A Novel Conditioning and Recording System of Low-noise Underwater Acoustic Signal

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***Abstract*—A novel conditioning and recording system of Low-noise underwater acoustic signal is proposed in order to coordinate the applied vector hydrophones. The low-noise analog circuit design is taken into account seriously according to the requirements of high precision and low distortion of underwater acoustic data. Compared with other similar systems, it features on miniaturization, high dynamic range, low distortion and low power consumption.**

Keywords-Underwater acoustic experiment, Low noise, Data recording, MSP430

I. INTRODUCTION

Most of underwater acoustic signals picked up by sensors like hydrophones are very weak, which requires a data acquisition system with high SNR performance.

In order to obtain high-quality experimental data, An underwater acoustic data recording system is accomplished based on low-noise analog circuit design techniques, this system also features on high dynamic range, low distortion signal acquisition while achieving high sample rate and real time storage. This paper describes the Date Recording system of Underwater Acoustic Data in detail, including both the hardware and software implementation, as well as the key design challenges and the techniques employed to meet the specifications.

The system is applied in the marine-self noise field measurement experiment which using the combined acoustic vector sensors. Therefore, four channel signals are collected and stored by this system. one channel is sound pressure signal, and other channels are particle velocity signals.

The workflow and the structure of proposed system are shown in Fig.1 and Fig.2.

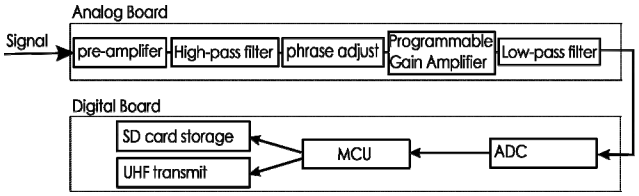

Figure 1. The workflow of the recording system

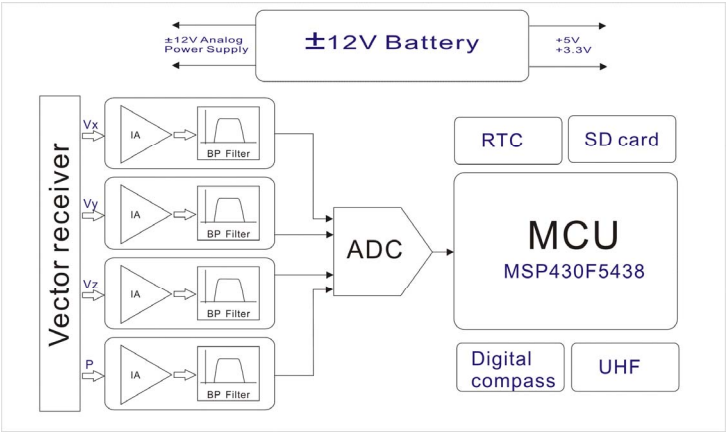

Figure 2. The structure of the recording system

This proposed system includes the following functions:

- Variable gain amplification of acoustic signals;
- High order band-pass filter;
- Data acquisition and storage.

According to the require of high dynamic range signal acquisition, the power supply of analog board comes from positive and negative 12 volt lithium battery. The acoustic signals after conditioning can swing up to ±10v with little distortion. Thus, it is suitable to choose a ±10v input range ADC like the 16-bit LT1859 for the digitization of analog signals. and the 5v、3.3v voltage is generated by low quiescent current LDO for the overall digital system power supply.

II. THE DESIGN OF HARDWARE

The design of analog circuit includes multi-level signal amplification、high-pass filter、low-pass filter and phase adjust section. The purpose of analog circuit mainly is to extract the useful signal from the noises, filter out unwanted interference and increase signal amplitude.

Low-noise preamplifier should be used because low noise is one of the important characteristic for the conditioning of underwater acoustic signal. The ADI instrument amplifier AD8221 is taken for amplifier of the velocity signals channel whose the noise density of input voltage is 8 nV/Hz. Due to the high source impedance of piezoceramic pressure sensors, the JFET input, monolithic

Published by Atlantis Press, Paris, France.

instrumentation amplifier AD8220 is selected instead. Using JFET transistors, the AD8220 offers extremely high input impedance, extremely low bias currents, therefore, minimize the current noise which is the main problem of high source impedance sensors.

The useful signal needs to be extracted form a variety of background noises by appropriate filters. Low-frequency signal is eliminated by the high-pass filter in order to avoid the output saturation cause by the low frequency marine hydrodynamic noise, and then the high frequency noise is almost completely removed by the 8th-order order low-pass Butterworth filter which has the least attenuation for all frequencies in the pass band. The Sallen–Key topology is used to implement both the 6-order high-pass and 8-order low-pass Butterworth filters that are particularly valued for its simplicity. Just one single amplifier, two resistors and two capacitors are needed by the 2-order filter of SK topology structure at the unit gain as are shown in Fig.3. The RC value can be calculated through the assisted tools of filter design, and pay attention to that the metal film resistors of smaller resistance value help to reduce system noise [1].

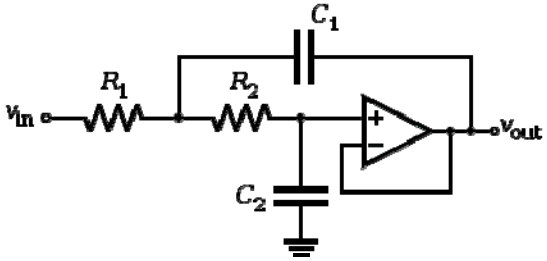

Figure 3. A unity-gain low-pass filter implemented with a Sallen–Key topology.

Where the undamped natural frequency fo and Q factor (i.e., damping ratio ζ) are given by

$$f_0 = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}} \quad (1)$$

And,

$$2\zeta = \frac{1}{Q} = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_1}\left(\frac{1}{R_1} + \frac{1}{R_2}\right). \quad (2)$$

So,

$$Q = \frac{\sqrt{R_1 R_2 C_1 C_2}}{C_2 (R_1 + R_2)} \quad (3)$$

The intensity of underwater acoustic signal is in the range of 10^4 orders of magnitude [2], The PGA section amplification circuit of this system carry out the adjustment of the overall gain from 20dB-80dB by different feedback resistors which are selected by analog switch DG211, so that the signal sampling of a large dynamic range is achieved. Besides, this system also includes amplifier circuits used in the impedance isolation and RC phase adjustment circuit.

It is better that it is independent for four-channel analog board or a PCB board is made for the minimum interference among four channels, and the even channels of ADC are grounded to achieve the previous purpose. In the noise test of the electronic system, the analog signal input is grounded, the electronic system is configured to 4000 times amplification, and we found the output noise is about 10mv. Therefore, the valid noise of input terminal is 10mv/4000=2.5uv. The analog circuits are fully tested for low *noise* (*less than 10uV* noise).

By the way, the high order filters also contribute to the low noise performance because it filtered out most of the high frequency noise. The low-pass and high-pass filters are cascade by SK topology using the low-noise amplifier OP2177. The magnitude-frequency characteristic is shown in Fig4. (The pass band is 10-500Hz in this case, and it can be adjusted as needed to design)

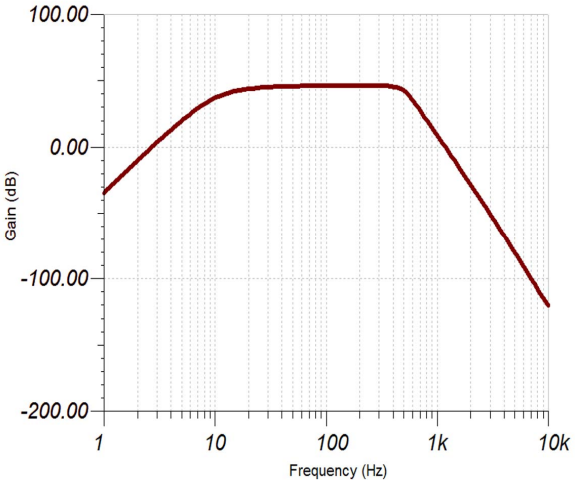

Figure 4. Amplitude frequency response of analog circuits

The design of digital circuit includes MCU and interface with various peripherals.

The Texas Instruments MSP430 family of ultra low power microcontrollers consists of several devices featuring lower power consumption, and 25MIPS CPU speed [3]. The 5xx series MSP430 chip -Msp430F5438A have been selected for governing digital system. This kind of devices are complete system on-a-chip and in clued many integrated peripherals like Direct Memory Access (DMA) modules, UARTs, etc. All these characteristics make them a very attractive choice for this design.

The media chosen to store the experimental data acquired during an inspection is a Secure Digital cards. Which is removable Flash-based storage devices that are gaining in popularity in small consumer devices such as digital cameras. Their small size, relative simplicity, low power consumption, and low cost make them an ideal solution for many applications. This interface combined with the MSP430, can form the foundation for a low-cost, long-life data logger. So, the SD card is a good choice for the underwater acoustic signal recording system when the data collection system takes a long time to collect and record huge amounts of data. It has two optional protocols: the SD mode and the SPI mode. All of data exchange can be completed by the four lines in the SPI mode, which greatly simplify the design of hardware circuit. The interface between SD and the MCU is use the SPI protocol which is shown in Fig.5.

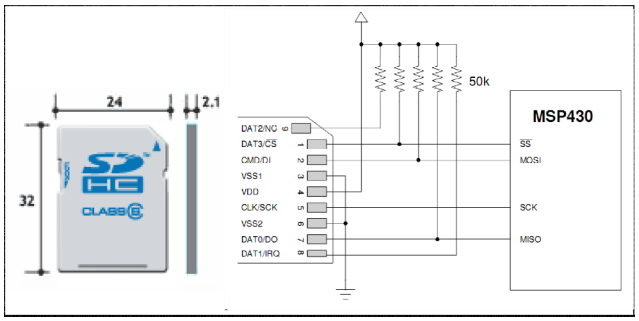

Figure 5. SD Card Schematic-SPI Mode

This system takes the 16bit softspan ADC chip LTC1859 in order to meet the 10V sampling of positive and negative analog signal. 16-bit resolution analog to digital conversion provides a responsive instrument capable of registering changes as small as one part in 65536 (0.000015% of the full scale measurement range). Besides, the voltage reference of chip internal is 10ppm, the SNR is 87dB, these features are all very important for a high-quality data acquisition system. It is connected to MCU through SPI interface, as is shown in Fig.6.

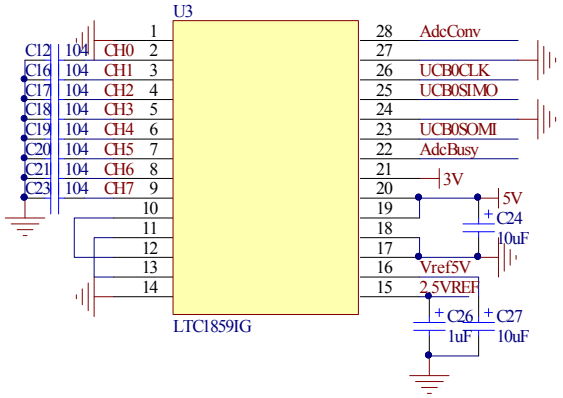

Figure 6. ADC chip interface with the MCU

The electronic compass, with a pointing accuracy of 1º rms, uses the low-power three-dimensional digital compass of the PNI Company, and it is linked to MCU through RS232 interface.

All the interfaces like SPI and 232 are industrial standard and therefore very convenient for firmware development and debug.

III. THE DESIGN OF FIRMWARE

The mount of data to be collected can be estimated as shown in Equation 4. Fs is the sampling frequency, Word_Size is the number of bytes needed to store one single sensor read (2bytes for a16-bit resolution), N_{ch} the number of sensor. T is the recording time in seconds. As at 10k sampling rate from four channels for an hour , the amount of data to be collected is:

$$Data\_Size = fs*Word\_Size* N_{ch}*T \quad (4)$$

$$=10240*2*4*3600=294912000bytes=280Mbytes$$

The 32G SD card can fulfill 4 days deployment storage.

The data from this recording system is writing directly in the sector rather than through the creation of file system storage, which results in higher writing speed.

The writing sector of SD card consists of three procedures: sent the writing sector command to the SD card; transmit data to the SD card; the SD card internal programming. Here I must say The SD card programming internal needn't the CPU intervention, however, the time-consuming of one sector can reach up to hundreds of mill-seconds [5]. So in order to achieve the high-speed writing of SD card, big RAM caches are essential. And The DMA capabilities available in the MSP430 MCU, that permit fast data transfers without CPU intervention, are of a great advantage in applications where high sampling rates are required. The strategy of high-speed recording proposed below also relies on the exploitation of the DMA capabilities

The classic double-buffer strategy is adopted, Two array of memory buffers of 512*12 bytes each is used to temporarily store the acquired data while is being transferred to the SD card. Let us focus on the data acquisition strategy implemented in the MCU:

1. 0.1ms timer interrupts is established for the sampling rate of 10k. The four channels is sampled once the interrupts is carried out, all of eight bytes from 2 bytes per channel is continuously written in the established AdcBuffer;
2. After 768 interrupts, the AdcBuffer of 6K is full, and the DMA is opened so that the data in the AdcBuffer is transmitted to the MMCBuffer of the same capacity;
3. Meanwhile, the new sampled data is over write in AdcBuffer.
4. The 6K bytes data will be transmitted to the SD card once the DMA transmission is completed;

The flow chart of this strategy is shown in Fig.7. With the 16K RAM and DMA modules of Msp430F5438A combined with 25Mips processing speed, the real-time data recording up to 20ksps four channels is achieved. The high-speed SD card is used in this Stand-alone data logger with configurable sample rate from as low as 0.001 Hz up to as high as 10,000 samples per second.

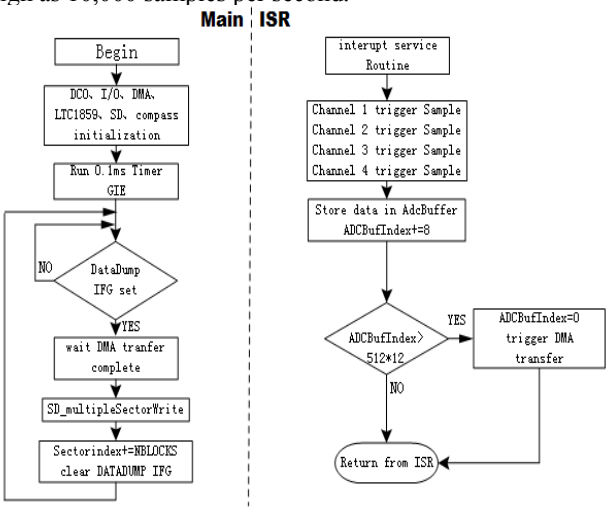

Figure 7. The system sampling and real-time handling

IV. CONCLUSION

Several tests have been performed in order to ensure the low-noise performance on the analog circuits and check the effectiveness of the strategies adopted to optimize the SD real-time writing performance of the recording system.

The system provides a reliable data acquisition platform for the underwater acoustic experiment, satisfying the requirements derived from the targeted application, in terms of sampling rate, resolution, data storage capabilities and power consumption. Besides, the dynamic range of signal is greater than 70dB, and the equivalent input noise is less than 10μv, the pass-band ripple is less than 0.1dB, the phase difference among channels is small. Also, the operating current of the whole system is about 80mA, the entire system is lightweight and portable if the high-energy lithium-ion battery is adopted, and it is convenient to be placed in equipment and deploy. In a word, this system is very feasible in the marine environment noise field measurement experiment for the use on underwater acoustic signal logging.

ACKNOWLEDGMENT

The first author wishes to thank Zheng yi and Yang guang for their valuable comments that improved the quality of this paper. And this paper was supported by the National Natural Science Foundation of China under Grant 40806044, and supported by the QingDao Science and Technology Planning Project Fund of China under Grant 10-3-4-9-2-jch, and supported by Research Fund for the Doctoral Program of the Shandong Academy of Sciences under Grant Y09-2.

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