# High Precision Multi-frequency Multi-function Receiver for Electrical Exploration

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**Abstract:** Pseudo-random multi-frequency (PRMF) signal's bandwidth is controllable, its energy concentrated on several frequencies, which equally spaced on log-scale coordinate, and it is used as excitation for electrical exploration to improve the working efficiency. To realize high precision data acquisition and processing of pseudo-random signal in electrical exploration, PRMF multi-function receiver for electrical exploration is developed. This receiver adopts up-to-date electronics and technology, such as low-power pentium-166 PC/104 embedded industrial computer, 24-bit CS5321/5322 A/D converter module, high reliable Actel anti-fuse FPGA, 32-bit data acquisition and processing software based WINDOWS operation system, adaptive correlation synchronization, weak signal detection based on cross-power, digital filter de-noising, and so on. Above measures make the receiver owns the advantages of fast signal processing, large dynamic range, lightweight, easy usage, good anti-interference ability, ability to receive PRMF signal and rectangular wave. It can carry out major electrical exploration methods, such as resistivity method, induced polarization method (time and frequency domain), complex resistivity method, controlled source audio magnetotelluric (CSAMT) method, and so on.

**Keywords:** receiver; data acquisition; weak signal; electrical exploration; geophysics.

## 1 Introduction

Electrical exploration methods have a broad range of applications, including minerals exploration, ground water investigations, the search for oil and gas, academic research into earth structure and volcanology, geothermal exploration, environmental investigations, and as a tool in archeological studies[1~3]. Traditional electrical method use rectangular wave as excitation. It suffers from low productivity and low cost effective instrument. Because most of electrical method instrument have only one function. They can just take one measurement at single measurement cycle[4]. To overcome above shortcomings, He jishan invented and named PRMF signal. The signal's energy concentrated on several equally spaced frequencies in log-scale coordinate. It is easy to inject larger power into earth. Comparing with rectangular wave, its bandwidth is controllable. In practice, measuring efficiency can be controlled by controlling the bandwidth of transmitted signal[5~6].

To expand PRMF signal's application in electrical exploration, pseudo-random multi-function receiver has been developed. It can not only receive each pseudo-random multi-frequency waveform, carry out multi-frequency IP method and multi-frequency CSAMT method, but also receive traditional waveform used in electrical exploration, carry out traditional electrical exploration method.

## 2 Instrument design strategy

According to requirement of field data acquisition, the receiver should have the following characteristic: good stability, low power consumption, portable, lightweight, large storage, high precision. To meet above requirement, following measures are adopted:

(1) PC/104 embedded industry computer. This computer owns the advantage of lightweight, low power consumption, high reliability, and high

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performance;

(2) CS5321/CS5322 24 bit A/D converter module. This A/D converter is specially designed for low power consumption. It is suitable for data acquisition of microvolt level signal.

(3) Two Actel FPGA ICs. They are used in address latch, address strobe, serial to parallel conversion of data, counter, frequency divider, logical control, and so on. This make instrument portable and reliable..

(4) FIFO buffer and 2.5-inch large storage hard disk. They ensure fast acquisition and storage of electrical data.

There are many different observation methods corresponding to electrical exploration. Each observation method owns several array types, and measure several parameters[1]. In the process of software design, the realization of each electrical exploration method is not only considered, easy usage, portability, and updateability but also should be ensured. To satisfy above requirement, object-oriented system design and analysis method are applied. Multi-function electromagnetic system to be developed is divided into several object with specified function and relationship. Visual C++, MATLAB and assembly language programming are adopted. Assembly code is used in data acquisition sub-system, to ensure fast data acquisition, Visual C++ is used in user interface, MATLAB is used in data processing and plot display.

# 3 Hardware design

Data acquisition system is composed of analog channel (2 electrical signal channels + 1 magnetic signal channels); 3 channel A/D conversion, FPGA & FIFO buffer; precision clock circuit; PC/104 computer system (Fig. 1).

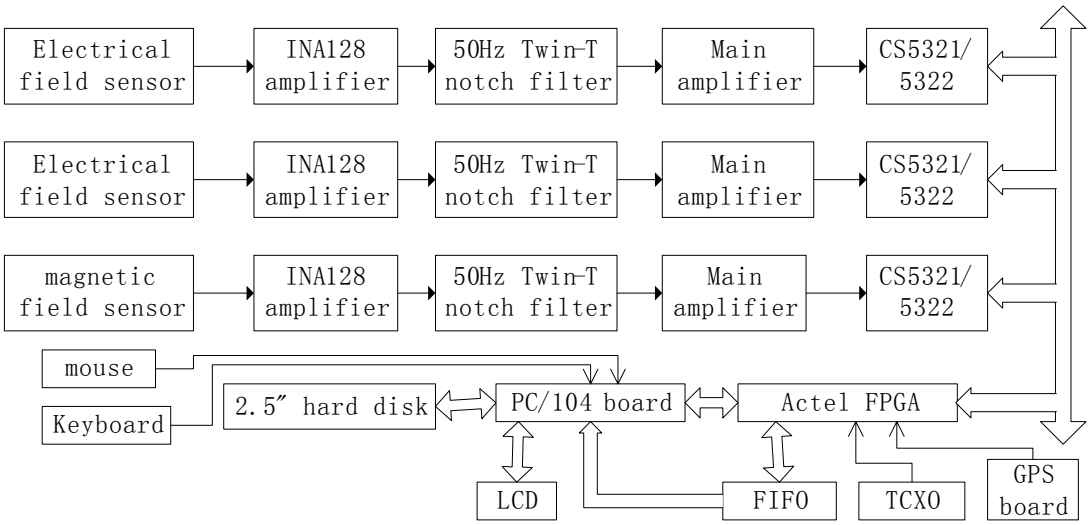


Fig. 1. Simplified schematic diagram of PRMF multi-function receiver

### 3.1 Analog channel

It includes 3-channel INA128 amplifier, 50Hz twin-T notch filter and programmable gain amplifier.

INA128 is a precision instrument amplifier manufactured by B-B Corp. The advantage of this amplifier is high precision, low power, high CMRR and wide bandwidth. The input protection voltage is 40V; it is very popular for electrical exploration instrument, which used in field condition.

Twin-T notch filter is used to remove 50Hz power line interference, its quality effect instrument's SNR and sensitivity. Two stages twin-T notch filter with Q as 20 are used in instrument.

Because the frequency of 50Hz power line often fluctuates, the notch frequency of first stage is tuned to 49.8Hz, 50.2Hz for second stage. Above measure ensure good notch filter performance.

Programmable gain amplifier is instrument amplifier composed of three operation amplifiers. The gain of main amplifier is 4, 8, 16 and 32 selectable, according to full scale input amplitude of A/D converter, input signal amplitude and best amplifying

zone of operation amplifier. Gain is controlled by electronics analogue switch.

LT1112S is adopted for main amplifier's 3-operation amplifier. Its internal noise is less than 0.3 uVp-p; bandwidth is 1MHz; maximum amplitude of output is 8 V; power consumption is 8.8 mW.

**3.2 channel A/D conversion, FPGA and FIFO buffer circuit**

This part is composed of Δ-Σ A/D converter, FPGA and FIFO buffer circuit, the function is A/D conversion and FIFO buffer for converted data. FPGA offer control logic for A/D converter, FIFO, interface and gain selection.

Δ-Σ A/D converter is CS5321/5322 chips produced by Cirrus Logic Inc. It include 4-order Δ-Σ modulator and programmable multi-stage FIR linear phase decimation filter. Its serial output is 2's complement code.

FPGA is ACTEL anti-fuse type MX4209, including about 9000 gates. FIFO data buffer is IDT7208. Serial data that come into FPGA are converted to parallel data as output; format conversion and de-multiplexing are carried out at the same time. 24-bit data come into FIFO buffer are divided into 3-byte data. The FPGA output three channel digital signals sequentially and come into FIFO buffer. When FIFO buffer is half-full or full-full, it generates a interrupt signal, PC/104 computer strobe it and input its data into memory and save data into flash storage or hard disk. Δ-Σ A/D converter with 120 dB dynamic range plus different gains in analog channel, the acquisition of weak electromagnetic signal can be satisfied.

**3.3 High accuracy clock circuit**

This part mainly offer standard clock for control logic and Δ-Σ A/D converter.

Clock generation circuit and control logic are made in same circuit board. Its function is to offer high accuracy real-time clock and logic control signal.

To reach the requirement of less than 1 us synchronizing error between different instrument, the crystal oscillator in computer board is replaced by T15L586 crystal oscillator produced by Bliley. The frequency of oscillator is 4.096 MHz, stability is $2\times10^{-7}$/s. T15L586 is clock base for computer, timer, and control logic. When GPS and data acquisition system is connected, and clock synchronization program is started, PPS signal from GPS reset high stability crystal clock, the clock difference between real time clock of PC/104 and GPS clock is less than 1 us.

According to clock sent from PC/104, logic device inside FPGA send control code of filter selection, gain selection, and so on, to controlled circuit, and send accurate second signal and minute signal, make data acquisition system work according to requirement.

**3.4 PC/104 embedded industrial computer**

The industrial computer's type is MOPSlcd6. It is a All-In-One Pentium CPU board which satisfy PC/104 and PC/104 – Plus standard. MOPSlcd6 not only owns main function of PC, but also owns display and 10/100Mb adaptive Ethernet. The function of PC/104 industrial computer is to control data acquisition system, store data acquired and status information of instrument, and processing data.

# 4 Software design

According to classification, function, and principle of electrical exploration, and object-oriented design and analysis method, software is composed of objects as transmitter setting, receiver setting, array type setting, raw data acquisition, electrical data acquisition, time-domain data processing, frequency-domain data processing, electrical parameter computing, plot and data I/O. These objects are interactional, work together as a effective system.

Transmitter setting object process information about transmitter, including waveform, current and voltage transmitted by transmitter. The parameters of waveform include type of waveform (such as rectangular wave, dual-frequency wave, 3-frequency wave, 5-frequency wave), wave frequency and frequency ratio.

Receiver setting object is used to set parameter of receiver, include sample frequency, gain, filter control, channel number, signal type (such as electrical field, magnetic field, transmitted current, synchronization signal and environment parameter) acquired by each

channel, and sensor connected to each channel. Receiver parameter setting is different according to different electrical exploration method.

Array type setting object offers parameter setting for different electrical exploration method. There is an array type corresponding to each electrical exploration method, such as pole-pole, pole-dipole, Schlumberg, gradient and dipole-dipole in resistivity method.

Raw data acquisition object control hardware of instrument according the parameter offered by receiver setting object directly, realize the data acquisition of raw time-domain data.

Electrical data acquisition object supports data acquisition for different electrical exploration task, such as resistivity method, induced polarization method (frequency domain and time domain), complex resistivity method, CSAMT, frequency domain electromagnetic method, transient electromagnetic method, magnetotelluric method, and so on.

Time domain data processing object realize time domain signal processing and analysis method required by electrical exploration, including trend remove, digital filtering, correlation, wavelet analysis, and so on.

Frequency domain data processing object realize frequency domain signal processing and analysis method, including FFT, power spectrum analysis, and so on.

Electrical parameter computing object compute measurement parameter required by each electrical exploration method, such as resistivity, impedance phase, percent frequency effect, relative phase, and so on.

Plot object generates plot for different data produced in data acquisition and processing, including data curve of raw time series data, data curve of processed time series data, frequency domain data curve of FFT result, profile of each electrical exploration parameter, such as apparent resistivity, phase, and so on.

Data I/O object realize I/O of acquired time domain data and each electrical exploration data.

Above 10 objects are variables of document, view and frame object offered by MFC, they work together to realize the functions of data acquisition software.

# 5 Conclusion

Pseudo-random multi-function receiver for geoelectrical exploration adopts low-noise, low-power consumption precision instrument amplifier; digital filter, programmable amplifier, FPGA, 24-bit A/D converter and industrial computer. It realizes the high precision data acquisition for each electrical exploration tasks. With the support of data acquisition software, it can receive signals with several frequencies at the same time. Resistivity method, induced polarization method, complex resistivity method, CSAMT and MT method can be realized by the receiver.

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