Comprehensive detection device and physical testing for mechanical properties of seabed sediments and shallow gas

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Abstract. In this paper, a comprehensive detection device for the mechanical properties of seabed sediments and shallow gas is designed, which is mainly composed of the seabed sediment mechanical properties detection part, the shallow gas detection part and the ultrasonic wireless transmission part. The mud water gas separation structure of the shallow gas detection part separates the shallow gas from the mud water, and then the methane concentration in the shallow gas is measured by the non-dispersive infrared methane sensor, which realizes the collection of the submarine shallow gas and the automatic real-time monitoring of the concentration. The measurement of the mechanical properties of seabed sediments realizes the real-time measurement of the three parameters of cone resistance, sidewall friction and pore water pressure, which characterize the mechanical properties of seabed sediments, through strain-sensitive elements. The ultrasonic wireless data transmission part is mainly for the data detected by the mechanical properties of the seabed sediments to be wirelessly transmitted to the sensor placement room through the ultrasonic transducer across the mud-water-gas separation structure. Finally, the data measured by the two parts are transmitted to the mother ship through the cable located in the sensor placement room. The experimental results show that it has the ability to comprehensively detect the mechanical properties of seabed sediments and shallow gas, and has strong operability.

Keywords: Mechanical properties of seabed sediments, Static cone penetration, Shallow gas detection, Ultrasound wireless transmission.

1. Preface
With the development of economy and science and technology, the ocean rich in natural resources has become a hot spot for resource development in the new era. Regardless of resource extraction or infrastructure construction, the construction of marine engineering facilities will be inseparable. Among them, determining the basic physical and mechanical properties of the submarine soil and the bearing capacity of the foundation are important test items for marine engineering surveys. In addition, shallow gas is widely distributed in the near bay area. Submarine shallow gas usually refers to the natural gas resources accumulated in the sediments under the seabed. The main component is methane gas. The leakage and eruption of shallow seabed gas will cause the construction platform to sink, overturn and even cause fires, which will seriously threaten the safety of construction personnel and cause great harm...
to the construction of marine engineering. Therefore, studying the mechanical properties of seabed sediments and comprehensive detection devices for shallow gas has become an urgent need for my country's marine energy development and engineering construction.

At present, the mechanical properties of seabed sediments are detected by static probing technology, which presses the probe into the sediments at a constant rate through hydraulic pressure. In the process of penetration, three parameters representing the physical and mechanical properties of seabed sediments are measured through strain sensing elements: cone-head resistance, side-wall friction and pore water pressure. At present, the main method for detecting shallow gas in China is the exploration borehole method. This method mainly collects samples rich in shallow gas through a probe, then extracts the shallow gas in the laboratory, and finally uses the gas chromatograph to measure the shallow gas. The detection results of this method are accurate for each gas component in the gas, but the detection time is long and the cost is relatively high. In addition, the detection of the mechanical properties of seabed sediments and the detection of shallow gas are carried out separately in the project, which is laborious and laborious, and sometimes even shallow gas detection is not performed, leaving huge hidden dangers. Therefore, this paper designs a comprehensive detection device for seabed sediment mechanical properties and shallow gas combined with static cone penetration technology.

During the detection, the hydraulic press on the ship penetrates the seabed sediment mechanical properties and the shallow gas comprehensive detection device into the seabed sediment. The sediment resistance will cause the deformation of the hollow column outside the strain sensitive element, and the strain sensitive element on the hollow column will output three Each small voltage corresponds to three parameters that characterize the physical and mechanical properties of seabed sediments. Then through AD sampling, the output tiny voltage signal is converted into a digital electric signal, the digital signal is converted into an analog signal suitable for transmission in the channel by a modulator, and the transmitting transducer is driven to convert the electric signal into an acoustic signal and enter the channel transmission; The receiving transducer converts the captured acoustic signal into an electrical signal, and restores the original information through phase-locked loop demodulation and decoding, thereby crossing the mud-water-gas separation structure and transmitting the signal to the sensor placement room. At the same time, the porous ceramic permeable stone at the lower end of the mud-water-gas separation structure is used to achieve solid-liquid separation, and then the gas-liquid separation is realized by the polymer gas-liquid separation permeable membrane inside the structure. The methane sensor based on the infrared absorption principle is located in the sensor placement chamber. When it reaches the shallow gas, the corresponding voltage value will be output. Finally, the signals measured by the two parts are sent to the mother ship at sea through the cable located in the sensor placement room, thereby realizing the comprehensive monitoring of the physical and mechanical properties of seabed sediments and shallow gas. The details are shown in Figure 1.

![Figure 1. Overall plan design.](image_url)
2. Testing of mechanical properties of seabed sediments

2.1. Mechanical characteristics sensing method
Multifunctional pore pressure static penetration probe is used to detect three values that characterize the physical and mechanical properties of seabed sediments: cone resistance ($q_c$), sidewall friction ($f_s$) and pore water pressure ($u$). The probe is mainly composed of a cone, a friction barrel and a water-permeable filter, and is connected to the outside through an 8-core cable. Figure 2 is the internal cross-sectional view of the probe sensor.

![Figure 2. Internal cross-sectional view of the probe sensor.](image)

1- connecting rod; 2- friction cylinder; 3- through hole; 4- pore water pressure sensor; 5- permeable hole; 6-permeable filter; 7- cone; 8- second deformation column; 9 strain gauge; 10- Internal platform of friction barrel; 11-first deformation column; 12-permeable hole

The sensor inside the probe is a piezoresistive pressure sensor, and its main component is a balanced bridge composed of four equal-value resistors. When the probe penetrates the sediment, the resistance of the cone will be transmitted to the first deformation column, and the internal platform of the friction cylinder will contact the second deformation cylinder, and the friction force of the sediment on the side wall of the friction cylinder will be transmitted to For the second deforming column, the resistance of the strain gauges attached to the deformation sensitive area of the two deforming columns will change, and the balance of the bridge will be broken. When a voltage of 5V is applied to the probe, the change in resistance will be converted into a tiny Voltage change. At the same time, the water in the soil enters the permeable channel in the cone through the permeable filter, and the pore water pressure sensor can convert the water pressure into a tiny voltage signal. Finally, the three tiny voltages are amplified, AD sampling and calculated to obtain three values that characterize the physical and mechanical properties of seabed sediments, thereby realizing the detection of physical and mechanical properties of seabed sediments. Figure 3 shows the sensor bridge of the probe.
2.2. Mechanical parameter measurement circuit
The three parameters that characterize the mechanical properties of seabed sediments measured by the static penetration probe are three voltages in the microvolt level, so it needs to be amplified to 0 to 3.3V so that it can be sampled by a single chip to obtain its voltage value. The amplifier circuit is shown in Figure 4. The amplifier chip uses AD620. This op amp has high precision, low offset voltage and low offset drift characteristics. An external circuit is connected between pin 1 and pin 8 to adjust the amplification factor. Pin 3 is the input signal, pins 4 and 7 are powered, pin 6 is output, and pin 5 is the reference voltage. Ideally, when the external pressure is zero, the four resistances of the bridge should be equivalent. The voltage difference of the output pins is zero, but in actual use, it is found that when the external pressure is zero, the probe will output a tiny voltage. The AD sampling of the single-chip microcomputer cannot identify the negative voltage, so a voltage follower circuit is formed with AD705 and connected to pin 5 of the AD620 chip to raise the reference voltage of the chip. The voltage value output by pin 6 is the amplified sum of the voltage and the reference voltage can then be sampled by the microcontroller to get its voltage value.
3. Shallow gas detection

3.1. Collection of shallow gas
Because the shallow gas is mixed in the muddy water, to detect the gas concentration value, it is necessary to extract the shallow gas from the muddy water to complete the shallow gas collection. The collection of shallow gas is mainly done by porous ceramics, permeable stones and waterproof and breathable membranes. The function of porous ceramics and permeable stones is to realize the separation of mud and water, and to extract the seawater rich in shallow gas from the sediment. The porous ceramics and permeable stones used in this article are made of corundum sand, silicon carbide, etc. as main raw materials, and are prepared through a special sintering process. They are resistant to high temperature, high pressure, acid, alkali and organic medium corrosion, and high open porosity. advantage. The hole diameter of the porous ceramic is 50 microns, and four rectangular windows with the same shape as the ceramic plate are opened on the shell of the muddy water chamber, and then the ceramic plate is glued into the rectangular windows. Due to the pressure difference between the inside and outside of the mud-water separation chamber, seawater rich in shallow gas can enter the probe through the window, while the mud and sand are blocked by the porous ceramics, realizing the initial separation of mud and water. Finally, a permeable ceramic tube with a smaller pore size of 10 microns was placed inside the mud-water separation chamber for further filtration, and the complete separation of the sediment and the seawater rich in shallow gas was achieved. The polymer waterproof and breathable membrane separates gas from seawater to achieve gas-liquid separation. The gas-liquid separation membrane used in this article is a polymer waterproof and breathable membrane made of polytetrafluoroethylene. There are billions of micropores distributed on every square centimeter of the membrane. The diameter of these micropores is much smaller than that of water droplets. Due to the existence of surface tension, it can block the passage of liquid water and solid particles, and at the same time allow gas to pass, so it has a good waterproof and breathable function, thus realizing the collection of shallow gas. The specific structure of the mud-water separation chamber and the location and installation of the waterproof and breathable membrane will be described in detail when the overall structure of the device is introduced in Chapter 3.

3.2. Detection of shallow gas concentration
Shallow gas is mainly composed of methane gas, and the most potential safety hazard is methane gas, so the detection of shallow gas concentration can usually be regarded as the detection of methane concentration. At present, the commonly used sensors for detecting methane concentration mainly include oxide semiconductor methane sensors, catalytic combustion methane sensors and non-dispersive infrared methane sensors. The oxide semiconductor methane sensor has poor selectivity when detecting high-concentration methane gas, while the catalytic combustion type methane sensor is prone to "poisoning". Compared with the above two sensors, the principle of the non-dispersive infrared methane sensor is that the infrared absorption peak intensity of methane gas is different from the infrared absorption peak intensity of other gases. After the infrared light of a specific wavelength passes through the methane gas, its emission The intensity of infrared light changes relative to the intensity of incident infrared light. By measuring the changed light intensity, the concentration of methane gas through which the infrared light passes can be calculated. It has fast response speed, high sensitivity, stable use, selectivity and Advantages such as better explosion-proof. Therefore, the non-dispersive infrared methane sensor used in this design can measure methane gas with a concentration range of 0-100%, and the resolution can reach 0.01%. The sensor has 5 pins: OUT, V+, V-, RXD and TXD. Among them, 3.3V working voltage is provided between V+ and V-, and the output of OUT pin is 0 to 2.4V. Methane can be obtained by calculation RXD and TXD can get temperature and humidity values through serial communication. Because the pins of the sensor cannot be soldered directly, a base is designed to fix the sensor and facilitate connection with the subsequent circuit, as shown in Figure 5.
3.3. Shallow gas concentration detection circuit
In this design, STM32RCT6 is selected as the main control chip for signal processing and long-distance cable transmission, and the smallest single-chip microcomputer system is formed to realize that the chip has 5 serial ports, 3 12-bit ADCs and 51 general IO ports to meet the needs of this design. First, the voltage value representing the methane concentration output by the methane sensor is sampled by the built-in ADC of the chip, and then converted into the methane concentration value through an algorithm. At the same time, the signal demodulated by the demodulation circuit is collected through the IO port to the single-chip microcomputer for processing, and three parameter values characterizing the physical and mechanical characteristics of the seabed sediment are obtained through the algorithm. The value is transmitted to the host computer for display. 485 communication adopts balanced transmission and differential reception, so it has the ability to suppress common mode interference and is more suitable for medium-distance signal transmission. This article chooses MAX485 chip as the transceiver of 485 communication, RO is the receiving output terminal, DI is the transmitting data receiving terminal, RE is the receiving enable signal (active low), DE is the transmitting enable signal (active high), A and B are 485 bus interfaces, the specific circuit diagram is shown in Figure 6.

4. The overall structure of mechanical properties and comprehensive detection of shallow gas
The mechanical characteristics and the comprehensive detection structure of shallow gas mainly include: reducing joint, mud-water separation chamber, adapter 1, compression gasket, adapter 2, gas-water separation chamber, gas detection chamber and sealing head. The multifunctional pore pressure static penetration probe is connected to the mud-water separation chamber through a reducing joint. The mud-water separation chamber is connected to the gas-water separation chamber through the adapter 1 and
the other end of the gas-water separation chamber is connected to the adapter 2 through the thread. Then the other end of the adapter 2 is connected with the gas detection chamber, and finally the gas detection chamber is connected with the sealing head through the adapter 3. The overall structure is shown in Figure 7.

The entire detection structure components are connected by internal and external threads, which are detachable, which is convenient for disassembly and cleaning after the detection is completed, and the entire device is hollow inside as a gas channel. The main parts of the structure are detailed below.

![Figure 7. The overall structure of the detection device.](image)

The shape of the mud-water separation chamber is cylindrical, the outer wall has four rectangular windows, the upper part has an internal thread, the lower part is an external thread, and the inside is hollow. The details are shown in Figure 8.

![Figure 8. The mechanical structure of the mud-water separation chamber.](image)

The lower external thread can be connected to the internal thread on the reducer and connected with the reducer; in order to connect with the multi-function borehole pressure static penetration probe, the rectangular window on the outer wall is for the entry of seawater rich in shallow gas, And isolate the sediment; the permeable stone is placed on the boss to place the permeable stone, and the upper internal thread can be connected with the external thread on the adapter 1, together with the boss to complete the position of the permeable stone.

The adapter 1 is cylindrical in shape, with standard external threads at the upper and lower ends. Two rectangular key grooves are opened on the outer wall of the adapter to facilitate fastening and disassembly. The inside of the adapter is hollow as a gas conveying channel. The details are shown in Figure 9.
The lower external thread is used to connect the mud-water separation chamber. When the lower external thread is screwed into the mud-water separation chamber and tightened, the adapter 1 will press the gasket on the upper part of the permeable stone in the mud-water separation chamber to complete the fixation of the position of the permeable stone. The external thread is used to connect the gas-water separation chamber. After tightening, the compression gasket inside the gas-water separation chamber will be compressed, and the waterproof and breathable membrane under the gasket will also be compressed.

The shape of the gas-water separation chamber is cylindrical, the upper and lower ends are internal threads, the inner wall has two symmetrical semicircular grooves, and in the middle of the gas separation chamber, there is a permeable membrane placement boss, the boss top and bottom are symmetrical, and there are many small holes as gas flow channels for placing waterproof and breathable membranes. There is a circular groove between the boss and the inner wall, and the groove is used to place the annular sealing ring, as shown in Fig. 10 and Fig. 11.

Figure 9. Mechanical structure of adapter 1.

Figure 10. Front view of the mechanical structure of the gas-water separation chamber.
The compression gasket is a circular metal gasket, the size is equal to the inner diameter of the gas-water separation chamber, and there are two symmetrical semicircular bosses on the outer walls of both sides, and there are also bosses corresponding to the permeable membrane on the gasket. Matching circular holes. First, use AB glue to stick the permeable membrane with the same size as the inner diameter of the gas-water separation chamber on the permeable membrane placement boss, and then place the circular rubber seal rings on the circular grooves on the left and right sides, and then press the gasket Put it into the gas-water separation chamber, and match the gasket boss with the semi-circular groove on the inner wall to fix the position of the gasket to prevent the rotation of the gasket from causing the dislocation of the circular holes and the gas cannot pass. Finally, the gasket is compressed by screwing the adapter 1 and the adapter 2, and then the annular rubber sealing ring under the gasket is compressed to complete the sealing around the waterproof and breathable membrane. The details are shown in Figure 12.

The shape of the gas detection chamber is cylindrical, the upper and lower ends are both internally threaded, and are connected to the gas separation chamber and the sealing head through the adapter 2 and the adapter 3, respectively, and the interior is hollow, serving as a gas channel and placing a gas sensor. There is a permeable membrane placement boss on the upper part, which is used to place a waterproof and breathable membrane to ensure that no sea water enters the gas detection chamber and damages the sensor and detection circuit. The structure of the adapter 2 and the adapter 3 is exactly the same as that of the adapter 1. The mechanical structure of the gas detection chamber is shown in Figure 13.
Figure 13. Mechanical structure of gas detection chamber.

The shape of the sealing head is cylindrical, with a semi-rounded corner at the lower part, and a signal line opening with internal thread for installing a waterproof connector, and the cable is led out from the waterproof connector. The upper part has an internal thread to connect with the adapter 3 so as to be integrated with the gas detection chamber. The details are shown in Figure 14.

Figure 14. Mechanical structure of sealing head.

5. Transmission of mechanical characteristics test parameters in water immersion pipeline

The parameters detected by the mechanical characteristics need to be transmitted to the single-chip microcomputer in the gas detection room for signal processing, and then transmitted to the mother ship through the cable. Therefore, it is necessary to cross the mud-water-gas separation structure, and the existence of a waterproof and breathable membrane in the structure cannot be transmitted in a wired manner, otherwise the membrane body will be damaged. At present, the most mature wireless transmission methods are electromagnetic wave wireless transmission and acoustic wave wireless transmission. In the design, an electromagnetic wave wireless transmission module and acoustic wave transducer were purchased and tested. The experimental results show that the electromagnetic wave wireless transmission method in the microwave frequency band can be transmitted for a short distance in an anhydrous pipe, and the larger the inner diameter of the pipe, the longer the transmission, but the signal is completely shielded in the submerged pipe. The sound wave wireless transmission method can transmit more than 20cm, so the design adopts the ultrasonic wireless signal transmission method. The main working process of the ultrasonic wireless transmission part is at the transmitting end, converting the digital signal measured by the submarine sediment mechanical characteristic detection part into an analog signal suitable for transmission in the channel through FSK modulation, driving the transmitting transducer, and converting the electrical signal into sound. The signal enters the channel for transmission; the receiving transducer converts the captured acoustic signal into an electrical signal, and through corresponding demodulation and decoding work, the original information is finally restored. Figure 15 is a block diagram of the ultrasonic wireless transmission part.
5.1. The choice of transducer
The transducer is a key component in the acoustic wave communication system. At the transmitting end, it is responsible for converting electrical signals into mechanical vibration signals (acoustic signals) and coupling them to the probe to achieve electroacoustic conversion; at the receiving end, it is responsible for receiving the probe on the probe. The sound wave signal is converted into an electric signal to realize the sound-to-electric conversion for the subsequent demodulation processing of the receiving circuit. Because the transmitter transducer of this system is encapsulated inside the probe, and the transmitter uses battery power supply, the transducer is required to have a smaller size and higher conversion efficiency. Choosing a suitable transducer is to ensure that the research in this article is a key to the successful realization of the communication system. According to the different sounding principles and working performance, the transducers are divided into piezoelectric transducers, traditional magnetostrictive transducers, rare earth giant magnetostrictive transducers and mechanical shock high-power transducers. Piezoelectric transducer refers to a transducer made of the forward and inverse piezoelectric effect of piezoelectric materials. It is currently the most mature and widely used acoustic wave transducer. The advantage is that the production process is mature, various shapes can be customized, and the conversion efficiency is high. The other types of transducers are too bulky for this design, so this paper chooses a piezoelectric transducer that is relatively simple to implement.

5.2. Selection of signal modulation method
The original data obtained by the static sounding probe can be encoded to obtain a digital baseband signal, which cannot be directly transmitted in the probe. Therefore, the baseband signal must be modulated to a certain frequency carrier so that it can be transmitted through the probe as a channel. The process of moving the baseband signal to the carrier signal is usually called modulation. Commonly used digital modulation methods include amplitude keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). Amplitude keying transmits information by controlling the change of the carrier amplitude. The commonly used binary amplitude keying ASK represents the "0" and "1" on the baseband by the presence or absence of the carrier. Frequency shift keying is to use a digital signal to modulate the frequency of the carrier. When the signal "0" is transmitted, it outputs a sine wave of frequency $\omega_1$, and when the signal "1" is transmitted, another frequency $\omega_2$ is output. Phase shift keying is a modulation method in which the carrier frequency and amplitude remain unchanged, and the carrier phase changes with the modulation signal. Generally, an absolute phase shift of 0 is used to indicate a digital signal "0", and a phase shift of $\pi$ to indicate a digital signal "1". Due to the flowing water in the probe, the acoustic signal will have amplitude fading and phase rotation during transmission. ASK relies on the change of the amplitude to express different information, and the random change of the amplitude will cause the receiver to be unable to judge the signal. The phase shift will make it difficult to demodulate the signal received by the receiver after PSK modulation. Compared with the above two signal modulation methods, FSK modulation is insensitive to changes in phase and amplitude, and the anti-noise interference performance of FSK modulation is compared. Good, so the FSK modulation method is selected in this design. The FSK modulation waveform is shown in Figure 16.

![Diagram of ultrasonic wireless transmission principle](image-url)
5.3. **Selection of signal demodulation mode**

There are two demodulation methods for 2FSK signals: coherent and incoherent. Because the 2FSK signal contains carrier signals of two frequencies, the demodulation end is composed of two 2ASK receivers in parallel. In addition, 2FSK demodulation has other non-coherent demodulation methods, such as frequency discrimination method, zero-crossing comparison method, and differential detection method. What this design chooses is the frequency discrimination method, the principal block diagram 17 is as shown.

![Block diagram of FSK demodulation principle.](image17)

5.4. **Modulation circuit**

Two direct digital frequency synthesis (DDS) modules respectively generate two unipolar sine wave signals with two frequencies suitable for data transmission in the probe, and the analog switch selects two sine waves according to the binary information sent under the control of the microprocessor. One of the signals, after being amplified by the amplifier circuit, drives the transducer to generate ultrasonic waves. The modulation principle is shown in Figure 18.

![Small voltage signal amplifier circuit.](image18)

This design uses the DDS dedicated chip AD9851 produced by Analog Devices as the carrier generator, which can quickly respond to changes in frequency. The analog switch is the CMOS switch ADG1433 produced by Analog Devices. There are 3 single-pole double-throw analog switches inside the chip. The TSSOP package helps reduce the circuit area. EN is the enable port of the analog switch. When the enable is off, all switches in a disconnected state. When enable is enabled, SxA or
SxB is output according to the input state of the control terminal Inx. EN and IN are directly driven by the microcontroller, and SA and SB are respectively connected to the corresponding carrier signal. Figure 19 is a modulation circuit diagram.

Figure 19. FSK modulation circuit.

5.5. Drive amplifier circuit
After DDS and analog switches, the FSK modulated signal is obtained. The DC component cannot carry valid digital information, so it must be filtered out by a DC blocking capacitor. Moreover, the energy of this signal is not enough to drive the transducer, and the signal needs to be amplified to excite the transducer. And add a low-pass filter at the back end to filter out clutter. The amplifier uses the high-speed low-noise voltage amplifier THS4001 produced by Analog Devices. The operational voltage range of this op amp is from ±2.5V to ±15V, the bandwidth is 270Mhz, and it has a high output drive capability of 100mA. The drive amplifier circuit is shown in Figure 20.

Figure 20. Drive amplifier circuit.
5.6. Demodulation circuit
This design uses XR2211 as the core chip of the demodulation unit. XR2211 is a monolithic phase-locked loop (PLL) system specially designed for data communication applications. XR2211 consists of a preamplifier, basic phase-locked loop, quadrature phase detector and comparator, and external components set the center frequency, bandwidth and output delay. Its working principle is to use a VCO phase detector and an external loop filter to form the most basic phase-locked loop circuit, and then compare the FSK comparator with the reference voltage to achieve FSK demodulation. The internal principal block diagram is shown in Figure 21.

Figure 21. Block diagram of XR2211 internal principle.

Figure 22 shows the XR2211 peripheral circuit. The relevant parameters of the peripheral circuit can be determined according to the following formula. In actual use, the parameters should be adjusted appropriately to obtain the best performance.

Figure 22. XR2211 peripheral circuit.
Center oscillation frequency $f_0$:

$$f_0 = \sqrt{f_1 f_2}$$  

(1)

$R_0$ and $C_0$ determine the center frequency of the phase-locked loop $f_0$

$$R_0 = R_0 + \frac{R_x}{2}$$  

(2)

$$C_0 = \frac{1}{R_0f_0}$$  

(3)

$R_1$ and $C_1$ determine the external loop filter

$$R_1 = \frac{R_0f_0}{f_1-f_2} \cdot 2$$  

(4)

$$C_1 = \frac{1250 C_0}{R_1 \xi^2}$$  

(5)

5.7. Voltage attenuation circuit

The high level amplitude of the signal demodulated by the demodulation circuit is 5.2V, which cannot be recognized by the IO port of the single-chip microcomputer. It needs to be reduced below 3.3V. The voltage attenuation circuit is shown in Figure 23.

![Voltage attenuation circuit](image)

Figure 23. Voltage attenuation circuit.

This circuit mainly divides the voltage through two resistors, and then through the voltage to follow the stable amplitude, the demodulated signal amplitude is reduced to below 3.3V, so that it can be recognized by the microcontroller.

6. Testing device experiment and field test

To realize 2FSK modulation, the frequency of the carrier signal needs to be determined first. Therefore, relevant tests have been carried out on commercially available acoustic wave transducers to determine the actual frequency of the carrier signal. The test result is shown in Figure 24.
Figure 24. Transducer test diagram.

The two transducers are glued to the wall of the probe with hot melt adhesive, the center distance is 20cm, the peak-to-peak value of the bipolar sine wave is fixed to 20 V, the frequency of the signal is constantly changed, the transmitting transducer is driven, and the oscilloscope is used to observe the amplitude and frequency of the received signal and draw the relationship curve between the amplitude and frequency of the received signal, as shown in Figure 25. In order to ensure that the two carriers are orthogonal and do not interfere with each other, the frequency of the high-frequency carrier is preferably an integer multiple of the frequency of the low-frequency carrier. Therefore, two carrier frequencies of 45k and 90k are selected.

Figure 25. Transducer frequency test curve.

The function of the carrier signal generating circuit is to use stm32 to configure two DDS chips to generate 45 kHz and 90 kHz carrier signals. Figure 26 shows the waveform of the carrier signal generated by two AD9851 frequency synthesis chips. It can be seen from the figure that the carrier signal generating circuit works normally and can output two sinusoidal carriers with frequencies of 45 kHz and 90 kHz.
Figure 26. 45 kHz and 90 kHz carrier signals.

The frequency selection circuit selects the corresponding carrier signal according to the data to be sent, thereby generating the FSK signal. Figure 27 shows the test waveform of the frequency selection circuit. Channel 2 is the binary information to be sent. The low-frequency signal (45 kHz) in Channel 1 should correspond to the symbol 0 to be sent, and the high-level frequency signal (90 kHz) corresponds to for the symbol 1 to be sent. It can be seen from the test waveform that the modulation circuit can get the correct FSK waveform.

Figure 27. FSK modulation waveform.
The drive amplifier circuit is to amplify the energy of the FSK signal so that it can drive the transducer. It can be seen from Figure 28 that the drive amplifier circuit can amplify the FSK signal amplitude to more than 16V.

![Figure 28. FSK signal amplification waveform.](image1)

The signal received by the transducer conversion is shown in Figure 29. In this figure, channel 1 is the received modulated signal, and channel 2 is the demodulated binary information. It can be seen from the figure that the original signal can be restored relatively well and the wireless transmission of the signal is realized.

![Figure 29. FSK signal amplification waveform.](image2)

In order to find out whether the device has the ability to accurately measure the methane concentration in the shallow gas in the seabed sediments, a verification experiment was carried out in the laboratory. Experiment with methane concentration from 10% to 90% from low to high. The
measurement results are shown in the figure. The blue is the gas concentration of the experiment and the red is the measured concentration. It can be seen from Figure 30 that the two curves basically overlap, the measurement results are quite accurate to meet the actual requirements.

Figure 30. Test results of different concentrations of methane concentration.

Afterwards, preliminary field tests of shallow gas detection were carried out on the Qiantang River in Hangzhou section. In the experiment, select shallow gas enrichment points that have been proven to have shallow gas for testing. First connect the mechanical characteristics with the shallow gas comprehensive detection device and the hollow connecting rod, and then lead the cable out of the hollow channel of the connecting rod, press it into the river bottom by a static penetration drill, and then connect another connection. The rod is pressed in with a static penetration drill, and so on, to press the device into the bottom of the river. The details are shown in Figure 31.

Figure 31. Field test.
The experimental results are shown in Figure 32. The blue curve represents the data measured by the device driving into the sediment, and the red curve is the data measured by the device not driving the sediment. It can be clearly seen from the figure that the output of the gas concentration value is 0.5% and remains unchanged before the device is driven into the sediment, and the gas concentration value in the first half after driving into the sediment is higher than the concentration value without the sediment. At about 14 meters below the surface of the river, the concentration value output by the device increased significantly and continued for a period of time before returning to the initial value. The test results show the feasibility of the detection device of this design, but it still needs to be improved.

The system designs and implements a comprehensive detection device for the physical and mechanical properties of seabed sediments and shallow gas. It can simultaneously detect the mechanical properties of seabed sediments and shallow gas at the same time, and use ultrasonic and FSK modulation to realize the wireless signal transmission of the part that cannot be used for cable data transmission. Experiments show that the error of the shallow gas concentration detected by the device is within the allowable range, and the data can be wirelessly communicated across the mud-water-gas separation structure, meeting actual requirements. The device has a great guiding role in the development of ocean engineering, can improve the quality of ocean engineering and effectively eliminate potential safety hazards caused by shallow gas in construction, greatly improve the efficiency of ocean engineering, and has a wide range of application prospects and significance.

![Figure 32. Field test experimental data in conclusion.](image.png)

**Figure 32.** Field test experimental data in conclusion.

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