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Design on the Time-domain Airborne Electromagnetic Weak Signal Data Acquisition System

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Abstract

According to principle of transient electromagnetic method as well as its signal characteristics, this paper designed and implemented a time-domain airborne electromagnetic weak signal data acquisition system. With the use of the floating-point amplification technology, the system amplifies the weak transient electromagnetic signal dynamically. CPLD and DSP were used as the decoding control circuit and the main controller for processing the sampled data, respectively. The transient electromagnetic signal acquisition system, which was designed with a dynamic range up to 144dB and a sampling rate up to 100 kHz, meets the requirements of the high sampling rate with high precision and it has been applied in the time-domain fixed-wing airborne electromagnetic mineral exploration.

Keywords: *DSP, CPLD, ATEM, Floating-point Amplifier, Data Acquisition*

1. Introduction

At present, China is implementing land resources survey and geological security projects based on mineral development, and China is also making efforts to identify the status of land resources as soon as possible. During the Eleventh Five-Year Plan period, China has launched a research and development project for geological prospecting using high-precision airborne geophysical technology and equipment. The project, "Fixed-wing Time-domain Airborne Electromagnetic Exploration Systems Research and Development", undertaken by IGGE, is an important topic in State High-Tech Development Plan (863 Program) project "Airborne Geophysical Exploration Technology Systems".

According to the principle of transient electromagnetic method, for the Time-domain Airborne Electromagnetic (ATEM) weak signal, this paper presents researches and designs of a data acquisition system based on DSP. The transient electromagnetic is a geophysical exploration method, with high sensitivity in resistivity change, fewer limitations in ground conditions, good probing depth. It is widely used in many areas, including as metal mineral exploration, drilling and aviation and marine activities.The time-domain airborne electromagnetic method, a branch of the airborne electromagnetic methods, combines aviation with geophysical technologyby using aircrafts as delivery platforms to load geophysical equipment and complete the data acquisition of geophysical information. Aero Geophysical Survey is one of the important means of completing national geological survey projects with deep exploration depth. Large area survey can be facilitated at low cost and high efficiency, which plays an important role in the national economy development **Error! Reference source not found.**.

2. ATEM System

2.1. Principle of Transient Electromagnetic Method

The transient electromagnetic method, also known as Time-domain Electromagnetic Method (TEM), is based on fundamental electromagnetic induction principles shown in Figure 1. A transmitting coil is firstly put on the ground or in the air. By changing the current flowing throught, a constantly varying electromagnetic field (named as "primary field") can be generated in the space surrounding the coil, producing an induced current in the rock and mineral beneath. The varying current induced will also produce a varying electrmagnetic field (named as "secondary field") in the space around the ore body. The receiving coil is then used to obtain the

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information of the secondary field, including resistivity, conductivity and other physical characteristics. Further analysis based on the information obtained will help us to investigate the distribution of the underground mine sources [2].

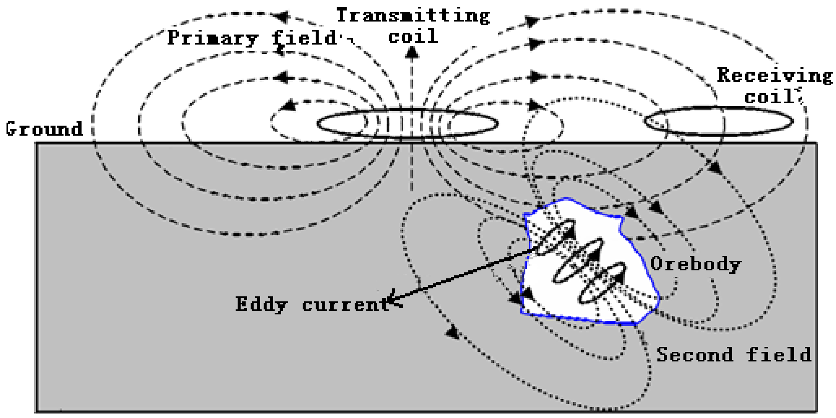

Figure 1. The schematic diagram showing the basic principles of the transient electromagnetic method

In order to improve the sensitivity of resistivity characterisation, reduce the limitation of ground conditions, deepen the probing depth and get better synchronization between transmitters and receivers, the transient electromagnetic method has recently become one of the most important exploration method in geophysical exploration field. It has been rapidly applied in metal mineral exploration, water resource survey, environment protection, aviation and marine activities **Error! Reference source not found.**.

2.2. Characteristics of Transient Electromagnetic Signal

In the electrical prospecting method, the intensity secondary field response of underground conductors decays exponentially with a decay function **Error! Reference source not found.**. The function is:

$$e(t) = \frac{K}{\tau} e^{-t/\tau} \quad (1)$$

Where e(t) represents the intensity of the secondary field response of conductive body, K is a time-independent constant, t is the time elapsed, and τ is a time constant dependent on the property of the conductive body.

Figure 2 is showing the characteristic curve of the TEM signal and its features are as follows:

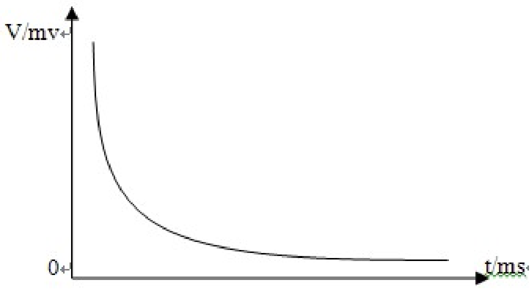

Figure 2. Characteristic curve of the TEM signal

(1) Large dynamic range: signal amplitude decays from n×105μV to n×10-1μV, up to 120db of dynamic range.
(2) Wide band: The frequency range of the TEM signal collected in this topic is 20 Hz to 25 kHz.
(3) Quick signal attenuation: Early TEM signals decay quicker and late signals decay slower.

2.3. ATEM System

Airborne Time-domain Electromagnetic Method Airborne Time-domain Electromagnetic Method (ATEM) is an important branch of airborne electromagnetic method (AEM).Its development is based on traditional ground electromagnetic method with the implementation of aerial survey. Similar as the ground electromagnetic methods, ATEM has its unique advantages, including fast speed, low cost, high efficiency, deep probing depth and etc. Besides, its application can be extended to geophysical survey work in areas where terrestrial method cannot be applied due to complexity, including swamps, deserts, lakes, forests and residential areas. ATEM is an effective exploration method and it is essential for land resources survey **Error! Reference source not found.**.

Figure 3 is showing schematic diagram of the frequency-domain airborne electromagnetic survey system platform developed by IGGE. The fundamental principle of the frequency-domain airborne electromagnetic method is the same as that of the time-domain method **Error! Reference source not found.**. The platform employs domestic Y12 IV aircrafts with transmiting and receiving coils installed at both ends of the fixed wings. Cabin equipment includes transmitters, receivers, aviation single-ray optically pumped magnetometer, aviation spectrometer, airborne geophysical data collection system as well as GPS navigation and positioning system.

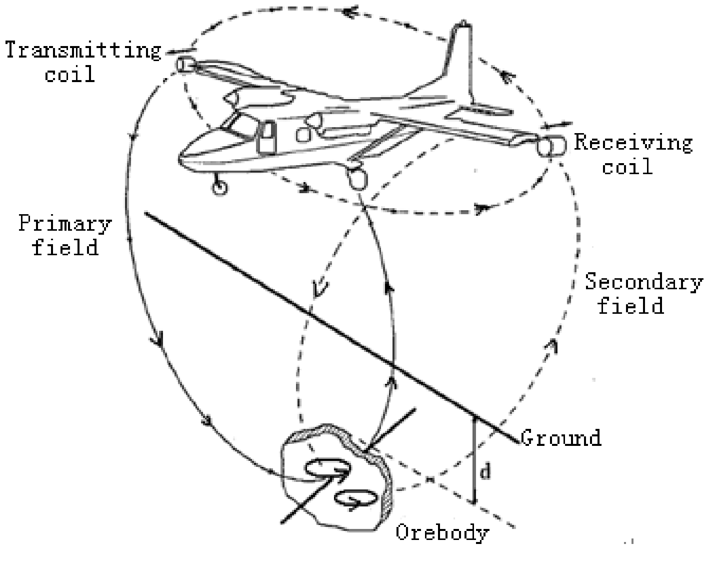

Figure 3. Schematic diagram of the frequency-domain airborne electromagnetic survey system

ATEM can be used to investigate the magnetotelluric properties, such as conductivity, permeability and etc. As the working platform of AEM is the aircraft, the main technical features of the AEM system are related not only to the instrument itself, but also to the type of the aircraft and the unique modifications made upon the airplane (Man Yan-long, 2009).

3. Floating-Point Amplification Technology

Floating-point amplification means the input signal can be amplified with dynamical extent and devices based on the principle of floating-point amplification are called floating-point amplifiers.

Figure 4 shows the schematic diagram of a floating-point amplifier which is composed of pre-sampling circuit, the second sampling circuit, programmable amplifying circuit and encoding circuit **Error! Reference source not found.**.

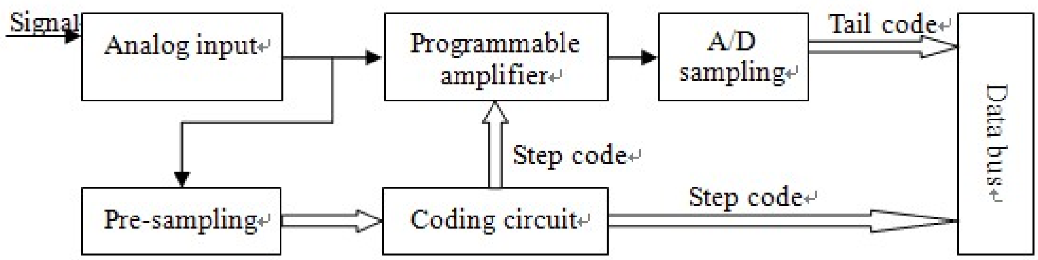

Figure 4. Schematic diagram of a floating-point amplifier

4. System Design Program

Figure 5 shows the overall system design program. The components enclosed in the dashed box is a floating-point amplifier circuit which is controlled by CPLD. Firstly, the TEM signal passes through the preamplifier and a low pass filter.Then CPLD will collect the raw signal with its internal coding circuit controlling the dynamic amplification. DSP then samples the signal again and transmits the results, which will also be displayed on the LCD, to the host computer.

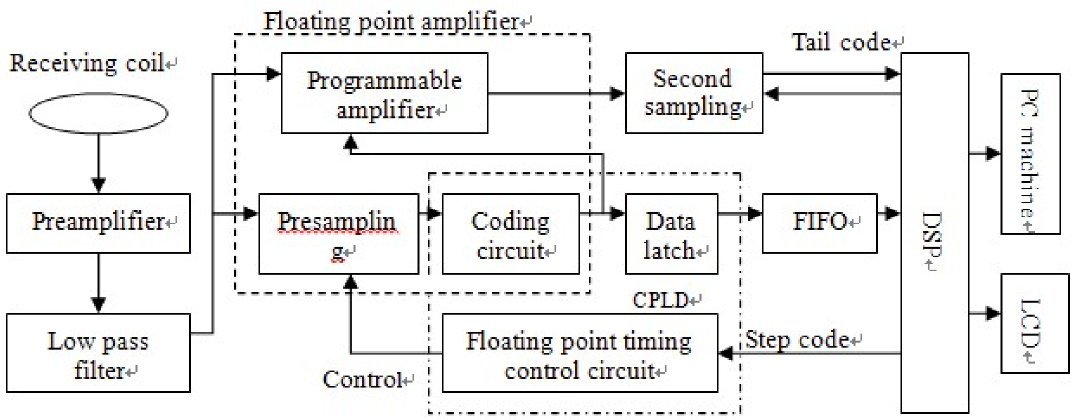

Figure 5. Schematic diagram of the system design

5. System Hardware Design

Figure 6 is showing the block diagram of the system hardware design, which can be further divided into two parts: DSP and CPLD. The DSP controller and CPLD controller are marked as the gray shaded area and the external circuit includes the minimum system of this two controllers as well as the external interfaces. The hardware circuit diagram is drawn using Protel99 SE.

5.1. DSP Subsampling Hardware Circuit

Figure 7 shows the DSP component of the hardware circuit diagram. It mainly contains a DSP minimum system circuit, a data memory expansion circuit, a level-shifting circuit, a LCD circuit, a second sampling circuit and a data transmission circuit.

5.2. CPLD Floating Point Zoom Hardware Circuit

Floating-point amplification circuit is controlled by CPLD chip EPM7128 and the controlling circuit block diagram is shown in Figure 8. It mainly contains a EPM7128 minimum system circuit, a low-pass filter circuit, a pre-sampling circuit, a programmable amplifier circuit and a FIFO (First Input First Output) memory circuit.

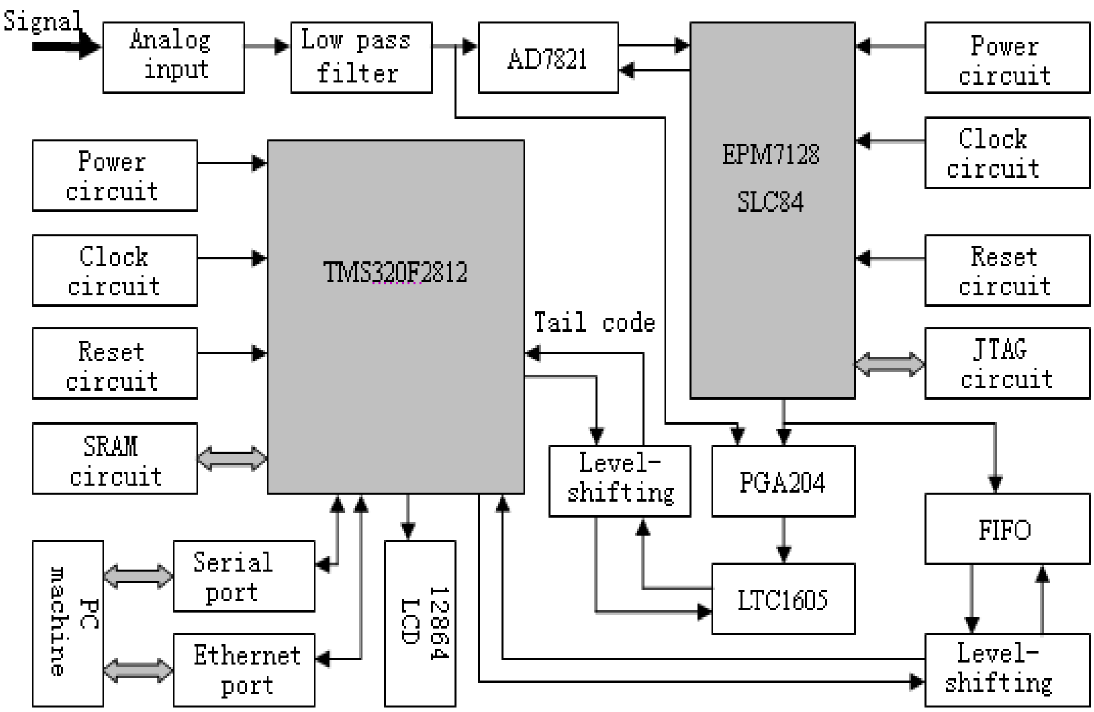

Figure 6. Block diagram of system hardware design

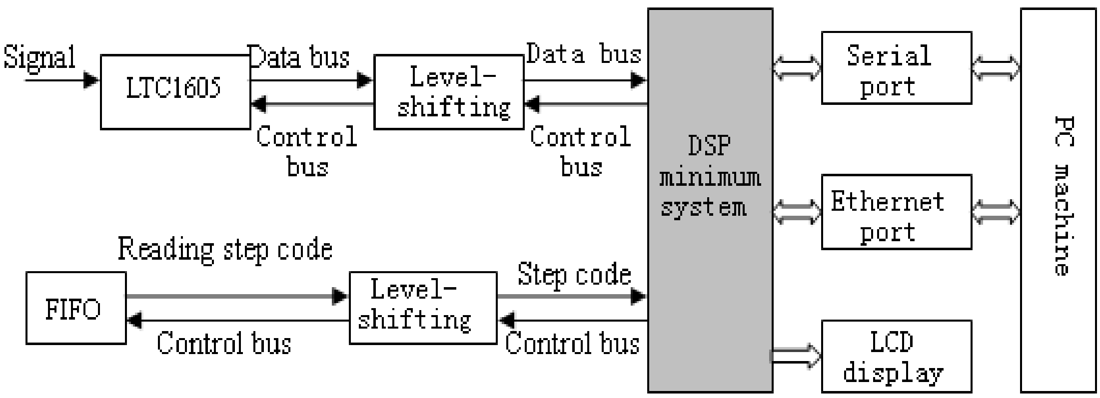

Figure 7. DSP component of hardware circuit diagram

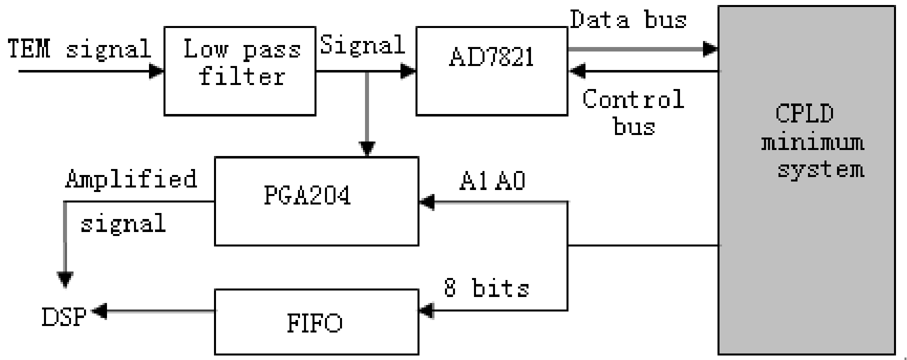

Figure 8. Diagram of a CPLD floating point amplifier circuit

5.3. Physical Map of System Hardware

Figure 9 shows the physical map of the system, in which the floating point amplifier circuit board is fixed onto the DSP subsampling circuit board.

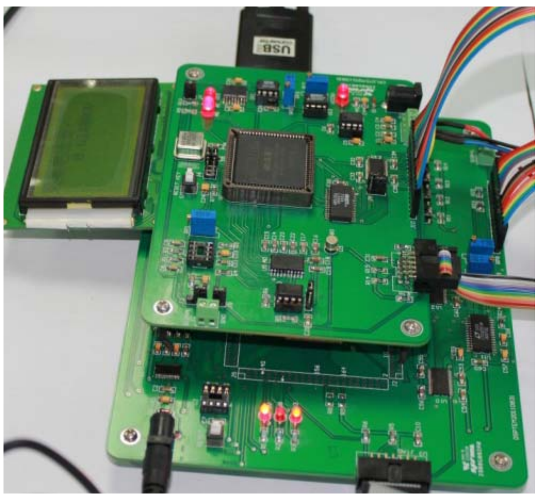

Figure 9. The physical map of the system

6. System Software Design

6.1. The Design of Sampling Circuit Software

The design process of the system software is shown in Figure 10. Once the system is turned on, the main program will initialize the DSP hardware system, including disabling the watchdog, setting the system clock and the peripheral clock, turning off the interrupts and peripheral interrupt, initializing the PIE control registers and enabling the PIE vector table. CPLD controls the floating-point amplification and processes the pre-sampling of transient electromagnetic signal. DSP will samples the signals again, processes the results and restores the original signal before transmitting the final results to the host computer and LCD for display purpose.

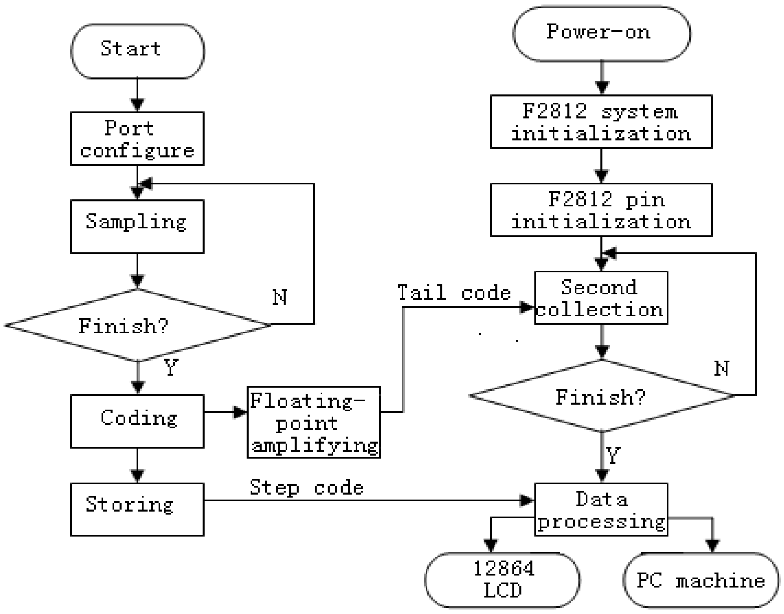

Figure 10. Software design flow chart

6.2. The Design of Data Collection Software

In order to get the characteristic curve of the secondary field as shown in Figure 2, the system also needs specialized data collection software to receive the data collected from the slave machine. The collection software should be able to readand save data, playback the data stored in the hard disk, display the data and collect the waveform simultaneously. The data collection software on the host computer is written in LabVIEW. LabVIEW is a program development environment developed by American National Instruments which uses the graphic visualization language, G-language, for programming. LabVIEW is widely used in the control of instrumentation, measurement, data processing and display areas**Error! Reference source not found.**. Figure 11 shows the interface of the data collection software.

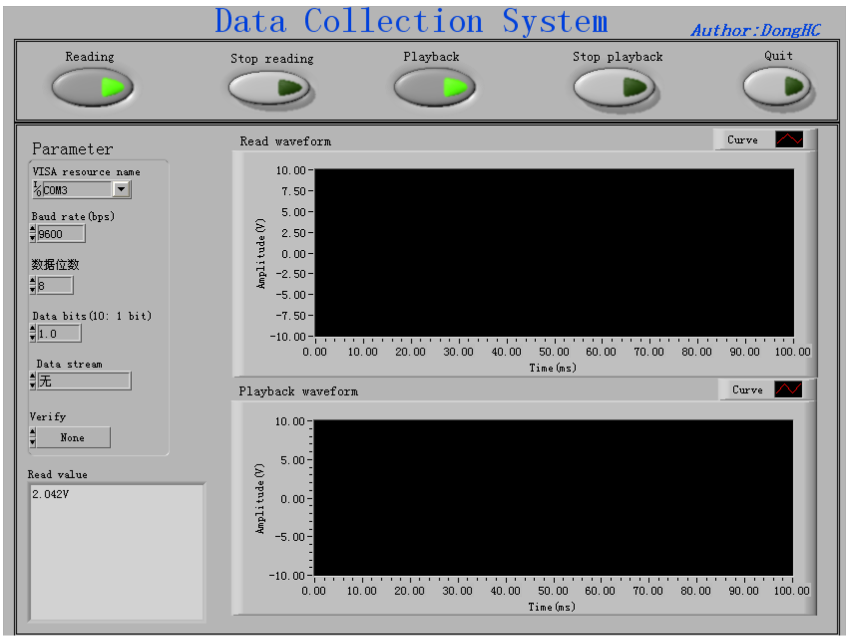

Figure 11. Interface of the data collection software

7. Test Results

Figure 12 shows the decay curve of the transient electromagnetic secondary field signal in system field testing. System uses a 25 Hz bipolar combination wave as the excitation source, a sampling frequency of 100 kHz will collect data of 500 points in 5 ms. As indicated by the acquisition curve, the induced electromotive force decays from the initial 500 mV to about 0 mV in the end. The data acquisition system collects the approximated decay curve of the secondary field signal, showing the attenuation of the secondary field information with time.

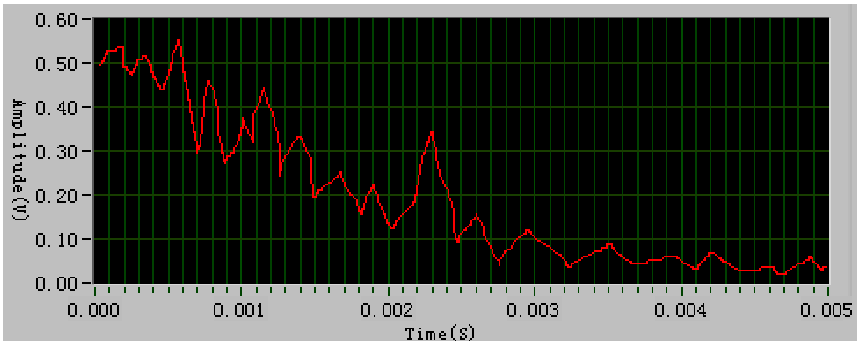

Figure 12. The attenuation curve of secondary field signal

8. Conclusion

In this paper, we made an in-depth study in the development of weak signal data acquisition system based on DSP, on the basis of the efforts made in the transient electromagnetic method by predecessors. The system increases the dynamic amplification range to 144 dB using floating point amplifier technology, and it has a sampling rate of 100 kHz, which meets the requirements for high sampling rate and precision. The field test proved that the system was able to capture the weak transient electromagnetic signal. The research work has some practical values and application prospect, and the system has been applied in the time-domain fixed-wing airborne electromagnetic mineral exploration.

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