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Design of Wireless Transmission System for Shallow Seismograph Based on 433 M Module

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Abstract

Because of its portability, the non-cable seismograph has become the future development trend of geophysical instruments. A new wireless data transmission device of 433 M module was proposed; a wireless network was built using the EL1663B_PA module of the SI4463 core, and through the SPI interface to modify the internal parameters. Data transmission used dual antenna mode, the main station as the center of the wireless network coverage up to 550 m or more. The wireless time synchronization system was designed to realize the wireless connection communication between the shallow seismograph and the sensor of each observation point. This program aimed to eliminate the necessary connecting cable and batteries between the conventional shallow seismograph and the detector, greatly reducing the weight of the equipment, and making the shallow seismograph truly low cost, lightweight, flexible and easy to operate and so on.

Keywords

Seismic Exploration, Wireless Network, Transmission Protocol, Time Synchronization, Low Cost

1. Introduction

In recent years, China has made a large number of investments in the high-speed rail, highways, airports and other infrastructure areas, which makes the shallow detection arouse more and more attention. The shallow seismograph transmis-

sion method is divided into two kinds, the cable and the non-cable, and the widely used is the cable acquisition technology [1]. The cable acquisition technology has the advantages of speed and stable data transmission. However, with the increase of detection difficulty and the application of new technology, the cable acquisition technology has also encountered some problems. First, the system is cumbersome and difficult to carry, and the total weight of all the equipment and the cable is 25 t or more in the standard seismic exploration, which directly affects the transport costs and mobility; Then a lot of time, manpower and resources need to be spent on the field equipment layout, and there exists the cable maintenance and downtime risk; Finally, the cost is high, and the cables and other transmission equipment need to be replaced even if they are not damaged by human or external forces after three years of use, or because of cable aging caused by data quality degradation [2] [3]. Compared with the cable seismograph, the no-cable seismograph operation is more flexible, and the acquisition station does not need cable connection [4]. According to the data quality of different acquisition points to determine the combination ways to make data processing more convenient and flexible, which effectively solves the shortcomings of the cable seismograph, the non-cable seismograph is predicted as the development direction of the next generation of seismic exploration equipment [5] [6] [7] [8].

The non-cable seismograph is mainly transmitted through wireless communication technology [9]. With the rapid development of modern wireless communication technology and wireless data dissemination theory gradually improved [10], Wi-Fi [11] [12], ZigBee [13] [14], Bluetooth, Ultra-wideband (UWB), Radio Frequency Identification (RFID), and 433 M wireless network technology is the mainstream of wireless data transmission technology. Various wireless technologies have their own advantages and disadvantages, as shown in Table 1. The Wi-Fi with high transmission rate is easy to be disturbed in the field environment, which causes the signal instability and data inaccuracy. Bluetooth, characterized by high security, high transmission rate and normal power consumption, has a shorter transmission distance, which cannot meet the requirement of working. Zig Bee has the lower transmission rate and the delay of communication. The UWB ultra-wideband technology has a poor anti-interference performance for the large frequency band. RFID with low cost and simple connection has the low transmission rate and the short transmission distance. Considering the cost and practicality comprehensively, 433 M network technology is a suitable way for its developed and cost-effective features. There are four criteria required by wireless communication system of seismograph for shallow layers: 1) lower traffic load; 2) lower power consumption; 3) communication distance of several hundred meters; 4) simple antenna for the workstation. Silicon Labs SI4463 wireless module was selected to constitute the simple network protocol with a center frequency of 433 MHz. The effectiveness and practicability of the system were proved by the actual field test.

Table 1. Comparison of several wireless communication technologies.

Name	Transmission Speed/Mbps	Communication Distance/m Distance	Frequency Range/ GHz	Safety	International Standard	Power Dissipation/ mA
433 M module	1	1000	0.433	Low	Not Formulated	<500
Wi-Fi	54	100	2.4	Low	IEEE.802.11b/ IEEE.802.11g	10~50
Bluetooth	1	15	2.4	High	IEEE.802.15.1x	20
ZigBee	0.25	20	2.4	Medium	IEEE802.15.4	5
UWB	53~480	10	3.1~10.6	High	Not Formulated	10~50
RFID	0.001	1	0.868~0.915	Low	Not United	10

2. Design of Wireless Transmission System

The module for wireless transmission system used the SI4463 [15] from Silicon Labs, the frequency range of 119 - 1050 MHz, the receiving sensitivity of −126 dBm, the output power of 20 dBm; support (G) FSK, 4 (G) FSK, (G) MSK modulation, and data baud rate of 100 bps to 1 Mbps, voltage range of 1.8 V - 3.6 V, working time-division duplex (TDD). It is particularly suitable for such short-range transmission of shallow seismographs. Table 2 shows the working mode of the SI4463 chip, the reaction time in the mode, and the current in the current state.

Table 2. Operating state response time and current consumption.

State/Mode	Response Time to		Current in State/mA
	TX/μs	RX/μs	
Shutdown State	15000	15000	3×10^{-5}
Standby State	440	440	5×10^{-5}
Sleep State	440	440	9×10^{-4}
SPI Active State	340	340	1.35
Ready State	126	122	1.8
TX Tune State	58	-	8
RX Tune State	-	74	7.2
TX State	-	138	18
RX State	130	75	10 or 13

2.1. Circuit Design

According to the structure of the network mainstation and sub-station of non-cable seismometer and data using dual antenna combination transmission characteristics, the circuit of the wireless transmission module is designed by SI4463, as shown in Figure 1.
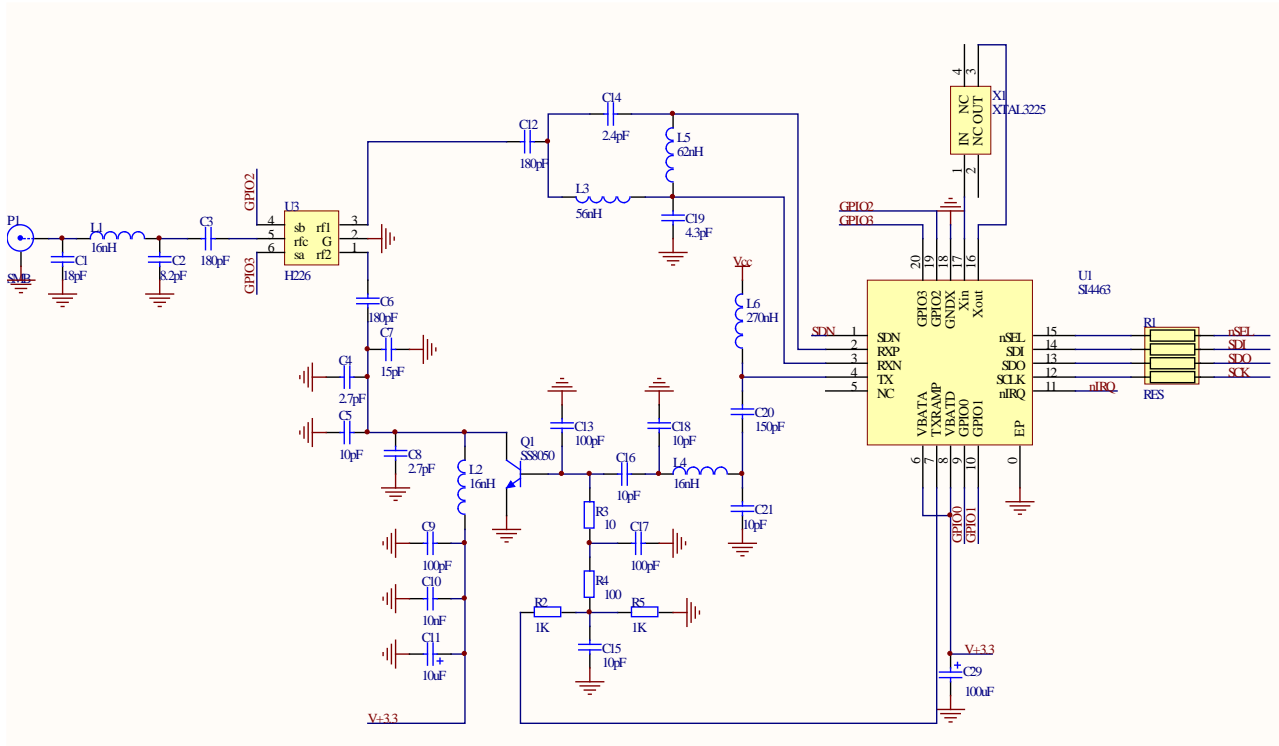
Figure 1. SI4463 wireless module.

The transmitting power required for data transfer is related to factors such as antenna height, communication distance and bit rate. The effective transmission distance of the network can be expressed by the following equation.

$$r = \left(\frac{\sqrt{30 \times EIRP}}{E_{\text{RXsens}}} \right)^{\frac{2}{n}} 2^{\frac{n-2}{2}}$$

$$E_{\text{RXsens}} = 1000 \sqrt{\frac{480\pi^2}{(c/f)^2 G_{\text{RX}}} p_{\text{RXsens}}}$$

(1)

where *EIRP* is the equivalent transmit power; *n* is the equivalent propagation constant of the medium, p_{RXsens} is the receiver sensitivity, G_{RX} is the receiving antenna gain; *c* is the speed of light; *f* is the electromagnetic wave frequency. From this equation it is known that choosing the lower carrier frequency can get a larger transmission distance in the case of the same transmit power. So we gave up the ZigBee network [16] [17] and the Wi-Fi network with higher data transmission rates [18], and selected the SI4463 module; the carrier frequency was set to 433 MHz and modulation mode was selected as GFSK. In order to improve the transmission distance of the module, SI4463 increased the power amplifier and the final output power of 30 dBm.

2.2. Data Transfer Protocol

According to the workflow of shallow seismograph, the amount of data of the downlink of the wireless transmission (*i.e.* the host to the sub-station) is small. A

large number of transmission data mainly occurred when the data acquisition was completed and the seismic wave data was uploaded. The sensitivity of SI4463 receiver and the bit rate of data transmission are related. In the bit error rate of less than 1% of the conditions, the SI4463 receiver sensitivity and the bit rate of the relationship between the curves are shown in **Figure 2**. If lower baud rate is used, it can greatly improve SI4463 receiver sensitivity. So the adaptive bit rate adjustment algorithm is used to adapt to the data transmission in complex environment.
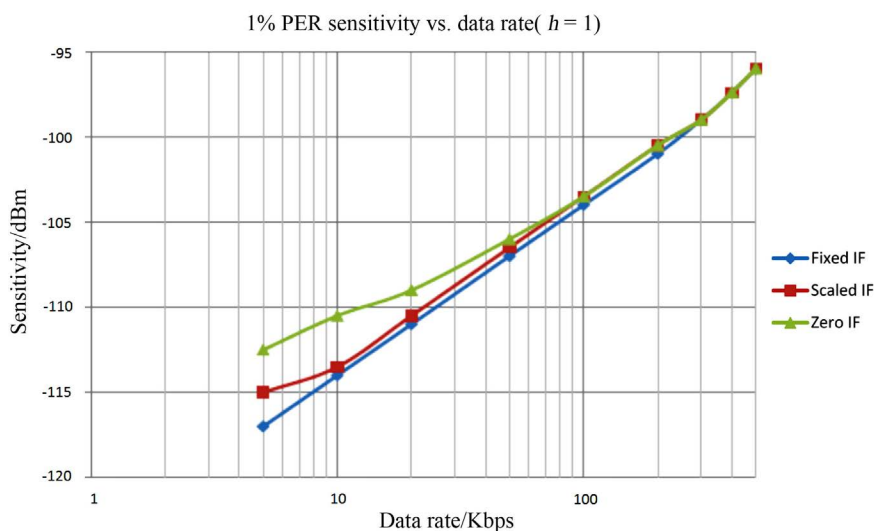

Figure 2. Relationship between sensitivity and baud rate of SI4463.

The host issues a command, due to the small amount of data there is no delay problem. Using lower 10 kbps bit rate data transmission to improve the reliability of command transmission. The command format is shown in **Table 3**. Including command packet identifier, command code, target node number, command length, command parameter and check code. After the sub-station receives the command, execute the corresponding command and reply. The reply packet structure is similar to the command package. Only the identifier is changed to 0×55, the target node number of the command packet is changed to the source node number.

Table 3. Command package structure.

Command Identifier/byte	Command Code/byte	Target Node Number/byte	Command Length/byte	Command Parameter/byte	Check Code/byte
$(0 \times A2)$ 1	1	1	1	n	2

When data acquisition is completed, data upload is a task of consuming network resources, so increasing the speed of data upload is a key issue in this design. SI4463 supports the highest baud rate 1 Mbps data transmission; the relationship between the receiver sensitivity and the bit rate is taken into account. In the establishment of the wireless network, through the test of sub-station uplink

signal strength, communication quality and bit-error rate selection of transfer process, we divided the bit rate into three, 100 kbps, 50 kbps, and 10 kbps, respectively.

SI4463 TX FIFO is 64 bytes, the packet length according to this design. Data transfer is made after the main station issues a data transfer request. Therefore, the structure of the packet is designed as shown in Table 4, including the response identifier, packet identifier, source node number, packet length, sampling point number, sampling data and check code, where n is the number of samples. Since the packet length is up to 64 bytes, the 8 bytes occupied by the additional information are deducted, and each packet transmits up to 18 samples of data.

In the transmission of commands and responses, in order to ensure the high reliability of the transmission, there is an ACK response transmission. In the packet transmission, in order to improve the transmission rate, the non-ACK response transmission was used to avoid the SI4463 to receive and send the conversion time to spend. Using the non-ACK response transmission can greatly improve the data transmission rate. The test analysis shows that a 64-byte packet with non-ACK response transmission time is about 7.6 ms, while the ACK response transmission time is about 10.2 ms in the case of 100 kbps bit rate. Therefore, a non-ACK response transmission was used to improve the data transmission rate, such a 2048 sample of the test data transmission time of about 1 second.

Table 4. Packet structure.

Response Identifier/ byte	Packet Identifier/ byte	Source Node Number/ byte	Packet Length/ byte	Sampling Point Number/byte	Sampled Data/ byte	Check Code/ byte
(0 × 55) 1	1	1	1	2	3n	2

However, in data transmissions, packet loss events will inevitably occur. The main station will discover the sample point number of the lost packet when the data connection is made and instruct the sub-station to retransmit the data. Table 5 shows the command parameter structure of the data retransmission, including the bit rate selection byte, which specifies the bit rate selection of the re-entered data; The sampling point number is the starting sampling point number of the packet to be retransmitted; The subsequent packet number is the number of consecutive retransmitted packets starting from the packet specified by the sample point number.

Table 5. Command parameter structure.

Bit Rate Selection/byte	Sampling Point Number/byte	Number of Packets/byte	Sampling Point Number/byte	Number of Packets/byte	...
1	2	1	2	1	...

2.3. Wireless Time Synchronization System

When the seismic wave is excited, the data acquisition command is sent by the

source excitation sub-station. However, from the excitation to the acquisition sub-station to resolve the command about 2 ms delay, the delay is uncertain. If there is communication channel interference, the delay may be longer, so the time synchronization must be performed. In this paper, a wireless acquisition system with a crystal oscillator of 8 MHz was used, and the time synchronization error did not exceed 25 μs in the one acquisition process. It can meet the vast majority cases of data acquisition synchronization requirements. If you need a higher time synchronization accuracy, a higher frequency of the crystal oscillator can be used.

As shown in Figure 3, the command of clock synchronization is sent by the main station, and the system timestamp information of the main station is included in the command packet. When the acquisition and trigger sub-station receive the command packet, the timestamp is taken as a starting point to intercept a valid signal in the record data and is transmitted back to the main station. All the acquisition and trigger sub-station time is always consistent in this process. Because the data transmission delays, the clocks of various sub-stations are not really aligned with the main station, but each acquisition and trigger sub-station clock is strictly aligned, so it still can guarantee the trigger side and the acquisition side of the time synchronization.
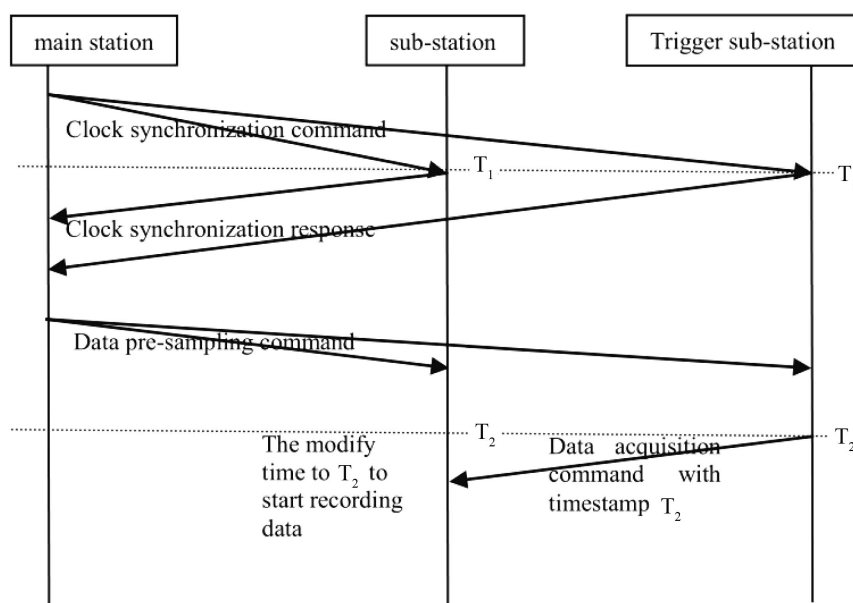

Figure 3. Wireless time synchronization system work diagram.

After the time synchronization was completed, the trigger sub-station triggers an artificial seismic wave and sends a data acquisition command that contains the system timestamp of the seismic wave excitation time. After the acquisition sub-station received the command, according to the timestamp in the packet and the current system clock, the storage address of the acquisition data of the seismic wave excitation time was calculated in the buffer. With this address as the starting point, the subsequent data is valid seismic wave data.

3. Analysis of the Actual Test Results

To verify the effectiveness of this program, an effective communication distance test was carried out in front of the square of main building of the Yangtze University, as shown in Figure 4. With the line length of 350 m, 200 m away from the test base station, the site is open, with no obvious obstacles, from the base station 200 to 300 m within a small number of trees. The weather is sunny, with no obvious wind direction.

Figure 4. Schematic diagram of the line layout of the wireless network communication distance.

In order to meet the different operating conditions, this program was equipped with high-gain of glue rod antenna and ultra-high gain of the elevated antenna, as shown in Figure 5. The glue rod antenna network, with the coverage of about 300 meters in diameter, is easy to carry and install, and to meet the general conditions of engineering seismic exploration. The elevated antenna network, with the coverage of about 560 m in diameter, is suitable for the obstacle in the work area.

Figure 5. (a) Glue rod antenna; (b) Elevated antenna.

The test program of effective communication distance of wireless network refers to the seismograph mainframe of wireless data module (base station) and the wireless data acquisition transmission port (sub-station) composed of SI4463 dual antenna transceiver system; When the base station is stationary, the sub-station and cell-phone range locator are moving along the line; The effective communication distances of 10 Kb/s, 50 Kb/s and 100 Kb/s transmission rates were measured in different combinations of glue rod and elevated antenna. After repeated tests, we obtained the transmission distance under different test conditions, as shown in Table 6.

Table 6. List of test results of wireless transmission distance.

Base Station	Sub Station	Transmission Rate (Kb·s⁻¹)	Effective Transmission Distance/m	Remarks
Glue Rod Antenna	Glue Rod Antenna	10	150	Barrier free, signal value greater than 70 dBm
Glue Rod Antenna	Glue Rod Antenna	50	120	Barrier free, signal value greater than 70 dBm
Glue Rod Antenna	Glue Rod Antenna	100	100	Barrier free, signal value greater than 70 dBm
Elevated Antenna	Glue Rod Antenna	10	240	Dwarf tree barrier, signal value greater than 70 dBm
Elevated Antenna	Glue Rod Antenna	50	180	Barrier free, signal value greater than 70 dBm
Elevated Antenna	Glue Rod Antenna	100	130	Barrier free, signal value greater than 70 dBm
Elevated Antenna	Elevated Antenna	10	320	Dwarf tree barrier, signal value greater than 70 dBm
Elevated Antenna	Elevated Antenna	50	250	Dwarf tree barrier, signal value greater than 70 dBm
Elevated Antenna	Elevated Antenna	100	200	Barrier free, signal value greater than 70 dBm

According to test results of effective communication distance, the base station is placed in the center of the survey line, and the effective coverage length of the wireless network can be doubled on the basis of the Table 6 effective transmission distance. When the mainframe, trigger side and data acquisition transmission end use the portable glue rod antenna, it can meet the general requirements of engineering seismic exploration, that is within 10 m between the group interval and 24-channel detectors to receive. As the increase of the group interval and detectors, according to the actual working conditions and requirements, a reasonable combination of antenna, up to 550 m above the effective communication distance, proves the effectiveness and stability of the scheme.

4. Conclusion

The rapid development of the seismic exploration puts forward higher requirements for the seismograph technology and equipment. In view of the increasingly complex construction environment and the increasing construction area and engineering quantity, the development of non-cable seismographs has been paid more and more attention by the industry. The reliability of data transmission system of wireless seismograph is a technology problem; a shallow seismograph wireless transmission system based on 433 M module is designed in this paper. It implements the command and data wireless transmission, reducing the weight of the instrument, saving time of line layout, and greatly improving the work efficiency. Verified by the field test, the effective communication distance of the wireless network can reach more than 550 m, fully meeting the needs of

shallow seismic exploration. This program can quickly recover the field data, and provide strong support for real-time construction of engineering geophysical prospecting.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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