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Design of a Single-Supply Microphone Amplifier and Data Acquisition System Based on STM32

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Abstract: Currently, acoustic wave detection methods are widely used in oil extraction and exploration operations. During transmission, the oil well casing acts as a natural filter, eliminating high-frequency signals and leaving behind weak sub-audio signals that are easily disrupted by environmental noise. Traditional dual-power supply amplifying circuits, while functional, suffer from high costs, complex usage, and instability. To address these issues, this paper presents the design of a single-power supply microphone amplifier and acquisition circuit based on the STM32F103ZET6 microcontroller. The system utilizes a 24-bit AD7192 chip for high-precision analog-to-digital conversion. The hardware includes a low-pass amplifying filter circuit with a cutoff frequency of 150Hz and an amplification factor of 6. Experimental results demonstrate that the proposed single-supply circuit effectively amplifies and denoises the collected acoustic signals, providing a cost-effective and reliable solution for dynamic fluid level detection in oil wells.

Keywords: Acoustic Wave Detection; Microphone; Single Power Supply; Amplifier Circuit; AD7192; STM32

1. INTRODUCTION

With the continuous development of the petroleum industry, acoustic well logging has stood out among various methods due to its accuracy and convenience. Dynamic fluid level detection instruments are crucial for determining oil well production systems and improving crude oil recovery[1]. In these instruments, microphones are used to detect downhole acoustic signals, which are typically weak and mixed with significant interference.

In previous designs, dual-power supply amplifiers were commonly used. However, they present challenges such as high cost, instability (as the negative supply is usually converted from the positive supply), and complex control logic. Therefore, designing a single-power supply microphone amplifier and acquisition circuit is highly necessary to reduce costs and improve system stability[2]. The primary objectives of this research are to develop a single-supply low-pass filter amplifier using the OP1177 operational amplifier, implement a high-precision data acquisition module using the 24-bit AD7192, and use an STM32 microcontroller to process and transmit data for visualization.

2. SYSTEM ARCHITECTURE AND HARDWARE DESIGN

2.1 Overall System Architecture

The proposed system consists of an acoustic signal simulator, a microphone, a single-supply low-pass filter amplifier, an AD converter, an STM32F103ZET6 main controller, and a PC for data visualization. The microphone converts the received acoustic waves into electrical signals. Because the system uses a single power supply, a DC bias circuit is introduced to elevate the voltage level, preventing the AC signal from distortion during amplification.The overall system block diagram is shown in Figure 1.

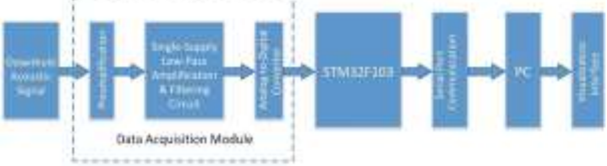

Figure 1: Overall System Architecture Block Diagram

2.2 Hardware Modules Selection and Design

Amplifier Circuit: The OP1177 was selected over the LM324 due to its high performance, low noise, and suitability for single-supply, high-precision applications. The circuit incorporates a capacitor (C3) to block DC interference, followed by a DC bias circuit using two 100kΩ resistors (R2, R4) to provide a 1/2 Vcc bias. The signal then passes through a voltage follower to ensure high input and low output impedance, a low-pass filter with a calculated cutoff frequency of 150Hz, and a non-inverting amplifier set to a gain of 6 times[3]. The specific schematic of this amplifier circuit is shown in Figure 2.

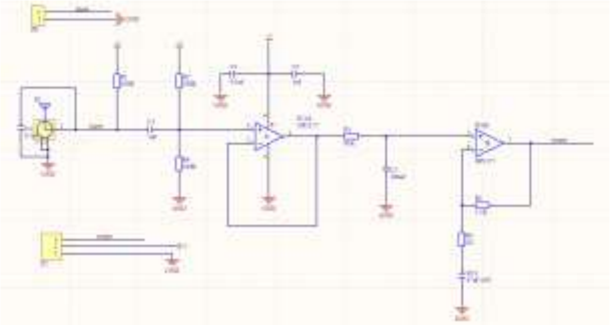

Figure 2: Schematic of the Single-Supply Low-Pass Filter Amplifier

ADC Module: The 24-bit AD7192 was selected as the core data acquisition component. Given that the microphone output amplitude ranges from 0.1mV to 2.5V, the signal's dynamic range is calculated to be approximately 87.96dB. While a 16-bit ADC theoretically meets this requirement, the 24-bit structure of the AD7192 was chosen to provide a higher actual effective resolution and minimize the impact of circuit noise. Furthermore, the system is designed to operate at a 1kHz sampling rate. Since downhole acoustic signals typically concentrate in the low-frequency band below 100Hz[4], this sampling frequency strictly adheres to the Nyquist theorem (operating at 2 to 5 times the maximum signal frequency) to prevent aliasing and guarantee waveform accuracy. Its built-in multi-channel architecture also eliminates the need for external multiplexers, significantly improving system integration and stability. The detailed connections of the AD7192 module are depicted in Figure 3.

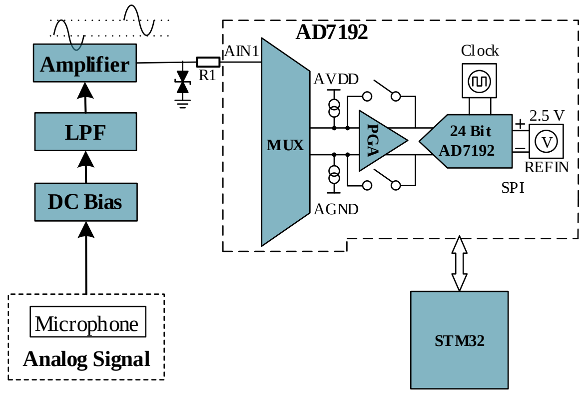

Figure 3: AD7192 Analog-to-Digital Conversion Circuit

3. SOFTWARE DESIGN AND IMPLEMENTATION

The system software is designed around the STM32 microcontroller. Upon startup, the system initializes the hardware parameters, clocks, and GPIOs. Timer 2 (TIM2) is configured to generate an interrupt every 1ms (1kHz sampling frequency). The main program flow is presented in Figure 4.

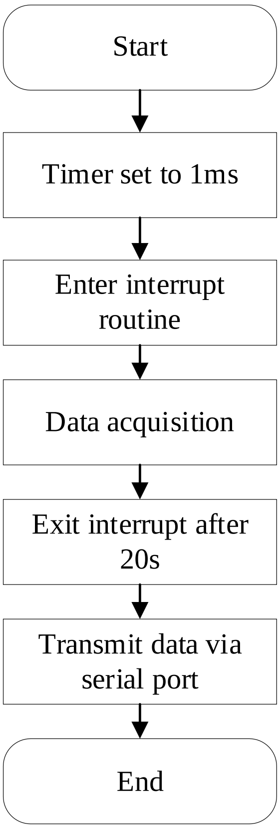

Figure 4: Main Program Flowchart

Within the interrupt service routine, the system triggers the AD7192 via SPI. The software waits for the RDY falling edge, reads the 24-bit data registers, and stores the converted digital values into a buffer. The collected data (lasting for 20 seconds per cycle, totaling 120,000 Bytes) is transmitted via UART to the PC. MATLAB is utilized to convert the hexadecimal data into decimal voltage values, which are then imported into Origin for waveform visualization.

4. SYSTEM TESTING AND RESULTS

4.1 Filter and Amplification Performance Test

To evaluate the filtering performance, the low-pass filter was tested with input signals of 100Hz, 150Hz, and 200Hz (100mV amplitude). The output amplitudes were 104mV, 72mV, and 64mV, respectively. These experimental results are summarized in Table 1.

Table 1: Group Experiment Test Results

Input Frequency(Hz)	100	150	200
Input Amplitude(mV)	100	100	100
Output Frequency(Hz)	100	150	200
Output Amplitude(mV)	104	72	64
Vout/Vin	104%	72%	64%

The results at 150Hz (Vout/Vin = 0.72) closely match the theoretical -3dB point (0.707), verifying the 150Hz cutoff frequency. The amplification performance was verified by inputting a 100mV signal, which yielded a 624mV output, perfectly matching the designed 6x gain. The oscilloscope waveform for the amplification test is shown in Figure 5(a) and Figure 5(b).

Frequency 100.000 000 Hz
Amplitude 100.0mVpp
Offset -4.950 Vdc
Phase 0.000 0 °
Load HiZ
Output 50Ω ,ON

Figure 5(a): Amplification Performance Test on Oscilloscope

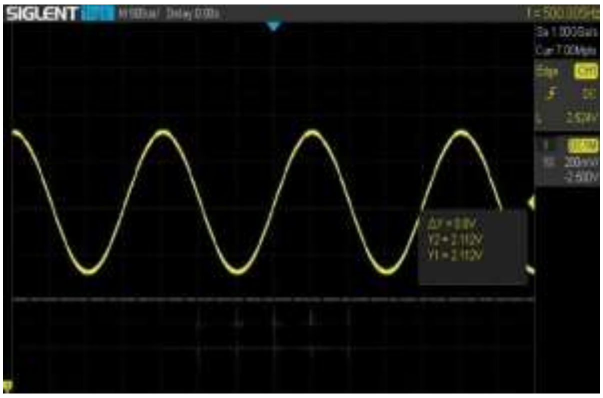

Figure 5(b): Amplification Performance Test on Oscilloscope

4.2 Acoustic Signal Input Test

An acoustic signal simulator was used to replicate the downhole environment[5]. The dynamic fluid level acoustic signal contains a blasting wave, collar echoes, and a liquid level echo. The comparison of the acoustic signal before and after processing is illustrated in Figures 6(a)-(c).

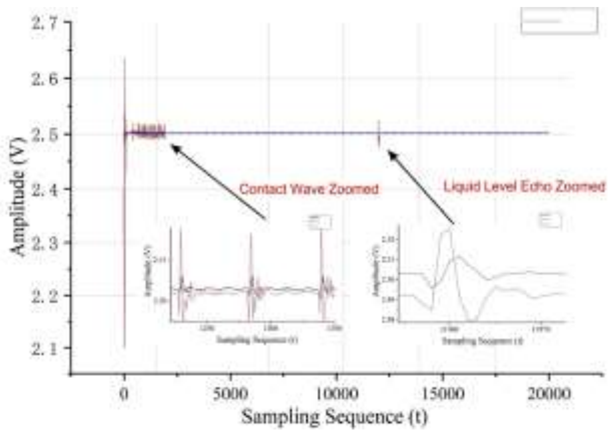

Figure 6(a): Comparison of Acoustic Signal Before and After Amplification and Filtering

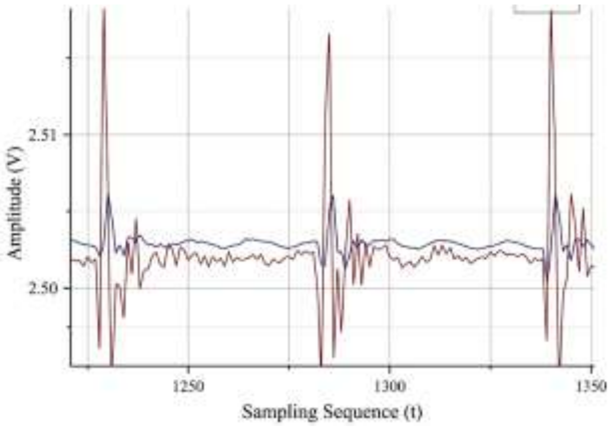

Figure 6(b): Comparison of Acoustic Signal Before and After Amplification and Filtering

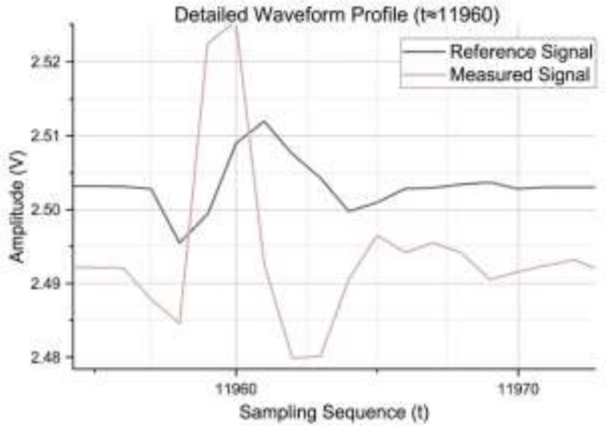

Figure 6(c): Comparison of Acoustic Signal Before and After Amplification and Filtering

The test results visualized on the PC demonstrated that the single-supply low-pass filter amplifier successfully smoothed the noisy raw signals, effectively filtering out high-frequency environmental interference and significantly improving the signal-to-noise ratio (SNR). The collar waves and the sudden mutation of the liquid level echo were clearly identifiable and amplified by exactly 6 times. This enhanced clarity facilitates easier feature extraction, providing a reliable data foundation for accurately calculating the dynamic fluid level depth, thus proving the circuit's excellent signal conditioning capabilities.

5. CONCLUSION

To address the limitations of traditional dual-power supply circuits—namely high costs, complex power management, and noise susceptibility—this paper successfully designed and implemented a novel single-power supply microphone amplifier and high-precision data acquisition system. By utilizing the high-performance OP1177 operational amplifier and introducing a precise DC bias circuit (1/2 Vcc), the system avoids AC signal distortion. This architectural transition significantly reduces the PCB footprint and overall costs while minimizing power consumption and enhancing operational stability. Furthermore, the STM32F103ZET6 microcontroller and 24-bit AD7192 converter provide a robust foundation for signal processing.

Rigorous empirical testing validated the theoretical design. The frequency response tests confirmed that the low-pass filter strictly adheres to the 150Hz cutoff, effectively attenuating high-frequency interference (dropping to 64% amplitude at 200Hz), while the amplifier stage reliably maintained a precise 6x gain. Acoustic signal simulation tests demonstrated a substantial improvement in the signal-to-noise ratio (SNR). Crucial acoustic features, including the blasting wave, collar echoes, and the liquid level echo, were clearly identifiable, ensuring high reliability for subsequent fluid level depth calculations.

Future work will focus on optimizing hardware by selecting temperature-compensated components to minimize thermal drift, and conducting reliability testing under extreme high-temperature and high-pressure downhole conditions. Additionally, future iterations will explore integrating advanced digital signal processing algorithms, such as adaptive filtering or machine learning-based echo recognition, to further elevate the system's intelligence and accuracy.

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