Wireless monitoring system for a high-power borehole-ground electromagnetic transmitter

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Abstract. Visual interfaces and wireless monitoring have played significant roles in the application of electromagnetic transmitters. Thus, we have designed a wireless monitoring system that is based on the Visual Studio 2015 Windows form application by using C# language and multithreading technology. The system can effectively implement many functions, including time monitoring via a real-time clock, modification of the transmitting frequency, transmitting mode change, and storage and verification of the transmitter status data. These functions enable the system to support status monitoring and transmitter operation control. The results of several field tests confirm that the proposed wireless monitoring system provides a user-friendly interface, and convenient and stable operation. The system is able to satisfy the wireless monitoring and multifunctionality demands for transmitters implemented in land electromagnetic exploration, and act as a reference for scientific researchers pursuing instrument development and electromagnetic prospecting.

1 Introduction

Electromagnetic (EM) methods have been extensively developed and applied (Deng et al., 2003; Zhang et al., 2004; Jin et al., 2010; Geng, 2016). Controlled-source EM methods are essential to metal deposits, column collapse, and groundwater exploration. Moreover, there has been an increasing trend of deep earth exploration (Daniels and Dyck, 1984; Wei, 2002), which requires implementation of EM instruments able to achieve high resolution, large detection depth, and high reliability (Chen et al., 2017). Thus, because the performance of the transmitter is of particular importance for EM exploration, research institutes, instrument manufacturers, and academia have been working to enhance the transmitting power of EM transmitters.

China University of Geosciences (Beijing) developed a high-power, multifunctional borehole-ground EM transmitter. This transmitter is used to excite stable current waveforms for artificial source EM exploration (Liu et al., 2011; Wang et al., 2011). However, the prospecting process requires that the user be able to freely change the frequency of the transmitted waveforms. In addition, it is essential to monitor the status of the transmitter during EM exploration (Tang, 2015; Chen et al., 2016; Wang et al., 2017). Therefore, in order to satisfy the requirements of the transmitter designed and developed by China

University of Geosciences (Beijing), a wireless monitoring system that facilitates simple operation, and implements a user-friendly interface, has been developed.

2 Software design

The software is designed based on the Visual Studio 2015 Windows form application program by using the C# programming language. C#, which is based on .Net, is a new object-oriented programming language derived from the C++ and Java programming languages. It can be applied to develop interface applications relatively easily, thereby shortening the development cycle. The features of C# are listed in Table 1.

Table 1. Features of C#

Feature	Description
Simplicity	Less error-prone
Object-orientation	Supports encapsulation, inheritance, polymorphism and interfacing
Modernization	Advanced language features
Compatibility	Supports COM and Windows applications

The functional block of the wireless monitoring software is divided into four parts, as is shown in Fig. 1, and a screenshot of the basic interface is shown in Fig. 2.

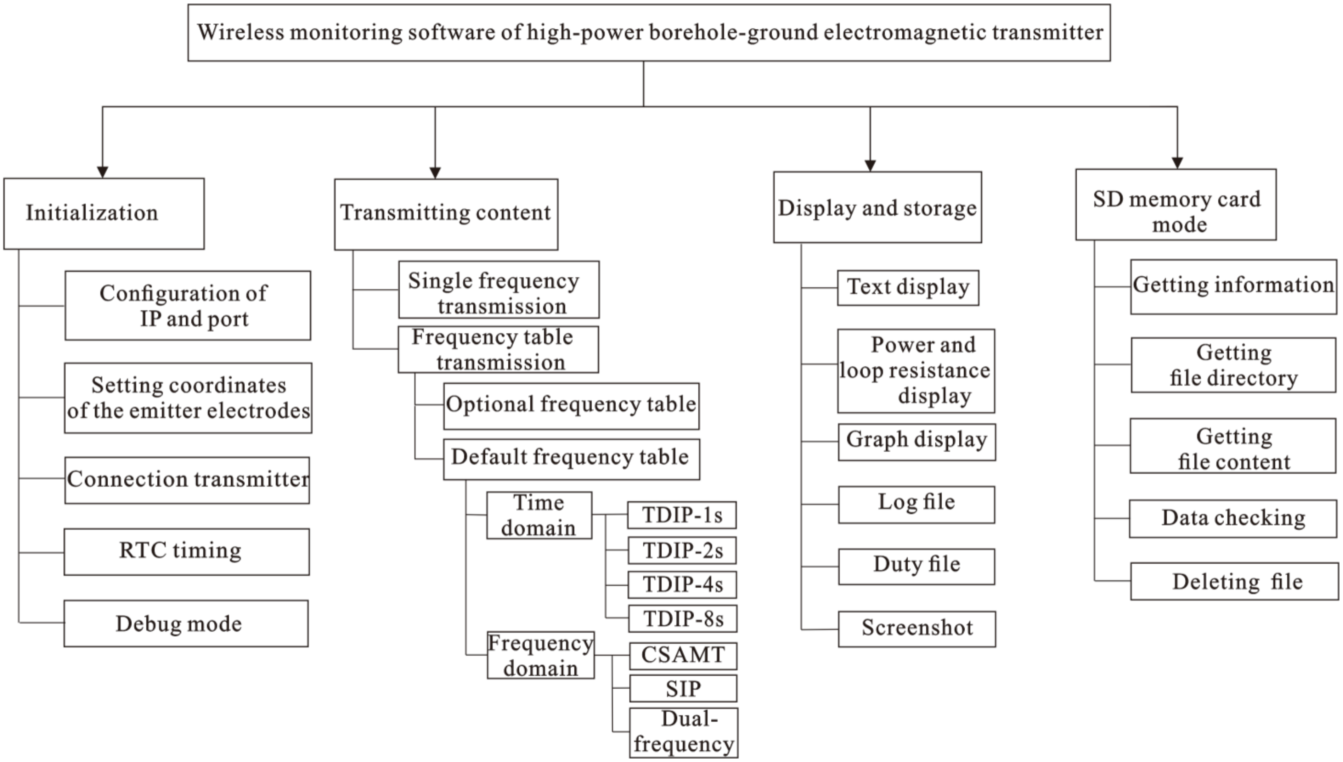

Figure 1: Functional block diagram

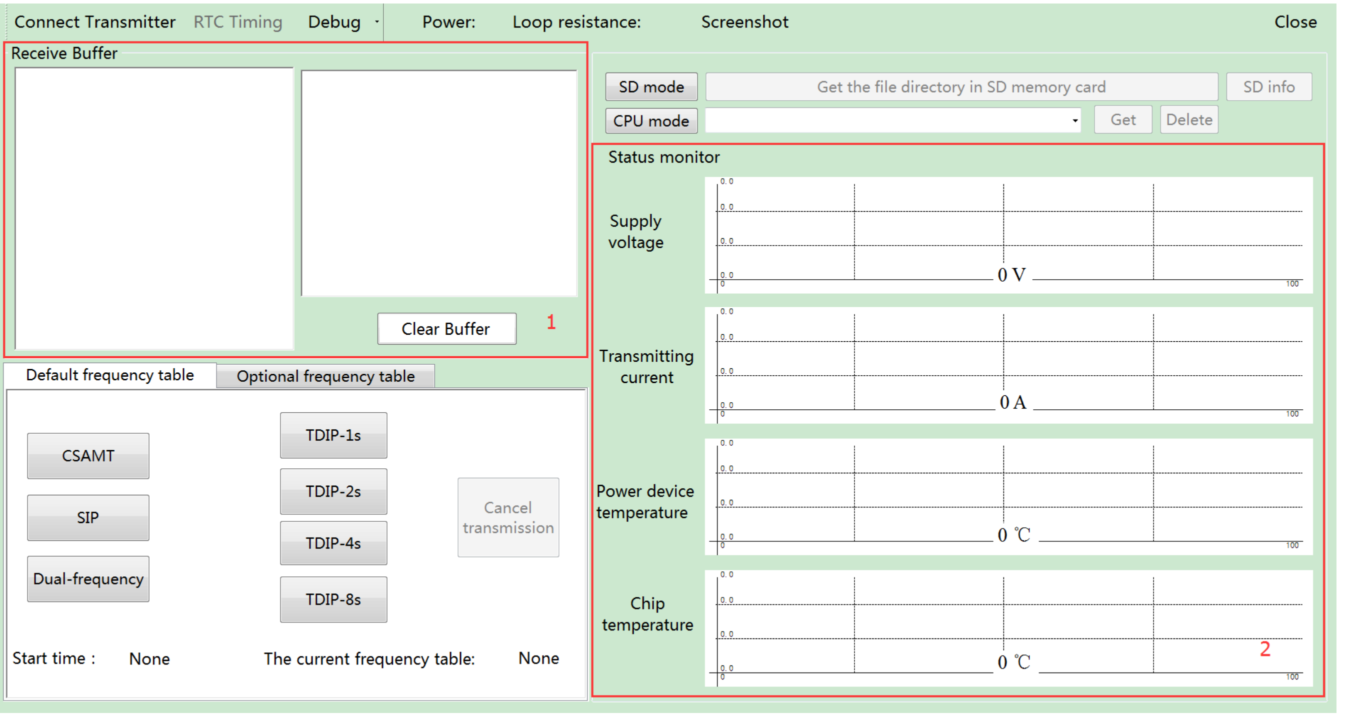

Figure 2: Software interface

3 Main function modules of the software

3.1 Initialization

As the software is designed for wireless communication, the Wi-Fi IP address and port number are first configured; then, the Global Positioning System (GPS) coordinates of the transmitting electrodes are set. In the design, these configurations are implemented by utilizing the Windows form application in Visual Studio 2015. Subsequently, the software is connected to, and communicates with, the transmitter via socket programming. After securing the connection, testing in debug mode is performed to ensure proper functioning of the transmitter; then, real-time clock (RTC) timing is initiated (Wang et al., 2011).

RTC timing refers to the ability of the clock to check its time against that of the GPS to ensure that they are in agreement; furthermore, if there is a discrepancy, then it will be corrected. It should be noted that the precision of the clock in the instrument relative to the GPS clock is in the order of microseconds; this scale satisfies the requirements of the instrument in terms of time accuracy (Zhang et al., 2004). In this design, a GPS-controlled pulse-per-second (PPS) signal is used as the synchronization reference signal to confirm clock agreement and initiate synchronization (Pierdavide et al., 2017). Moreover, because the rising edge of a PPS signal in GPS corresponds to a precise Coordinated Universal Time (UTC), the hardware is able to realize and maintain precise GPS timing.

3.2 Transmitting content

3.2.1 Single frequency transmission

The single frequency tab is located in the drop-down menu of the debug mode, which is primarily used in the test preparation phase. The single frequency list is shown in Fig. 3, and ranges from 0.01 Hz to 10 kHz. Note that the transmitter can not only transmit the listed frequencies, but also the frequency entered in the text box, as shown in Fig. 3.

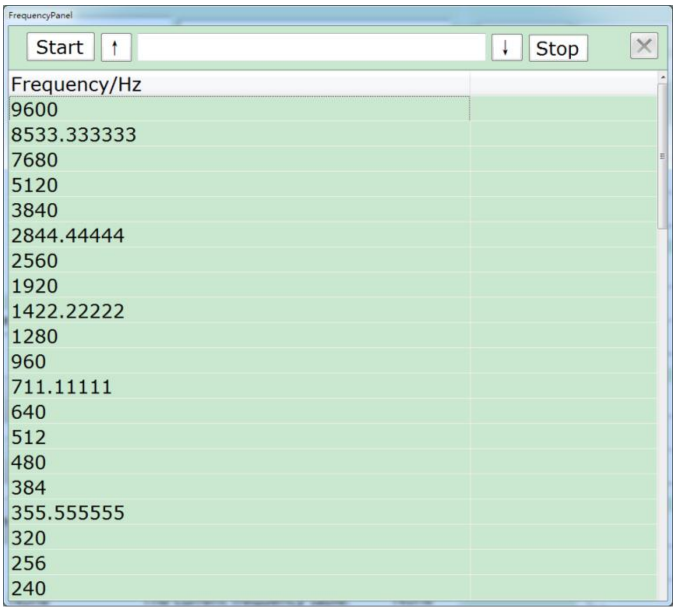

Figure 3: Signal frequency table

3.2.2 Frequency table transmission

Frequency table control implementation is divided between the default frequency table and the optional frequency table tabs, as shown in Fig. 4.

The default frequency table tab includes the frequency and time domains. The frequency domain enables controlled-source audio-frequency magnetotelluric (CSAMT) (Sandberg and Hohmann, 1982), spectrum-induced polarization (SIP) (Johnson, 1984), and dual-frequency (100 Hz and 400 Hz) implementation. The time domain enables time domain-induced polarization (TDIP) (Marshall and Madden, 1959), which includes TDIP-1s, TDIP-2s, TDIP-4s, and TDIP-8s. In addition, we provide the one touch trigger mode, which avoids the tedious setting of parameters and improves convenience, where the current waveform can be easily transmitted by clicking on one of the functions in the default frequency table tab shown on the left in Fig. 4.

Additionally, a function for preventing misoperation is included that is necessary to ensure stable operation of the transmitter. When a function button in the default frequency table tab is selected, the only other function button enabled is the cancel transmission function button shown on standby in Fig. 4. Thus, when a function button in the default frequency table is selected, the user is able to cancel cycle transmission as desired but can not operate other functional buttons, thereby acting as additional means to prevent spurious triggering.

The optional frequency table tab is shown on the right in Fig. 4. As shown in the Fig. 4, the users can select the appropriate frequency table and set the transmitting mode and suitable time. Because the software system uses UTC and our local time is eight hours ahead of UTC, if the start working time is before 8 a.m., the start workday is one day before the local time. Given the time difference, our design has addressed this problem by setting the start workday as shown on the right in Fig. 4. Therefore, it can be considered that the proposed software offers flexibility to users.

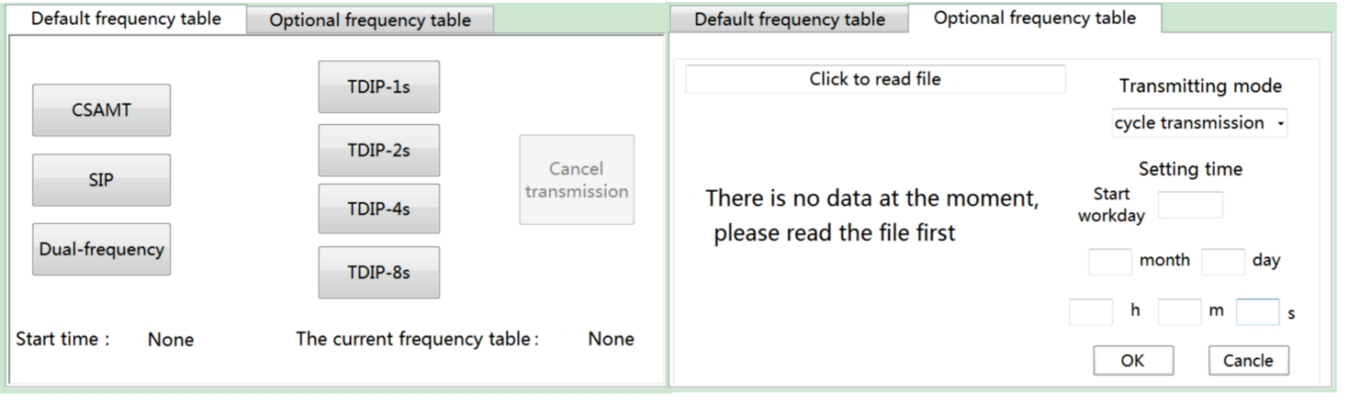

Figure 4: Frequency table interface

3.3 Display and storage

The software is designed with the ability to display data in real time, as illustrated by the displayed functions highlighted in red boxes (denoted by “1” and “2”) in Fig. 2. Box 1 highlights the receiving buffer function, which presents the data received via the wireless communication in the form of text. The receiving buffer displays the time and frequency information in the text box on the left, and the transmitter status information in the text box on the right; this information includes the corresponding values for power supply voltage, transmitting current, power device temperature, space temperature, chip temperature, and transmitting power. Box 2 displays the graphs for power supply voltage, transmitting current, power device temperature, and chip temperature. The purpose of these graphs is to allow the users to monitor the above mentioned output information so that they can identify any problems with the transmitter operation.

The proposed software also incorporates a data storage function. Two files, which are respectively referred to as the duty file and log file, are initiated in the background of the software after a successful connection between the software and transmitter is established. The two files record important information in real time in order to provide data for subsequent data processing. This function avoids the burden and errors of manual recording and provides convenience for researchers. In addition, the software is equipped with a screenshot function to record the instantaneous working state of the transmitter. The screenshots of the duty file and log file are shown in Figs. 5 and 6, respectively.

Information of Transmitter on June 17,2017

GPS of point A:4327.49743,N,11803.46769,E				GPS of point B:4327.50385,N,11804.27219,E		
Time	Frequency (Hz)	Supply voltage (V)	Power supply current (A)	Power device temperature (℃)	Space temperature (℃)	Chip temperature (℃)
1:10:37	7.5	957.3	54.6	35.1	22.5	33.5
1:10:38	7.5	957.8	54.5	35.1	22.5	33.2
1:10:39	7.5	957.3	54.8	35.1	22.5	33.4
1:10:40	7.5	957.6	54.5	35.1	22.6	33.4
1:10:41	7.5	957.6	54.5	35.1	22.6	33.4
1:10:42	7.5	958.1	54.6	35.1	22.6	33.5
1:10:43	7.5	958	54.7	35.1	22.6	33.3
1:10:44	7.5	957.8	54.8	35.1	22.6	33.4
1:10:45	7.5	956.8	54.4	35.1	22.7	33.5
1:10:46	7.5	957.6	54.4	35.1	22.5	33.5
1:10:48	7.5	958.3	54.2	35.1	22.6	33.5
1:10:49	7.5	957.1	54.2	35.1	22.5	33.5
1:10:51	7.5	957.8	54.1	35.1	22.6	33.4
1:10:52	7.5	957.8	53.8	35.1	22.6	33.5
1:10:53	7.5	957.6	54.1	35.1	22.6	32.3
1:10:55	7.5	958.1	54.9	35.1	22.7	33.6
1:10:56	7.5	958.1	54.2	35.1	22.7	33.5
1:10:58	7.5	957.8	54.5	35.1	22.6	33.3
1:10:59	7.5	958.1	54.5	35.1	22.6	33.6

Figure 5: Screenshot of the duty file

```
Record time: 2017-06-17 01:10:30,619
Thread ID:[1]
Log level:   INFO
Class: ATK_RM04_Client.NetworkDebuggingAssistant
Detailed information: Open

Record time: 2017-06-17 01:10:30,633
Thread ID:[1]
Log level:   INFO
Class: ATK_RM04_Client.NetworkDebuggingAssistant
Detailed information: Establish frequency table

Record time: 2017-06-17 01:10:33,000
Thread ID:[1]
Log level:   INFO
Clas: ATK_RM04_Client.NetworkDebuggingAssistant
Detailed information: Open the window of modifying connection parameter

Record time: 2017-06-17 01:10:33,797
Thread ID:[1]
Log level:   INFO
Clas: ATK_RM04_Client.Connect
Detailed information: Determine parameters and close the connection window

Record time: 2017-06-17 01:10:33,823
Thread ID:[1]
Log level:   INFO
Clas: ATK_RM04_Client.NetworkDebuggingAssistant
Detailed information: Connect successfully
```

Figure 6: Screenshot of the log file

3.4 SD memory card mode

The proposed software is also equipped with an SD memory card mode. As a part of the hardware, the SD memory card performs real-time storage of transmitter status information in a text file named by date and time. After the transmission is completed, the software retrieves all names of the files in the SD memory card by clicking the corresponding button, and we select the file we want. The hardware control unit will then send the file via wireless transmission technology, and finally, the software will receive and store the file on the computer. Because the data storage is updated every second, and the total operating time is typically several hours, the text file is relatively large. Thus, in order to avoid problems associated with data loss or format disorder in wireless transmission, a data check function is incorporated into the software. Each row of the stored data has a row number and a fixed format and length. An example of the output string is, N1_20170528090438#1.250000Hz$D:925.8,25.9,26.7,22.6,34.4,E, where N1 is the row number, 20170528090438 is the date-time, 1.250000Hz is the frequency, 925.8,25.9,26.7,22.6,34.4 are the transmitter status information, and the rest are the identifiers. In the transmission process, the system evaluates whether the format and length of each row of data is correct or not. If the format or length is incorrect, the software will send a re-transmission instruction to the transmitter, and the transmitter will subsequently transmit the corresponding correct data, thereby improving the accuracy of the wireless transmission.

4 Field testing

In order to verify the stability and reliability of the proposed wireless monitoring software, several indoor and field tests were carried out. In June 2017, a field experiment was conducted in the Inner Mongolia Autonomous Region in China by using the artificial-source transmitter developed by China University of Geosciences (Beijing).

4.1 Software interface for field testing

A screenshot of the software interface implemented for the field testing is presented in Fig. 7. It can be seen that the current frequency table transmitted was CSAMT, the current frequency was 1.875 Hz, the power was 52.0 kW, and the loop resistance was 17.8 Ω. The receiving buffer received the relevant frequency, time, and transmitter status information. The status monitoring field presented the graphs in real time based on the data received from the transmitter via wireless technology. The continuity of these graphs further confirms the effectiveness of the wireless transmission function.

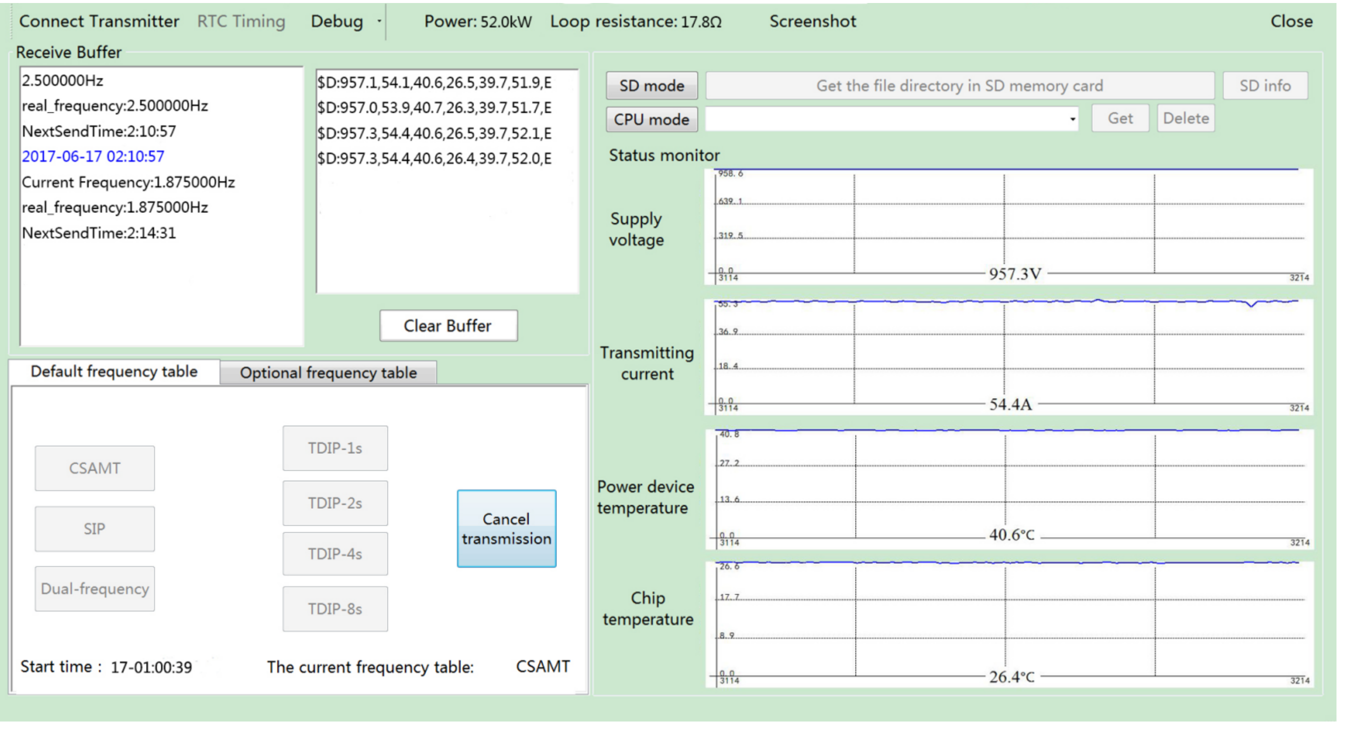

Figure 7: Field experiment monitoring interface

4.2 Data processing

The real-time data output graphs were derived based on the data of the duty file (Fig. 8). The graphs were plotted by a data playback applet, which is designed using MATLAB. The horizontal and vertical axes represent time and amplitude, respectively. It can be seen that the transmitter was in use for approximately 1 h and 40 min, the maximum transmitting voltage was 957.8 V, the maximum transmitting current was 54.6 A, and the transmitting power was calculated as approximately 52.3 kW. Additionally, the continuity of the plotted data indicates that the recorded data is relatively comprehensive, and therefore demonstrates the reliability of the wireless transmission of the software for a high-power borehole-ground transmitter.

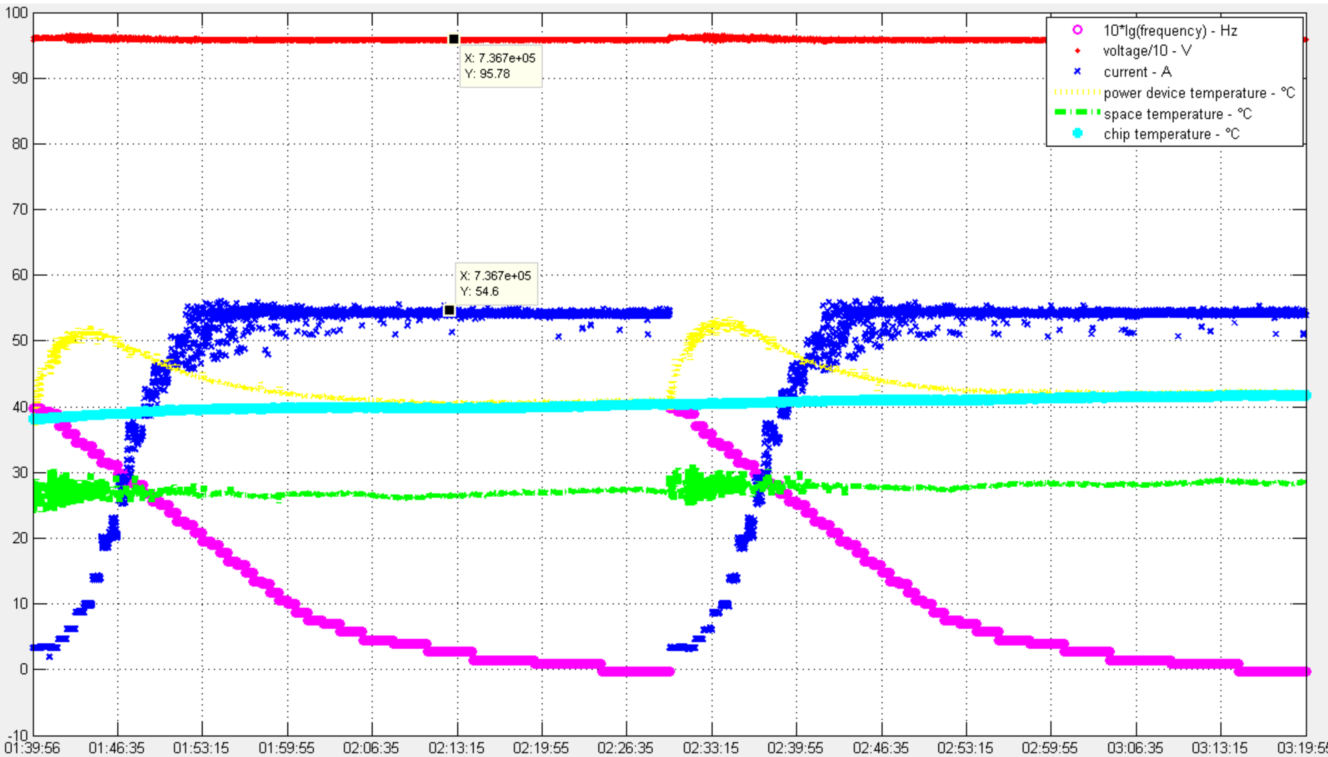

Figure 8: Graph of data playback

5 Conclusions

In this paper, a wireless monitoring system designed for high-power borehole-ground EM transmitters was presented to meet the demands for transmitters used in land EM exploration.

The results of several indoor and outdoor field tests indicate that the software is stable, easy to operate, and effectively monitors the operating status of an EM transmitter. The software offers two advantages, the first of which is high security. The software is able to perform the function of real-time monitoring of the EM transmitter via wireless technology, and eliminates the risk of the tester possibly being exposed to the transmitter during the testing process. The second advantage is simple operation. The software simplifies a series of configuration operations and enables transmitter control via clicking on a function in the software program. However, there exist problems of distance and universality. The software control system and the transmitter can not be too far apart owing to the limitation of the wireless transmission mode. The distance is up to 50 m in the field. Moreover, the software control system is designed for self-developed EM transmitters, and can not be used in other EM transmitters. The primary reason is that we could not determine the communication protocol of other transmitters. In summary, the system provides convenience and a reference for researchers engaged in instrument development and EM exploration.

Acknowledgments

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