

The development and test research of multi-channel **Synchronous** synchronous transient electromagnetic receiver

Fanqiang Lin ^{1,2}, Xuben Wang ^{2,3}, Kecheng Chen ¹, Depan Hu ⁴, Song Gao ¹, Xue Zou ¹, and Cai Zeng ¹

¹College of Information Science and Technology, Chengdu University of Technology, Chengdu 610059, China

²College of Geophysics, Chengdu University of Technology, Chengdu 610059, China

³Key Lab of Geo-Detection and Information Techniques of Ministry of Education, Chengdu 610059, China

⁴Geoenvironment Monitoring Institute in Chengdu, Chengdu 610071, China

Correspondence: Fanqiang Lin(linfq@cdut.edu.cn)

Abstract. As a result of the drastic reduction of shallow mineral resources, the exploitable potential and reserve of proven mines ~~have been proven are insufficient~~, and the mineral resources in deep ground need to be more refinedly explored. ~~Because~~ There are some disadvantages of the existing instruments ~~have less channels and insufficient~~, such as few channels and slow sampling rate, ~~the development and experiment of the etc.~~ Therefore, multi-parameter transient electromagnetic instrument with ~~multi-channel synchronous receiving are therefore proposed~~ synchronous receiving has been developed and tested. The instrument is composed of two controllers, embedded controller and programmable logic controller, which can provide diversified information combination for the following information processing. Under the grounding electrode source emission mode, the real-time synchronous transient electromagnetic acquisition system ~~in six channels with 128k sampling rate is achieved~~ of six channels is achieved with sampling rate of 128k SPS(Sample Per Second). The data of the six channels are recorded in the full time range in the time domain. At the same time, experiments were carried out in the laboratory, open areas and actual mine. Through data analysis, the measured data curves of the mining area ~~is~~ are highly consistent with the existing geochemical exploration curves and geological profile.

1 Introduction

Transient electromagnetic (TEM) method belongs to the active field source method of time domain electromagnetic ~~method~~. ~~The principle is that the conductive geological body existing underground produces induced eddy currents under the action of alternating electromagnetic fields, and the eddy current further generates secondary magnetic fields. In transient electromagnetic method, it often using periodic bipolar waves as the launch signal, data acquisition is completed during the bipolar wave intermittent, thus effectively avoiding the coupling problem in the frequency domain electromagnetic method. The instrument collects and studies characteristics of the intensity, distribution, space and time decay of the second field, and then deduces the underground anomalies. The transient electromagnetic signals contain very rich frequency components, which are very useful for low-resistivity geologic bodies with high penetration, which can effectively improve the actual exploration depth. Conventional transient electromagnetic (TEM-) use mostly magnetic source or electrode source mode, the magnetic source mode TEM volume effect is relatively small, high detection accuracy, but the effective detection depth is usually less than 500 meters, and~~

the high Geological response is not sensitive. However, LOTEM can increase the exploration depth up to 10 km. However, due to the large distance between the LOTEM transmission and reception, the accuracy of the collected data is relatively low, as well as a poor signal-to-noise ratio and increased possibility of interference on the way of long-distance transmission (Brunke et al., J.R. Wait firstly proposed the use of transient electromagnetic method to search for conducting ore bodies in 1951. In recent decades, the TEM receiver has been widely used in metal mineral, petroleum, natural gas exploration and other fields (Danielsen et al., 2003; Haroon et al., 2015), so many kinds of TEM receiver have been developed and manufactured, such as V8 receiver from Phoenix Geophysics (Phoenix Geophysics, 2017). As a result, domestic scholars such as Xue Guoqiang proposed short offset transient electromagnetic (SOTEM) device method (Xue et al., 2013; Chen et al., 2016; Chen et al., ADU-07e from Metronix (Metronix, 2017), KMS-820 from KMS (KMS, 2017), the reduce of transeeiver distance can both greatly enhance the exploration depth, but also effectively improve the signal to noise ratio. In recent years, it has a very broad application prospect in such fields as engineering environment, geological disaster investigation, underground gob area, groundwater, petroleum, coal and other non-metallic mineral exploration and advanced geological prediction.

2 Literature review

which are easy to use and have good performance. Meanwhile, the TEM detection theories have also been developed. In 2010, internationally renowned geophysicist Zhdanov proposed the following directions for future electromagnetic exploration instruments and methods in the 75th anniversary of "Geophysics": Multi-component emission, Multi-channel reception and Pseudo-seismic data collection (Qi et al., 2015, Ayuso et al., 2016). As the demand for resources and energy increases due to economic development, the depth is increased to the second depth space (500-2000m) on the basis of the existing exploration depth (500m depth range). The fine exploration within this range will be a long-term and heavy task to study new theories and methods and to develop equipment with higher adaptability to make up the lack of traditional exploration methods and instruments. China's overall theoretical level and engineering practice in the field of transient electromagnetic remain at the same level with the international, but the domestic instruments in the technical indicators comparing with foreign countries there is still a certain gap, which will be constraining China's original innovation and quantitative calculation of the bottleneek (Zhong Xue Guoqiang proposed short offset transient electromagnetic (SOTEM) method (Xue et al., 2013, Chen et al., 2016, Zhang Chen et al., 2017). With the development of electrical prospecting theory, instrument's design and development, many kinds of instrument products have been made. The main development directions are automation, intelligence, refinement and lightness. As a result, various institutions of higher learning and research institutes in China have introduced various forms of transient electromagnetic prospecting instruments in their decades of development. By comparing most of the transient electromagnetic surveys at home and abroad since recent 20 years, the main problems and gaps in the domestic transient electromagnetic instrument lie in that: some technical indicators are lagging behind; the function is insufficient; the consistency is low, and so on. It can be seen that the development of new acquisition devices, the reduction of transeeiver distance can both greatly enhance the exploration depth and improve the signal to noise ratio (SNR). Because of the transformation of new launch modes, acquisition methods, need for deeper exploration depth, and the development of new instruments and

evaluation methods of electromagnetic methods, etc. are particularly important(Li et al.,2012). The core need to obtain more diverse subsurface geological information, multi-channel number, low SNR and high synchronization are the key elements for TEM receiver development, which are useful to obtain more abundant underground geological information and improve the accuracy of detection. Therefore, we propose a multi-channel synchronous transient electromagnetic receiver, which has the characteristics of multi-channel synchronous parallel acquisition, large capacity (64G) storage function with full time synchronization and the sampling rate up to 128k SPS, while the sampling rate of V8 receiver is 96k only.

The main purpose of this paper is to develop-introduce a receiver system for synchronous acquisition of multiple electromagnetic signals in transient electromagnetic prospecting to achieve multi-parameter and multi-channel synchronous reception. High-speed programmable logic devices are used to achieve high-level synchronization between channels. Waveform Transmitting current waveform acquisition and multi-channel receive-reception can be synchronized by using high-precision GPS-timing unit to synchronize, combined with-Global Position System(GPS) timing unit which is controlled by serial port of micro controller, while a programmable high-precision counter to-is used to store another data information synchronously, which is adopted to further improve the synchronization accuracy -when the receivers work in distributed mode.

2 Multi-channels Multi-channel receiver hardware and software design

2.1 Receiver framework

Receiving system consists of four parts, namely: FPGA(Field Programmable Gate Array) unit, ARM(Advanced RISC Machine) unit, analog acquisition unit and power supply circuit. System block diagram shown in Figure 1. Analog-board-channel-numbers are-The numbers of analog board are marked as channel 1/2, 3/4, 5/6 channels-respectively, respectively, and each analog board have two channels. The board contain-contains the signal conditioning circuit, amplification and acquisition of all channels which are completely independentand-, and multi-channel real-time synchronized acquisition is achievedin-multi-channel.

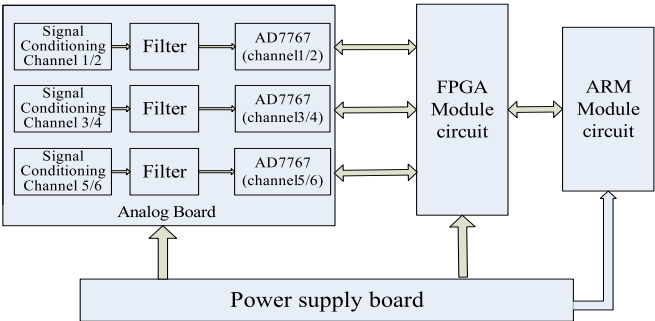


Figure 1. System block diagram of hardware

2.2 Design of analog circuit board

Analog board mainly includes signal conditioning (including: the first stage instrumentation amplifier, the second stage programmable amplifier, low-pass filter), protection circuit (positive and negative polarity of each input stage clamp diode), the natural potential compensation circuit(Liu et al.,2016), single-end to differential circuit and analog to digital converter.

- 5 The first stage amplifier uses a dedicated high-precision, low-noise INA114, and ~~using the~~ AD5272 high-resolution digital potentiometer is used to design the precision gain op-amp, to achieve high-precision amplification and range adjustment. The two circuits are shown in Figure 2 and Figure 3.

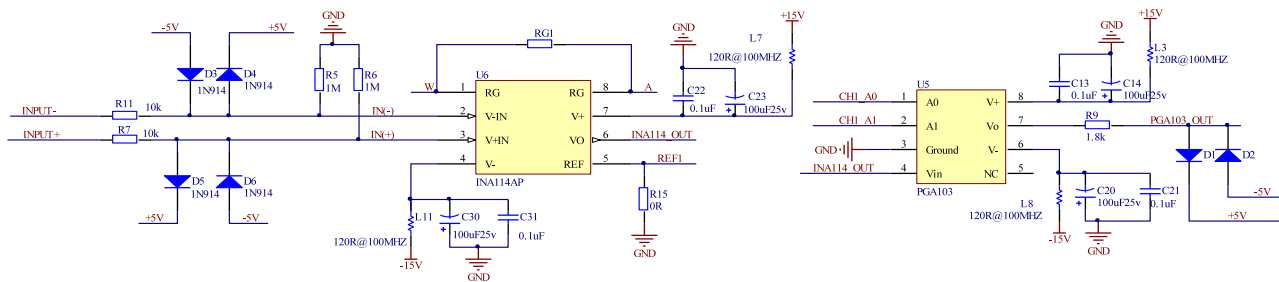


Figure 2. INA114 Instrument Amplifier and Programmable Gain Amplifier Circuit

- 10 It utilizes the PGA103 ~~program-controlled-amplifier, making use of~~ Programmable Gain Amplifier, and a general IO port to complete the three level amplification ratio adjustment.

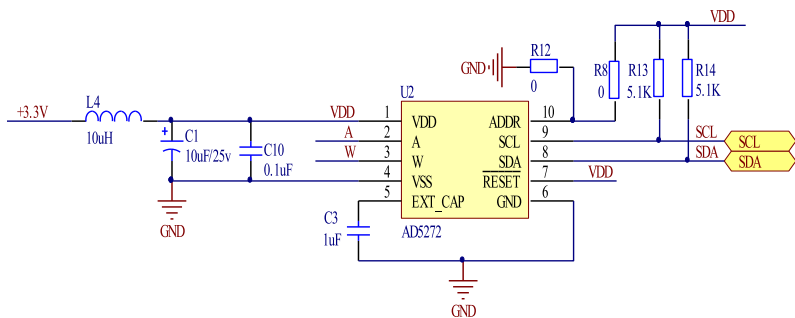


Figure 3. AD5272 Digital potentiometer

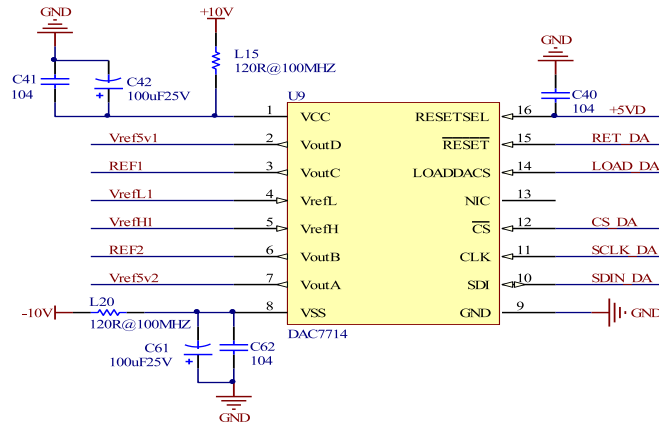


Figure 4. DAC7714 compensation and Vref circuit

Natural Potential Compensation ~~uses the~~ DAC7714, a 12-bit digital-to-analog converter with four output channels, ~~which can~~ is used to provide natural potential compensation and full-scale voltage of both channels. The DAC7714 circuits is shown in Figure 4. The multi-channel receiver has a wide input range, which is -5V to +5V, and the amplitude of the signal in actual test is at the millivolt level.

- 5 Single-end to differential device is ~~based on the~~ designed on the basis of the needs of analog-digital converter settings, while ~~the instrument uses the~~ ADA4941 is used in the instrument. The system utilizes 24-bit AD7767, a 24-bit high resolution $\Sigma - \Delta ADC$ with over-sampling on each channel, ~~reducing to reduce~~ noise from the front end and ~~reducing the~~ need for front-end anti-alias filter, ~~which using a and~~ daisy chain technology to realize the multi-chip ~~series~~ cascade connection for an efficient parallel ~~devices~~ synchronous acquisition (Liu et al.,2017). ~~The design of the two channels as a result of a~~ The two circuits are shown in Figure 5 and Figure 6. And the dynamic range of analog-digital converter is up to 144dB, because the analog to digital converter is a 24-bit resolution.
- 10

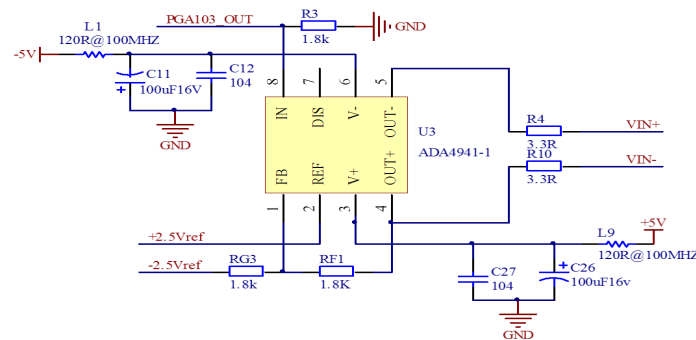


Figure 5. ADA4941 single to differential convertor circuit

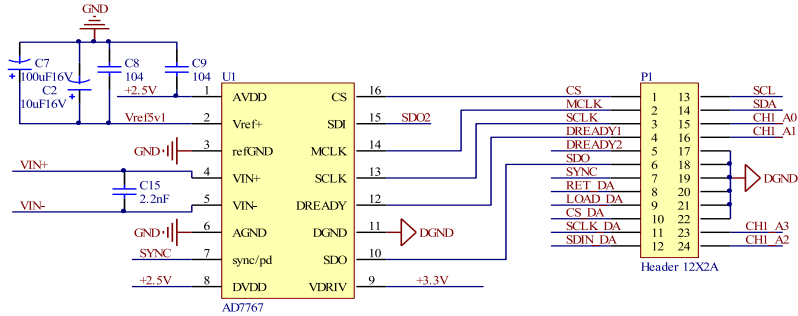


Figure 6. AD7767 analog to digital convertor circuit

By adopting modular design, it is two AD7767 series, the FPGA controller to control the three analog boards by three connectors, and then through the FPGA internal logic program, the six channels are the chips are cascaded, and FPGA controller is used to control three analog circuit boards separately, and therefor the overall data package and storage in real-time is achieved. The AD7767 has a maximum output data rate of 128kHz, so the band width of the receiver is from DC to 12.8kHz. For the good collection accuracy, the input signal to the receiver should be less than 12.8kHz.

2.3 Design of digital logic controller board

Multi-channel synchronous receiver with-uses embedded controller and programmable logic controller (FPGA) in-as dual-controller approach(Oballe-Peinado et al.2017) , this control method-which is flexible and more-popular-widely used. FPGA as the core-is the core logic control part of the system-to collect the front-end-of the logic-control components for the main use of its internal-parallel-processing-functions, collection system, and the synchronization between the various functional units can be easily achieved by its parallel processing function, though which a number of internal-logic-modules-logic modules are driven by the system clock,-you can easily achieve the synchronization-between the various functional-units.This instrument uses the XC6SLX9 chip that-belongs-as the core acquisition controller, that belongs to the Spartan-6 family-series of well-known FPGA chip maker Xilinx. FPGA unit module-It is shown in Figure 7. FPGA unit is mainly composed of SD card unit circuit, SRAM buffer circuit and the SPI interface which is used to communicate with STM32 controller.-It is responsible for- the synchronous acquisition and control interface of 6-six channel signals, filter frequency output interface, and GPS's second-pulse signal interface, and power interface.

The embedded control unit adopts the STM32F4 series of ST Microelectronics which is popular in industry. The embedded control part has completed the functions of keyboard ,and FPGA communication control interface, GPS location informa-

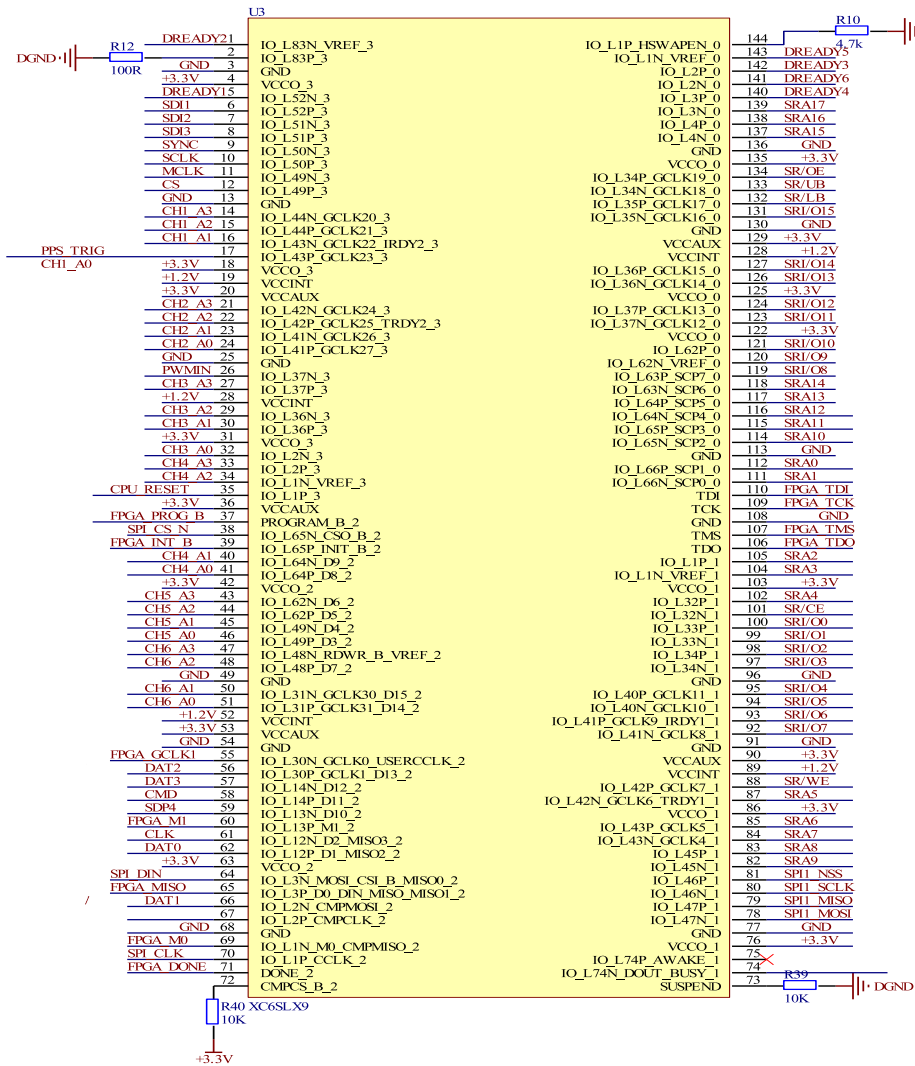


Figure 7. XC6SLX9 FPGA circuit diagram

tion collection and liquid crystal display. The embedded unit ~~communicate~~ communicates with the FPGA controller by SPI interface. It also collects the GPS time information, such as latitude and longitude, etc. which is outputted by the GPS module through the serial port, and simultaneously ~~displays it~~ displayed on LCD. ~~The system also designs a~~ A 6*8 metrix keyboard ~~which can be designed to~~ set some parameters of the system. When the GPS satellite signal is locked, the receiving system can collect the data according to the preset instruction by start key. Both ~~of selecting of~~ selecting the channel for collection and setting the channel on or off can be finished with the LCD and keyboard control in actual work. And ~~it using~~ general purpose IO port ~~is used~~ to control DAC7714 chip ~~which can be used~~ to achieve natural potential compensation and fine gain tuning. And the STM32F407 diagram is shown in figure 8.

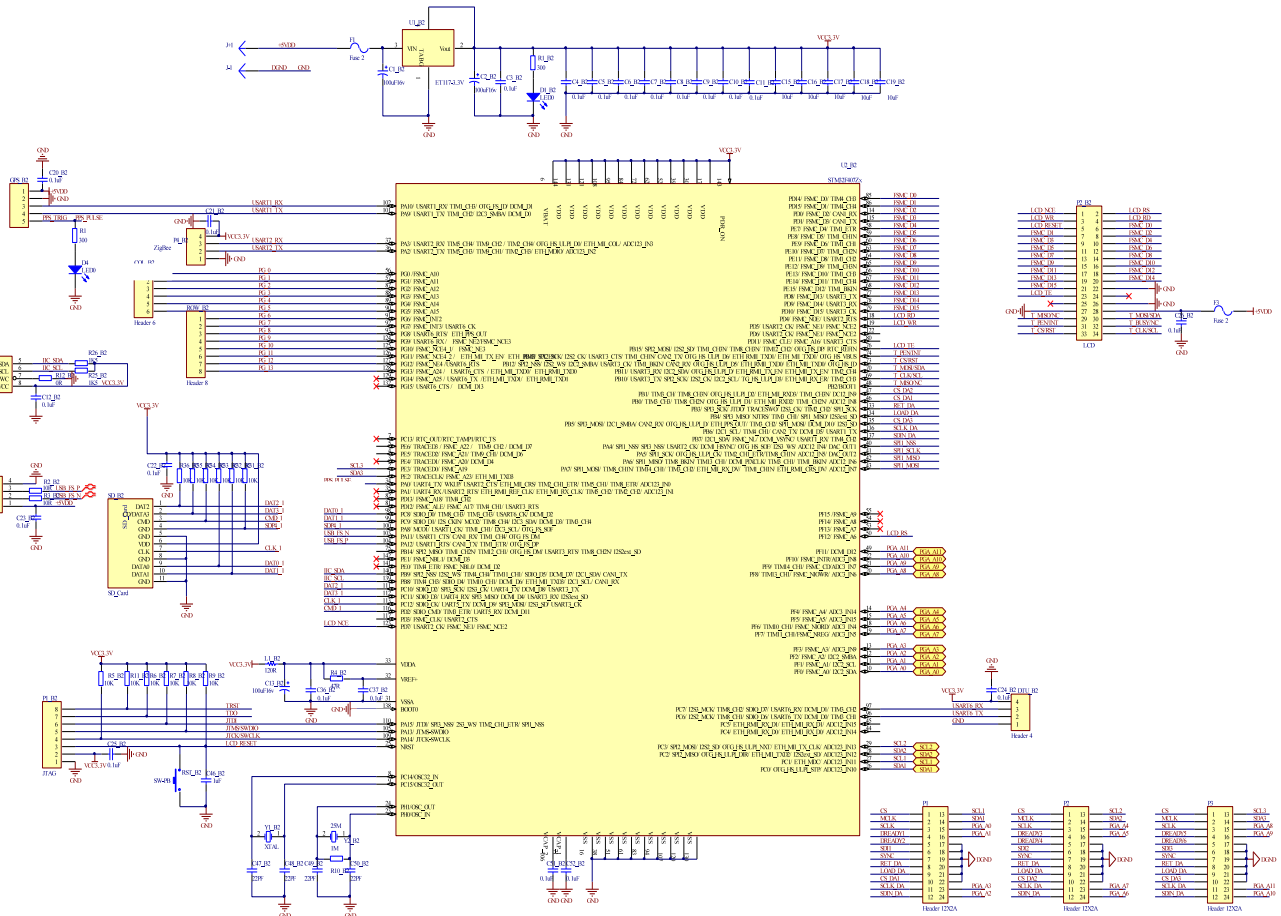


Figure 8. STM32F407 circuit diagram

2.4 Design of high-precision linear power circuit

After comparing the multi-output power supply circuit board designed by the switching power supply module, a Low Drop Out linear power chip with high precision and high ripple rejection is selected(Joo et al.,2017,Duong et al.,2017). On the power supply board, three independent connecting plugs are used to supply power to each analog board(Ren et al.,2015). Here, the high-reliability TPS7A family series of voltage regulators designed by Taxi-Instrument-Texas Instrument which features wide input voltage range, low noise, and high supply ripple rejection is selected. The power board have has 4 different voltage output-output voltages: + 10V, -10V, + 5V, -5V for preamplifiersand-filters. Another separate + 5V power supply for digital potentiometers on analog board ,and DAC7714, etc., and a 3.3 V Power provides digital logic power for Analog-to-Digital converter AD7767(Yun et al.,2017). which are shown in Figure 9. The high precision and high power supply rejection rate

diagram is shown in figure 9. Since all chips are low-powered, and the overall power consumption of the receiver is lower than 10 watts.

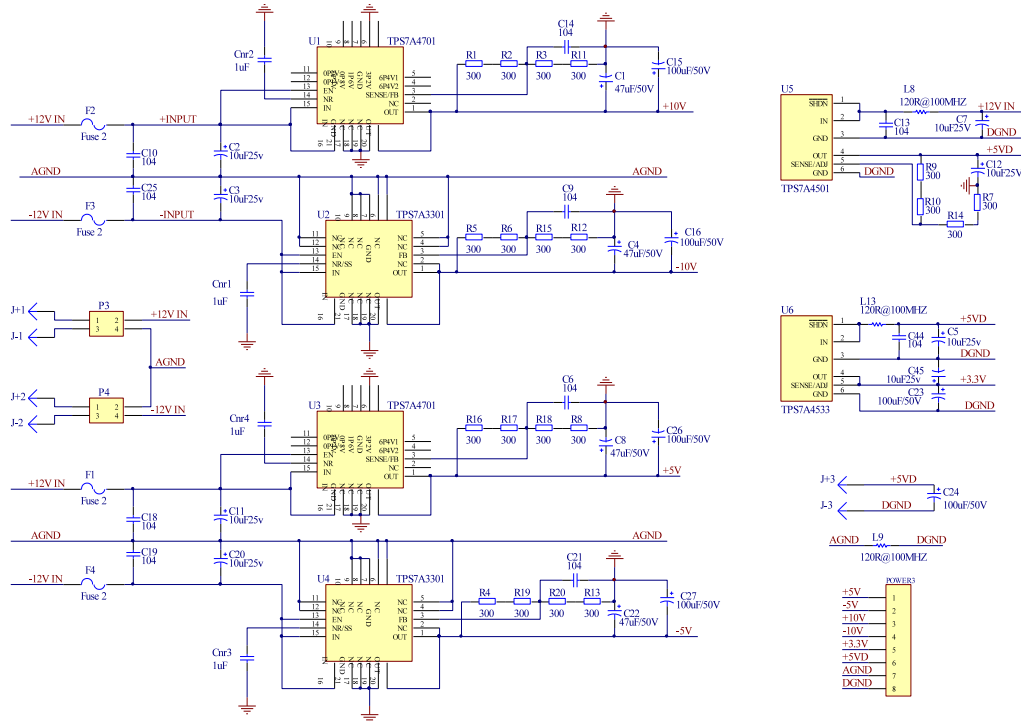


Figure 9. Power circuit

2.5 Software design

- 5 The software mainly includes two parts: 1)FPGA acquisition control board program, which involves the use of 4-bit data transfer on the SD card storage, and STM32 real-time communication ,data with STM32, and data processing in data buffer area ,data processing and other parts. etc. 2)and STM32 control board program, this part which includes the gain adjustment of the first stage preamplifier, the second stage of ratio setting of the second stage programmable amplifier, and natural potential compensation control(Khomutov et al.,2017).
- 10 FPGA mainly control-controls the front-end analog-digital convertercomponents, data storage and interaction-interactions with STM32. The FPGA chip first loads the stored program file after power-on, reads the flash through the SPI interface, and then waits for the operation control commands sent by the STM32, such as system initialization, parameter setting and sensor calibration(Wang et al.,2017). FPGA's program combine the collected data, the current time Time information and the channel number together for the later storage numbers are stored in a package through FPGA program. Those information is stored in

the first 8 bytes of each sector in SD card. ~~GPS timing unit provided by the second pulse signal~~ The pulse per second(PPS) ; ~~FPGA synchroize the transeeiver~~ provided by GPS timing unit updates the internal base time of FPGA in every two seconds. It can reduce the ~~cumulative error in long time collection~~ time cumulative error.

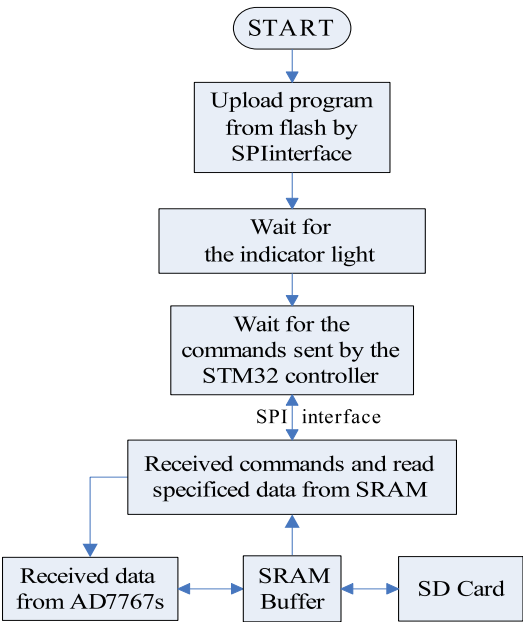


Figure 10. Flowchart of system program

- 5 Embedded controller is responsible for coordinating the ~~work operation~~ of the entire system, such as the system gain adjustment of each channel, GPS time information reception and status monitoring, real-time ~~data acquisition and display of information, and FPGA controller communication~~ display of acquired data, and interface communicating with FPGA controller(Zhang et al.,2017). The system flow chart is shown in Figure 10.

3 Performance test

- 10 Performance test of the receiver system mainly ~~include~~ includes DC testing, AC testing and field testing(Ziolkowski et al.,2010,Zhou et al.,2015).In the DC stability test, we first ~~test~~ tested the magnification range of each channel and the magnification consistency. Taking the first channel as an example, as shown in Figure ~~2-11~~ below, the input signal is a blue curve with a range of $\pm 50\text{mV}$. The red curve is the magnification curve of the first channel when each input signal is calculated. ~~According to~~ Under the same test conditions, the six channels are connected in parallel,~~under and~~ the same input ~~signal conditions~~.

Table 1. Magnification test of each channel

Channel No.	Magnification mean
Channel 1	94.42
Channel 2	94.46
Channel 3	94.39
Channel 4	94.68
Channel 5	94.32
Channel 6	94.59

the acquisition of signals are received separately by six channels at the same time, the average magnification. The average magnification times of each channel are shown in Table 1, the portion of the difference between each channel is small. 1.

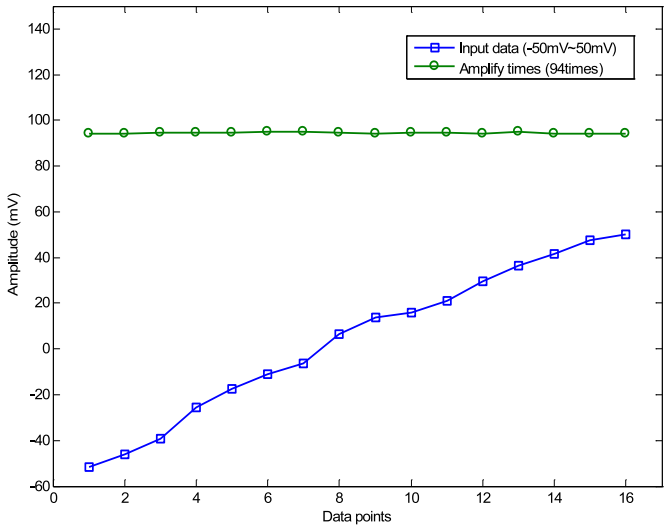


Figure 11. First Channel Amplitude ratio in DC Test

Next is the conformance test between channels for of the receiver. The test is to better maintain a high degree of high consistency between channels. The test project is: Sequence the seven connection. In the test, positive terminals of the six channels , with the odd-numbered terminals connected together and the even-numbered terminals connected together. After connecting in this way, two terminals appear, that is: the common terminal of the odd terminal and the common terminal of the even terminal are connected with the standard sine wave signal, the are connected together, while the negative terminals are connected with each other. The two connected terminals are input with standard sine waves. The amplitude of the input signal is 20mV peak-to-peak and the frequency is 150Hz. For the same point in time, the extraction of the value of each channel

Table 2. Error analysis table of inter-channel consistency

Channel No.	Group1(mV)	Group2(mV)	Group3(mV)	Group4(mV)	Average(mV)	Average Error(mV)	Error Percentage(%)
Channel 1	20.7398	20.7372	20.7382	20.7359	20.7378	0.0020	0.1901
Channel 2	21.0451	21.0465	21.0510	21.0465	21.0473	0.0022	0.3432
Channel 3	20.7961	20.7927	20.7938	20.7964	20.7948	0.0013	0.1328
Channel 4	21.0050	21.0044	21.0057	21.0015	21.0042	0.0008	0.2303
Channel 5	21.0529	21.0504	21.0500	21.0530	21.0516	0.0013	0.0282
Channel 6	20.8906	20.8911	20.8906	20.8914	20.8909	0.0004	0.2013

The extracted numerical values of each channel at the same time are compared to obtain the average of each channel error, the average absolute error and error percentage, as shown in Table 2. The average error is less than $2.2\mu V$.

In the AC testing, the six channels of positive and negative parallel are access to the sine wave terminals are connected in parallel, and the sine waves are input from the standard signal source. The waveform output by the system after the acquisition is output waveforms after the system acquisition are shown in Figure 3, the input signal peak-10mV, frequency of 12. The peak to peak value of input signal is 10mV, and the frequency is 20Hz. As can be seen from the figure, each channel has high consistency the consistency between each channel is quite high and no phase offset occurs. After the system is enlarged, each channel-waveform shows peak-to-peak input signals are amplified by the system, peak to peak value displayed by waveforms of each channel reaches to 1000mV through amplifier.

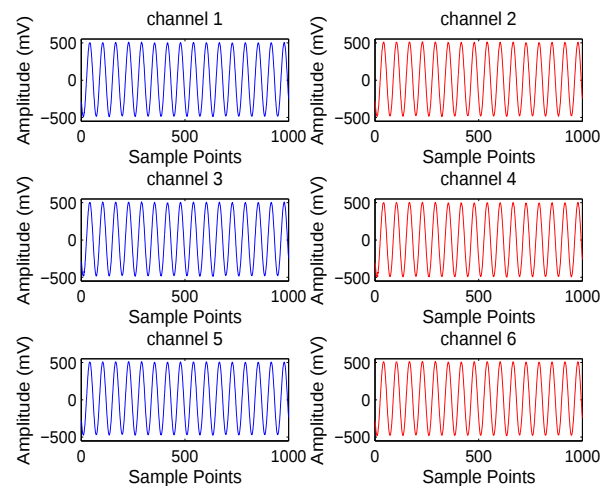


Figure 12. Standard sine wave of six channels in synchronous receiving

Figure 4 is the first channel in Figure

$$SNR = 20 \times \log \frac{FullScaleValue}{RootMeanSquareNoiseVoltage} \quad (1)$$

In Figure 13, the left figure is about the waveform of 3 cycles of data acquisition by the first channel shown in Figure

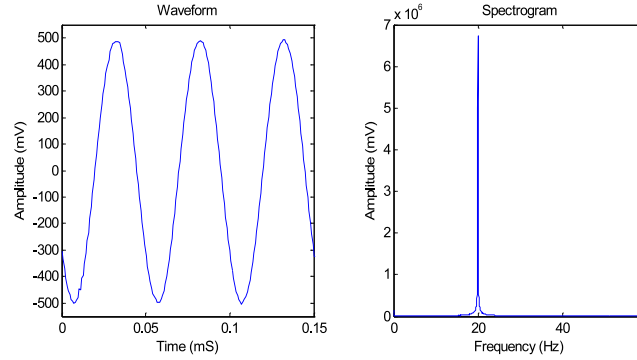


Figure 13. waveform and its spectrum diagram

12. The right figure is about the frequency spectrum formed by waveforms in the left one, which underwent fast fourier transform. it can be seen from the frequency spectrum of the sine wave in the left time domain, and. As is shown in the right one, the frequency of the input sines waves is 20Hz, with few harmonic components in the right frequency domain., which indicates the excellent performance of analog circuit board and high stability of power circuit.

In Figure 14, six channels are connected to zero, and 2000 points of each channel are displayed. According to formula 1, the SNR of each channel is approximately 100dB by calculating.

10 4 Field testing

In the field testing, sensor is a hollow coil with 400 turns and it's diameter is a diameter of 50cm, the effective area of the coil is used as the test sensor, and its effective area is 40m². The transmitter uses Phoenix's Phoenix T-4 transmitter, which transmits is a small power transmitter, which manufactured by Phoenix. This transmitter can launch up to 40A current, it powered by battery group, and it can launch many kinds of waveforms, such as TD50(numbered by Phoenix), which is a bipolar pulsed numbered TD50-waveform with a 50% duty cycle(Wang et al.,2015). The V8 is the eighth generation of receiver technology developed by Phoenix since 1975. The sample rate is 96k, on board memory is only 512M bytes. It cant' stored all received data. The synchronization of V8 system is synchronized by GPS time. But the sample rate of the multi-channel TEM receiver is 128k SPS, and synchronization mechanism is realized by GPS and 28-bits counter. The accuracy of synchronization can be improved, and all the time information and data information are stored in SD card simultaneous.

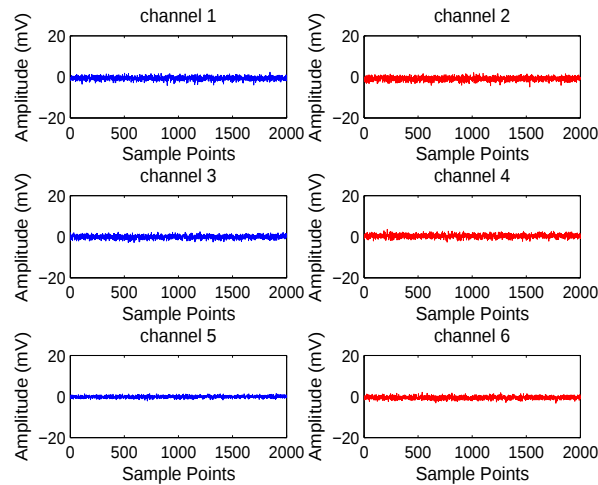


Figure 14. AC test waveform and its spectrum diagram. The noise of the circuit itself when each channel is connected to zero.

Two sites were selected, the first one of which is a relatively open site and the second one while the other is the actual mining area. The test uses a near-field measurement method. The transmitting source of the field adopt grounded electrode. Near-field measurement method is used in the test. Grounded electrode source is adopted as the field source. Four aluminum plates as electrodes are respectively buried 40cm deep in the ground with 40cm of aluminum plate and covered with salt water and soil, so that the grounding resistance is less than 10 ohms. The spacing of distance between the transmitting electrodes is 300 meters, the power supply using four batteries, voltage control A and B is 400 meters, and the four batteries are used as the power supply. The voltage ranges between 40-50V, while the emission current of is 3A, and the launch frequency of emitting frequency is 25Hz.

During the test, the power supply electrode is electrodes are stationary, while the preset measurement and emission level is at an offset of line is parallel with the emission points A and B. The offset is 40 meters. During the test, two machines were used, one of them is used to record the emission current waveform and the other is used to receive the voltage of the. The changing rate of the magnetic flux density (dB/dt) at the preset point. Figure 5 is received by the coil. Figure 15 below shows the original one-cycle data one original one cycle.

The open area to be tested where the test was carried out, is formed by the mixing and filling mixture of soil and slag. Each survey measurement line was observed at 8 measuring points. After the data was stored, it was processed by computer program written in MATLAB and the secondary field information of each measuring point was extracted and processed. The following two profile curves were profile curve was formed.

Figure 6 shows the cross-section of this line. The cross-section shows 16 shows the profile, which indicates that the overall response tends to be flat. The difference between the two launch points is due to the close proximity of the emitter point

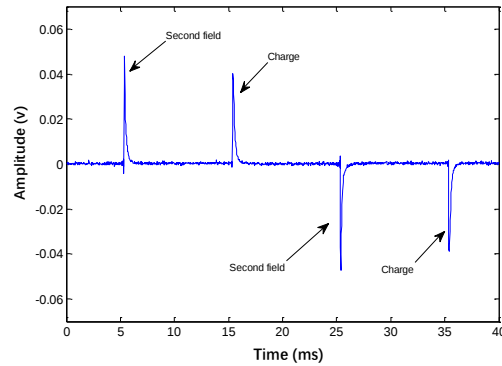


Figure 15. single-eye single cycle waveform(40ms40ms)secondary field and a field waveform

received by the signal is signals received at the measurement points close to the transmitting nodes are relatively strong, closer to the middle, the profile line slowly flat while the central part of the profile becomes flat slowly.

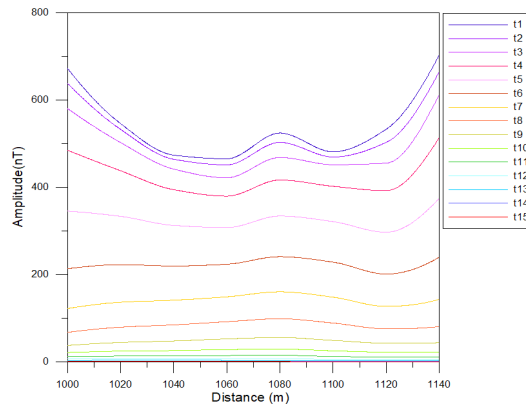


Figure 16. Close Profile is close to the transmitting source L1-line profile

In order to test the performance of the receiver further, a mining area in Leshan, Sichuan Province was selected for the field test, and a relatively gentle geodetic survey line was planned. The use of electrode source emission, emitter distance of is adopted, and the distance between the transmitting electrodes stance is 400 meters. The testing line offset is 80 meters, measuring point spacing of and the distance between the measuring points is 40 meters.

Mining area test is still using a

A continuous launch mode is used in mining area test, and the transmission signal frequency is 25Hz. Figure 7 is a waveform of the two periods of the raw data collected in the mining area. Compared with Figure 6, it can be clearly seen that there is a big difference in the magnitude of the change of the magnetic induction between the secondary field and the charging due to

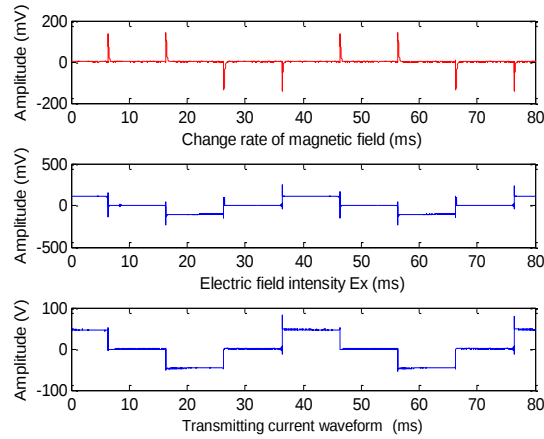


Figure 17. Waveform diagram in mining area

~~the fact that the area is a metal mine~~, ~~Less heat loss of electromagnetic waves~~. ~~Due to the inconvenience of the layout of multi electrode pairs and coils, the data receiver and current waveform receiver are configured as two channels, while one channel of current waveform receiver is used to receive currents. Synchronous receiver with 32 channels can be realized, according to the bandwidth of the storage speed of SD card.~~

- 5 ~~Waveform diagram acquired in mining area (two cycles)~~ ~~The second-field extraction, filtering and interpolation are performed on the~~ The Figure 17 is composed of three sub-figures in mining area, the first is change rate of magnetic field(dB/dt), the second is Electric field intensity Ex, and third is transmitting current waveform, all sub-figure display two periods. The upper two sub-figures and the bottom sub-figure are come from two receivers, which work in sync mode. The high-precision synchronization mechanism is implemented with a high reliability GPS module and a 28-bit counter in FPGA. The receiver's
- 10 ~~time information is refreshed every two seconds by PPS of GPS module. The 28-bit counter is used to record the pulse, which come from 25MHz clock in FPGA board. The 28-bit counter value and collecting data and time information are packaged and stored in SD card. The error for each count value is 40ns. Each sample data point can be tracked by the stored time information and data information in SD card. After data collection, no matter how many receivers work in mine area at the same time. The full-time range store technology supplied a valuable method to enhance the accuracy of the synchronization.~~
- 15 ~~After the collected data collected in the mining area~~. ~~After 200 superimposed waveforms, the waveform are second-field extracted, filtered and interpolated, the waveform is formed. The waveform curve of the time domain is smoother~~, ~~after, 200 superimposed waveforms~~, which can well reflect the response of underground ~~media-geological bodies~~ to transient electro-magnetic. The data of each measuring point are processed in the same way to obtain the pure secondary ~~fields-field~~ curves, and the time ~~sampling is performed to form a sectional view~~ ~~domain order waveforms are extracted to form the profile~~ of
- 20 the measuring line. In ~~Fig-8~~ ~~Figure 18~~, $t_1 \sim t_{12}$ respectively represent the extraction time, and ~~connect~~ the extracted values of different collection points ~~are collected~~ together to form 12 curves at different times.

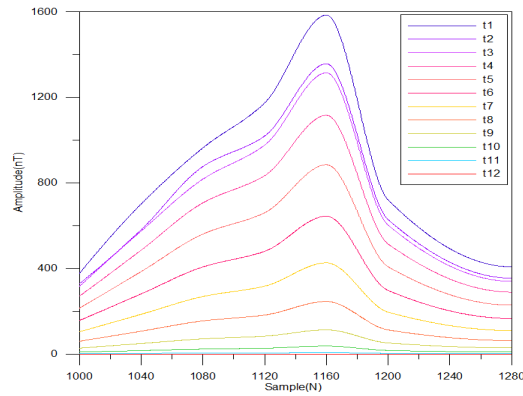


Figure 18. Survey line profile of copper mining area

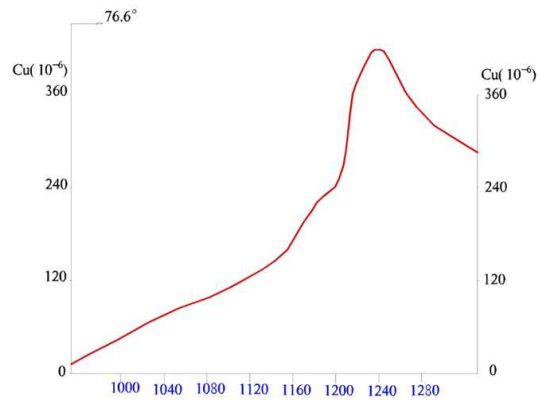


Figure 19. Geochemical Anomaly of geochemical exploration of copper area along the survey line

As can be seen from the comparison of Figures 9 and 10 with Figure 8 by comparing Figure 19 and Figure 20 with Figure 18, the high anomaly point is near by 1160 test point, which happens to be a sloped metal vein. Thus it is verified that the receiver can acquire the signal of transient electromagnetic emission very well. By analyzing and comparing the profile and the measured with the actual geochemical distribution, it can be obviously seen that the abnormality of the curve curves is highly consistent near 1160 point. In addition, the anomaly is more in line consistent with the geological structure in this area.

5 Conclusions

The purpose of this paper is to develop a set of receiver device that can adapt to application of be applied in transient electromagnetic prospecting. First, the hardware circuit and software program circuits and software programs are designed to realize all functions which are presented above. By means of dual controller, the instrument can receive six channels signal

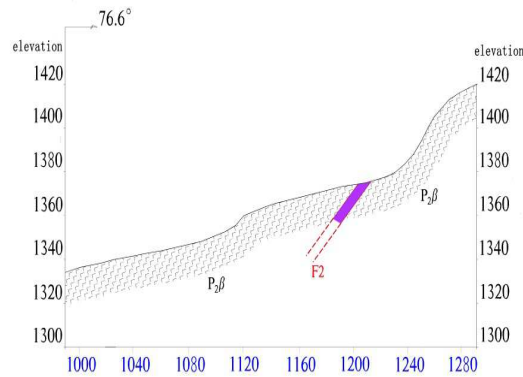


Figure 20. Geological profile of mining area

synchronously signal synchronously through six channels. Then, the data stored in SD card is are processed by computer program and generate graphic programs to generate graphs. The overall performance was tested, All the channels reached an error of of the receiver was tested and verified. All the collected data error of each channel is less than 0.35%, and each channel can connect different sensors, such as coil, magnetic probe, electrode. This kind of receiver can be used to collect transient

5 electromagnetic information acquisition. It has high precision, . Due to its high precision and high sampling rate, it can capture the fast falling edge of TEM, ultra-low noise and soon and ultralow noise and so on. Hence, the multi-channel synchronous acquisition of magnetic field information in three directions and electric field information in two directions and the rate of change of changing rate of magnetic induction intensity can be used for time domain reception. Meanwhile, pseudo-Random the receiver can be used for pseudo random signal reception and distributed 3D-reception provide strong support for further

10 exploration of different ways. 3-dimension data reception, which can improve geophysical exploration efficiency.

Code availability. The codes of the receiver are available upon request(linfq@cdut.edu.cn)

Data availability. The circuit schematics of the receiver are available upon request(linfq@cdut.edu.cn)

Appendix A

A1

15 *Author contributions.* FQ developed the main hardware and a part of software, XB instructed all the authors. And others participated in the experiments and software development.



Figure 21. [Receiver](#)



Figure 22. [T4 transmitter](#)

Competing interests. The authors declare that they have no conflict of interest.

Acknowledgements. This work was supported by National key research and development project(no.2016YFC0600300),National natural science Foundation of China (NO.41674078),and Field observation and research base of ministry of land and resources of China for Geohazards in earthquake disturbed area of Longmen Mountain in Chengdu.

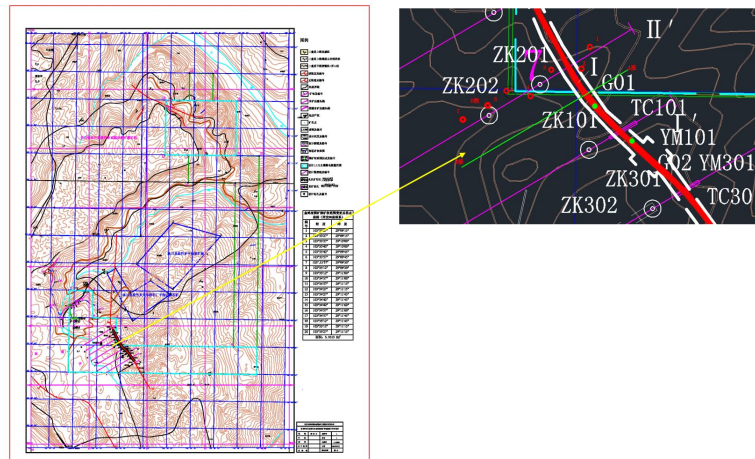


Figure 23. [Mine Picture](#)

References

- Ayuso, S., Blanco, J. J., Medina, J., Gomez-Herrero, R., Garcia-Poblacion, O., Gracia, T. I.: A coincidence detection system based on real-time software, *Geoscientific Instrumentation Methods and Data Systems.*,2,1-36, DOI: 10.5194/gi-5-437-2016,2016.
- Brunke, H. P., Widmer-Schmidrig, R., Korte, M.: Merging fluxgate and induction coil data to produce low-noise geomagnetic observatory data meeting the INTERMAGNET definitive 1 s data standard, *Geoscientific Instrumentation Methods and Data Systems.*,2:487-493. DOI:10.5194/gi-6-487-2017,2017.
- Chen, W. Y., Khan, M. Y., Xue, G. Q.: Response of surface-to-borehole SOTEM method on 2D earth, *Journal of Geophysics and Engineering*, 3,987-997. DOI:10.1088/1742-2140/aa6fcc,2017.
- Chen, W. Y., Khan, M. Y., Xue, G. Q., Cui, J. W., Zhong, H. S.: Study on the response and optimal observation area for SOTEM, *Chinese Journal of Geophysics-Chinese Edition.*,2,739-748. DOI:10.6038/cjg20160231,2016.
- [Danielsen J E, Auken E, Jørgensen F, et al. The application of the transient electromagnetic method in hydrogeophysical surveys, *Journal of Applied Geophysics.*, 53\(4\),181-198,DOI: 10.1016/j.jappgeo.2003.08.004,2003.](#)
- Duong, Q. H., Nguyen, H. H., Kong, J. w., Shin, H. S., Ko, Y. S., Yu, H. Y., Lee, Y. H., Bea, C. H., Park, H. J.: Multiple-Loop Design Technique for High-Performance Low-Dropout Regulator, *IEEE Journal of Solid-state circuits.*,10,2533-2549., DOI: 10.1109/JSSC.2017.2717922,2017
- [Haroon, A, et al. "Joint inversion of long-offset and central-loop transient electromagnetic data: Application to a mud volcano exploration in Perekishkul, Azerbaijan." *Geophysical Prospecting* 63.2\(2015\):478-494.](#)
- Li, W. yao., Yan, Chong. Wei., Zou, Zheng. Wei., et al.: Research progress of transient electromagnetic apparatus, *Journal of YunNan university (natural science edition).*, 34,233-241. 2012.
- Liu, H., Wang, W. D., Xiang, C. L., Han, L. J., Nie, H. Z.: A de-noising method using the improved wavelet threshold function based on noise variance estimation ,*Mechanical System and Signal Processing.*, 99,30-46, DOI: 10.1016/j.ymssp.2017.

- Liu, J. N., Ai, W., Wen, F., Liu, D. H.: Design of Cascaded Multi-channel Signal Isolated Acquisition Circuit, Instrument Technique and Sensor., 12,148-151,180 ,2016.
- Joo, S., Kim, S.: PSR enhancement techniques for output-capacitor-free LDO regulator design, Analog Integrated Circuits and signal Processing., 2:319-327, DOI: 10.1007/s10470-017-1045-9, 2017.
- 5 Khomutov, S. Y., Mandrikova, O. V., Budilova, E. A., Arora, K.; Manjula, L.: Noise in raw data from magnetic observatories, Geoscientific Instrumentation Methods and Data Systems.,2,329-343. DOI:10.5194/gi-6-329-2017,2017.
[KMS:KMS-820,http://www.kmstechnologies.com/kmscompanyoverview.html](http://www.kmstechnologies.com/kmscompanyoverview.html), last access: 1 January 2017.
[Metronix: ADU-07e, http://www.metronix.de/metronix/index.php](http://www.metronix.de/metronix/index.php), last access: 1 January 2017.
- Oballe-Peinado, O, Hidalgo-Lopez, JA, Castellanos-Ramos, J, Sanchez-Duran, JA , Navas-Gonzalez, R, Herran, J, Vidal-Verdu, F.: FPGA-
10 Based Tactile Sensor Suite Electronics for Real-Time Embedded Processing, IEEE Transactions on industrial electronics., 12,9657-9665, DOI: 10.1109/TIE.2017.2714137, 2017.
[Phoenix Geophysics: V8 receiver, http://www.phoenix-geophysics.com/products/receivers/v8/](http://www.phoenix-geophysics.com/products/receivers/v8/), last access: 1 January 2017
- Qi, Y. F., Yin, C. C., Wang, R., and Cai, J.: Mutlti-Transient EM full-time forward modeling and inversion of m-sequences, Chinese J. Geophys., 7,2566-2577, doi:10.6038/cjg20150731.2015.
- 15 Ren, Z. D., Guo, C. S., Lin, P. F.: Design of High-Performance LDO with Buffer Impedance Attenuation, Microelectronics.,2,225-227,232,2015.
- Wang, H. F., Chen, S. D., Zhang, S. Yuan, Z. W., Zhang, H. Y., Fang, D., Zhu, J.: A High-Performance Portable Transient Electro-Magnetic Sensor for Unexploded Ordnance Detection, Sensors (Basel, Switzerland)., 11,DOI:10.3390/s17112651,2017.
- Wang, X. L., Gao, J. X., Tian, J. S., and Zhang, Y. T.: Design of power transformer in MTEM transmitter power, Atlantis Press., 161–164,
20 <https://doi.org/10.2991/cmcs-15.2015.47>, 2015.
- Xue, G. Q., Chen, W. Y., Zhou, N. N., Li, Hai.: Short offset TEM technique with a grounded wire source for deep sounding, Chinese J. Geophys.,1:255-261,doi:10.6038/cjg20130126,2013.
[Wright D. 2004. Detection of hydrocarbons and their movement in a reservoir using time-lapse Multichannel Transient ElectroMagnetic data \[D\]. Edinburgh: University of Edinburgh.](#)
- 25 Yun, S. J., Kim, J. S., Kim, Y. S.: Capless LDO Regulator Achieving-76 dB PSR and 96.3 fs FOM, IEEE Transactions on Circuits and Systems II-Express Briefs.,10,1147-1151. DOI: 10.1109/TCSII.2016.2628965,2017.
- Zhang, X. H., Du, J. L., Fan, C. G., Liu, D, Fang, J. L., Wang, L. S.: A Wireless Sensor Monitoring Node Based on Automatic Tracking Solar-Powered Panel for Paddy Field Environment, IEEE Internet of Things Journal., 5,1304-1311. DOI: 10.1109/JIOT.2017.2706418,2017.
- Zhang, X.Y., Zhang,Q.S.,Wang,M.,Kong,Q.,Zhang,S.Q.,He,R.H.,Liu,S.H.,Li,S.H.,Yuan,Z.Z.: Development of a full-waveform voltage and
30 current recording device for multichannel transient electromagnetic transmitters, Geoscientific Instrumentation Methods And Data Systems.,2,495-503, DOI:10.5194/gi-6-495,2017.
- Zhong, H. S., Xue, G. Q., Li, X., Zhi, Q. Q., and Di, Q. Y.: Pseudo wave field extraction in the multi-channel transient electromagnetic (MTEM) method, Chin. J. Geophys.,59,4424–4431,2016.
- Zhou, N. N., Xue, G. Q., Chen, W. Y., Chen, J. L.: Large-depth hydrogeological detection in the North China-type coalfield through short-
35 offset grounded-wire TEM, Environmental Earth Sciences., 3,2393-22404. DOI:10.1007/s12665-015-4240-y,2015.
- Ziolkowski A, Parr R, Wright D, Nockles, V., Limond, C., Morris, E., Linfoot, J.: Multi-transient electromagnetic repeatability experiment over the North Sea Harding field. Geophysical Prospecting., 58,1159-1176,2010.