as communication.

Keywords: *cic filter, decimator, half-band filter, underwater communication, down sampling*

Introduction

Recently, studies on the underwater network based on an acoustic communication have been actively conducted to observe and control the marine environment for marine resource development, marine disaster preparedness,

military defense, etc. [1-3]. In general, since an acoustic communication uses a low frequency of several tens of KHz, a data transmission speed is slower than an electromagnetic wave communication using a band of several hundred MHz to several tens of GHz. However, since the electromagnetic wave rapidly decreases according to the distance in the water, electromagnetic wireless communication cannot be established in the water. On the other hand, acoustic communication can be performed in the water up to several tens of kilometers. Therefore, most countries such as USA, Europe, China and Japan use acoustics for underwater communication [4-6]. The WHOI Acoustic Communications Group in the

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United States has established an acoustic communication system that links a number of underwater mobile-boat-buoy-underwater probe-submersibles^[4]. In the SUNRISE project supported by the EU, Underwater IoT based on Underwater WSN is studying ^[5]. Japan JAMSTEC is studying underwater communication network while providing and analyzing real-time ocean information using satellite tracking buoy ^[6]. In Korea, Hanwha, LIG NEX1, SK Telecom and Hoseo University, etc are studying underwater communication ^[7,8].

In this paper, we have studied digital sampling rate down converter for acoustic communication between underwater basestation controller and underwater basestation based on the underwater acoustic communication system of Hoseo University research group ^[8]. The underwater communication system needs a simple, low-power system because it is difficult to replace a power supply and a battery due to installation environment constraints. By the way, most of acoustic communication systems are implemented using a microprocessor based on software due to the use of acoustics that support low rate data processing. However, the Hoseo University research group uses OFDM and CDMA for the underwater acoustic communication system and has designed dedicated hardware. So, a low-complexity and low-power consumption digital down converter is required.

We designed the decimator of underwater acoustic communication system based on CIC filters ^[9]. The CIC filter consists of two basic blocks, an integrator and a comb. The CIC decimator connects N integrator blocks operating at F_{in} sampling rate, a $1/R$ down sampler and N comb blocks operating at F_{in}/R . (F_{in} : the sampling frequency of the input signal, R: the ratio of the sampling frequency (F_{in}) of the input signal to the sampling frequency (F_{out}) of the output signal, $R = F_{out}/F_{in}$). The following is the transfer function of the CIC filter and the magnitude response at the output of the filter.

$$H(z) = \frac{(1 - z^{-RM})^N}{(1 - z^{-1})^N} = \left(\sum_{k=0}^{RM-1} z^{-k} \right)^N \quad \dots(1)$$

$$|H(f)| = \left| \frac{\sin(\pi Mf)}{\sin\left(\frac{\pi f}{R}\right)} \right|^N \quad \dots(2)$$

where M is the differential delay. As shown in Equation (1), all coefficients of the CIC filter are ‘1’. So, the circuit can be constructed with only adders without

storages and multiplier operators, which is efficient in terms of design complexity, size and power consumption ^[10]. In general, down sampling requires an anti-aliasing filter to avoid aliasing that occurs during this process.

Since the CIC filter includes the LPF function, it is not necessary to implement a separate LPF. However, as shown in Equation (2), the CIC filter has a sinc function form whose passband droop is large and transition region is wide. Particularly, since the carrier frequency is low in the underwater acoustic communication, the data link interval is narrow and a high-order filter having a narrow transition region is required. Therefore, in this paper, we propose a decimator for underwater acoustic communication that can compensate a narrow passband and a wide transition region.

In Section 2, we describe the frequency allocation of underwater acoustic communication system and then describe the hardware structure of the decimator. In Section 3, we show the results of the design simulation. Finally, Section 4 concludes the paper.

Method

Frequency Allocation: The distributed underwater acoustic sensor network consists of underwater basestation control systems, underwater basestations and underwater sensor nodes. Figure 1 shows the frequency allocation of a distributed underwater acoustic sensor network proposed by the Hoseo University research group. There are total eight communication links. Four communication links of them are defined between the underwater basestation and the underwater basestation control system as shown in the Figure 1. One downlink (DL) for transmitting data from underwater basestation control system to underwater basestation and two uplinks (UL0, UL1) for data transmission from underwater basestation to underwater basestation control system are allocated to frequencies lower than 20 KHz to allow communication up to 10 km, and one uplink (UL2) is allocated for utilization of high-speed transmission environments within 1 Km. Since uplink and downlink use different frequencies, full-duplex data transmission is possible. Table 1 shows various frequency requirements. Bandwidth of UL0 and UL1 is 4 KHz and transition region is 1 KHz. In other words, data links in underwater acoustic communication require a narrow passband and a rapidly-attenuated transition region.

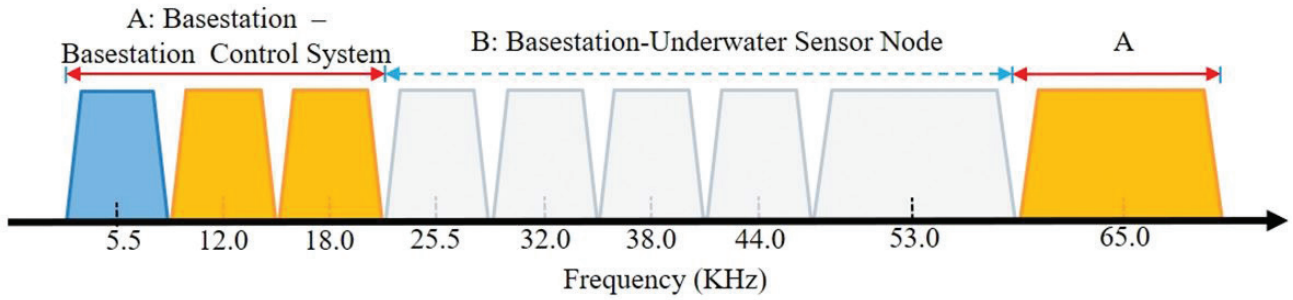


Figure 1: Frequency allocation of a distributed underwater acoustic sensor network proposed by the Hoseo University research group

Table 1: Carrier frequency F_c , bandwidth, transition region, passband signal sampling frequency(F_s), baseband data processing frequency(F_B), and sampling rate changing factor according to links ($R = F_B/F_s$)

Link	Carrier frequency (F_c , KHz)	Bandwidth (KHz)	Transition region (KHz)	Passband signal sampling frequency (F_s , KHz)	Baseband data processing frequency (F_B , KHz)	Sampling rate changing factor ($R = F_B/F_s$)
DownLink	5.5	5	1	500	5	1/100
UpLink 0	12	4	1	500	5	1/100
UpLink 1	18	4	1	500	5	1/100
UpLink 2	65	10	1	500	10	1/50

Architecture of a Decimator: As shown in Table 1, the highest carrier frequency of communication between the underwater basestation and the underwater basestation control system is 65 KHz (UL2) and the passband signals are sampled at 500 KHz (F_s), which is about 7.5 times of the highest carrier frequency. While the carrier frequency signals are converted to the baseband signals, the sampling rate is also converted. the baseband data processing frequencies are 5 KHz and 10 KHz for UL0, UL1, DL and UL2, respectively. Therefore, the sampling rate should be reduced by 1/100, 1/100, 1/100 and 1/50 for UL0, UL1, DL

and UL2, respectively. In this study, the data sampling rate conversion was divided into three stages.

Previous Architecture: We designed a decimator of an underwater acoustic sensor network by cascading three CIC filters^[9]. As shown in Table 2, the sampling rate was reduced to 1/5 in the first stage and in the second stage in common for all links. In the third stage, the sampling rate was reduced to 1/4 for UL0, UL1 and DL, and to 1/2 for UL2. Therefore, the total sampling rate was reduced to 1/100 and 1/50.

Table 2: Comparison of sampling rate changing factors between previous architecture and proposed architecture

Link	Sampling rate changing factor of previous architecture			Sampling rate changing factor of proposed architecture		
	the 1st stage	the 2nd stage	the 3rd stage	the 1st stage	the 2nd stage	the 3rd stage
DownLink	1/5	1/5	1/4	1/10	1/5	1/2
UpLink 0	1/5	1/5	1/4	1/10	1/5	1/2
UpLink 1	1/5	1/5	1/4	1/10	1/5	1/2
UpLink 2	1/5	1/5	1/2	1/5	1/5	1/2

Proposed Architecture: As mentioned above, the CIC filter has a relatively narrow passband and a wide transition region. However, since the underwater acoustic communication requires that transmission frequency band is low and a link interval is narrow, CIC

filters are not suitable for that communication. So, as shown in Figure 2, we added a compensation filter and a halfband filter to flat a passband and narrow a transition region, respectively, in order to overcome the problems of CIC filters.

Figure 3 shows the frequency response when only three CIC decimators are connected in series to change the sampling rate to 1/100 times in UL. Figure 3(a) shows the frequency responses for each of the three decimators and the three cascaded connection in 250 KHz and Figure 3(b) shows them in 5 KHz. As shown in Figure 3(b), the magnitude of the frequency response is -3.75 dB at 2.45 KHz and -3.92 dB at 2.5 KHz. That is, passband droop and aliasing occur.

As shown in Figure 3(b), the first and second stage CIC decimators seems like all-pass filters in 2.5KHz band and the third stage one has the greatest effect on the final frequency response of the decimator. Therefore, it is necessary to add a compensation filter for the third CIC decimator to compensate the attenuation of the passband region, and a LPF with a narrow frequency transition region to prevent aliasing.

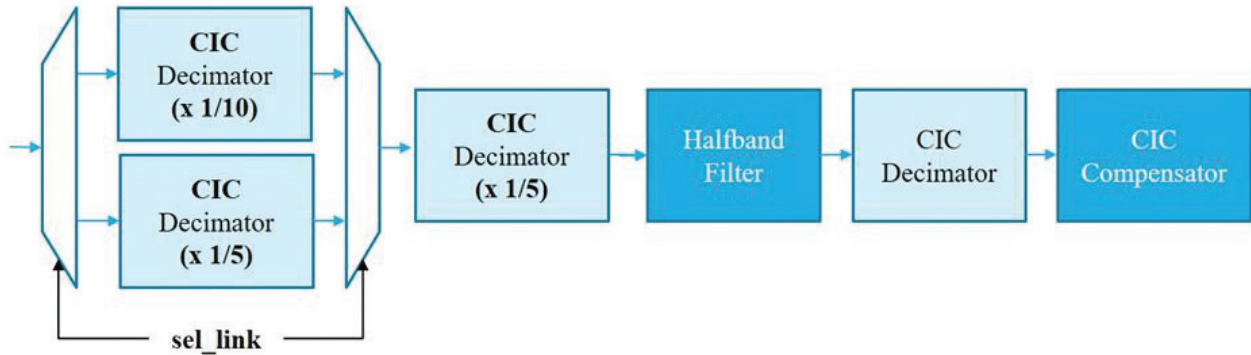


Figure 2: Blockdiagram of the proposed decimator

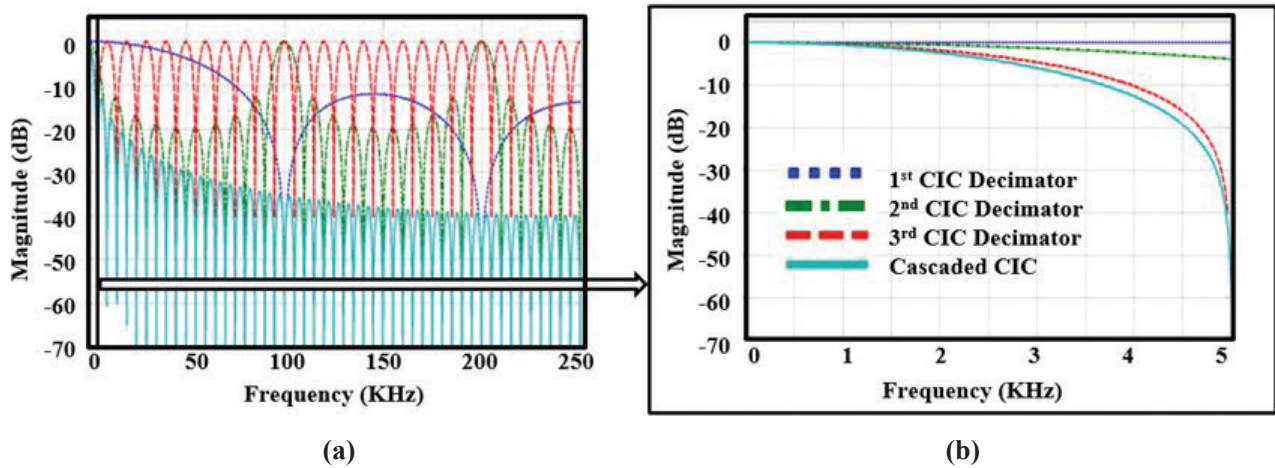


Figure 3: Frequency responses for each of the three decimators and the three cascaded connection (a) in 250 KHz and (b) in 5 KHz.

As shown in Figure 2, the sampling rate is highest at the first CIC filter input, and goes lower toward the backend. Therefore, placing a compensation circuit at the last stage of the circuit is preferable in terms of area and power consumption, so the compensator is connected behind the third CIC filter as shown in Figure 2. The compensation filter was implemented to have an inversed magnitude response of the third CIC filter as shown in the following equation^[11].

$$|G(f)| = \left| \frac{\sin\left(\frac{\pi f}{R}\right)}{\sin(\pi Mf)} \right|^N \approx \left| \frac{\pi Mf}{\sin(\pi Mf)} \right|^N = |\text{sinc}^{-1}(Mf)|^N \dots(3)$$

A halfband filter is a LPF that is often used to reduce the data bandwidth by a factor of 2 and its transition region is located at the 1/4 of the sampling frequency of the input signal. All even (or odd) coefficients of it are '0', and the other coefficients are symmetrical^[12]. We added this halfband filter before the third decimator. The third decimator reduces the sampling rate by half for all links. Sampling rate changing factor of proposed architecture is summarized in Table 2.

Results and Discussion

The proposed decimator was simulated using Matlab. Figure 4 shows the frequency response of the

third CIC filter, the compensation filter, and the filter in which two filters are connected in series. The passband of the cascaded filter is flattened by the compensation filter. However, the characteristics of the transition region are worse because the frequency response of the stop band also increases. An LPF is required to remove the signal from the stop band region.

Figure 5 shows the frequency response of the third CIC filter, the compensation filter, the halfband filter, and the filter in which three filters are connected in series. It is confirmed that the signal in the stopband region is sufficiently low to prevent aliasing. In the DL, the magnitude of the frequency response is -3.67 dB at the passband frequency of 2.45 KHz and -55 dB at the stopband frequency of 2.5 KHz. The frequency response in the pass band is improved and the frequency response at the stop band is sufficiently low to solve the problem of the aliasing.

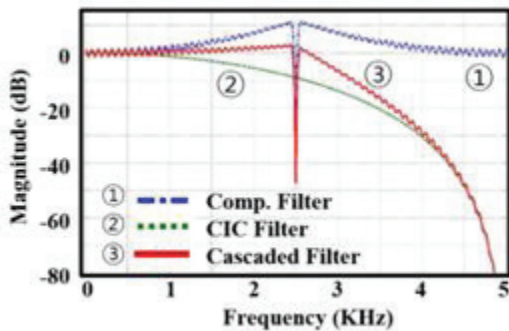


Figure 4: Frequency responses for the compensation filter ①, the third CIC filter ② and the cascaded filter of ① and ②

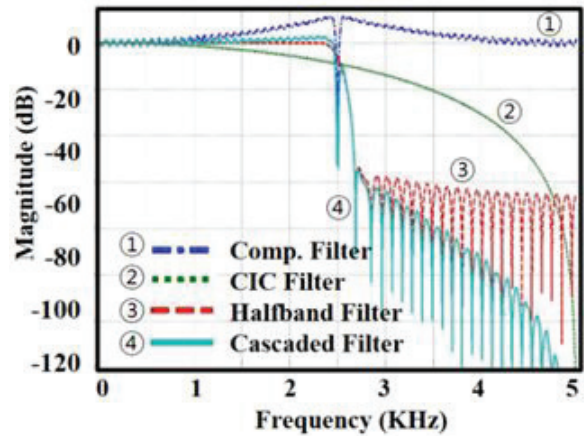


Figure 5: Frequency responses for the compensation filter ①, the third CIC filter ②, the halfband filter and the cascaded filter of ①, ② and ③

Figure 6 shows function simulation results of verilog-hdl design using ModelSim. Input signal (data_in) of the decimator passes through the first and second CIC filters, the halfband filter, the third CIC filter, and the compensation filter, so that the sampling rate was lowered. We verified the verilog-hdl design by comparing Modelsim simulation results with matlab fixed-point simulation results. There were max 1-bit error in the last 16-bit data output signals (data_out_comp).

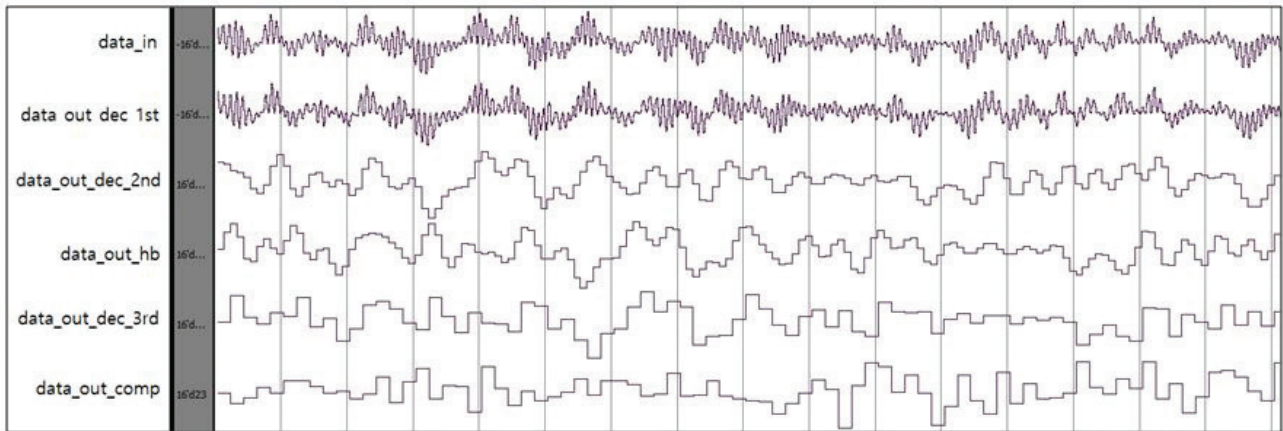


Figure 6: From the top, input signal of the decimator (data_in) and output signals of the 1st CIC filter (data_out_dec_1st), the 2nd CIC filter(data_out_dec_2nd) passes through the first and second CIC filters, the halfband filter, the third CIC filter, and the compensation filter

Conclusion

The low-complexity decimator was designed for communication between the underwater basestation control system and the underwater basestation of the

distributed underwater acoustic sensor network proposed by the Hoseo University research group. The decimator was based on three serially-connected CIC filters that consist of only adders without multipliers and storages.

Because the CIC filters had passband droop and a wide transition region, they were not suitable for underwater acoustic communication with narrow channel spacing. We designed the compensation filter for the third CIC filter that was the most influential on passband droop and connected it to the output of the decimator that operated at the lowest sampling rate to reduce power consumption. In addition, the halfband filter was added to attenuate high frequencies more steeply. We confirmed the frequency specification of our proposed decimator by simulation with Matlab and verilog-hdl, and verified the function through function simulation. The proposed decimator will be integrated with the modem system designed in Hoseo University research group in the future and used in the underwater acoustic sensor network.

Ethical Clearance: Not required

Source of Funding: Self

Conflict of Interest: Nil

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