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 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

10 storage and verification of the transmitter status data. What mentioned above make it possible for the wireless monitoring system to support status monitoring and transmitter operation control. The results of several field tests confirm that the proposed wireless monitoring system enables 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

15 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 electromagnetic 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;

20 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 electromagnetic 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

25 transmitter is used to excite stable current wave forms 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 wave forms. 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 requirement of the transmitter designed and developed by China University of Geosciences (Beijing), wireless monitoring system that facilitates simple operation, and implements a

30   user-friendly interface, has been developed.

2 System design

The system is designed as based on the Visual Studio 2015 Windows form application program by using C# programming language. C#, which is based on .Net, is an object-oriented new programming language derived from C++ and Java programming languages. It can be applied to relatively easily develop interface applications, thereby shortening the

35   development cycle. The features of C# are shown 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 system is divided into four parts, as is shown in Fig. 1, and a screenshot of the basic interface is shown in Fig. 2.
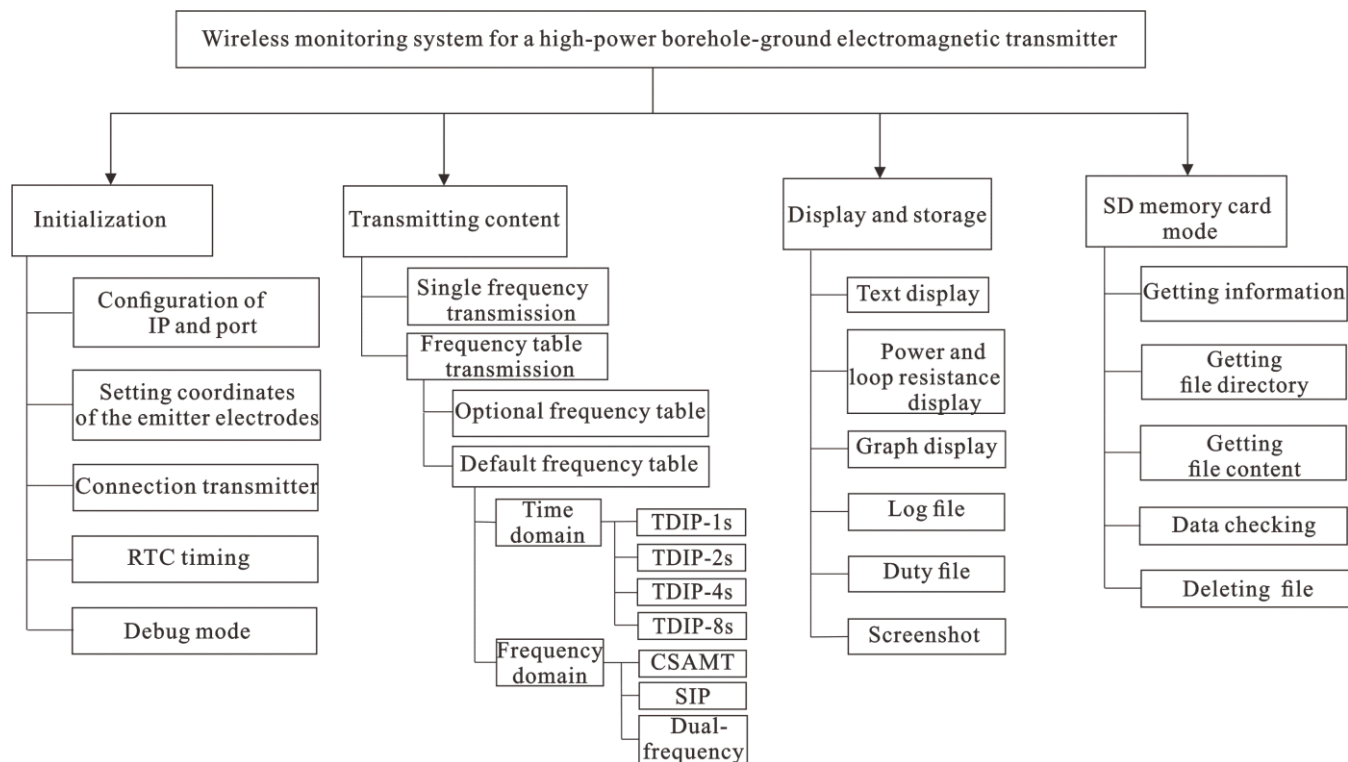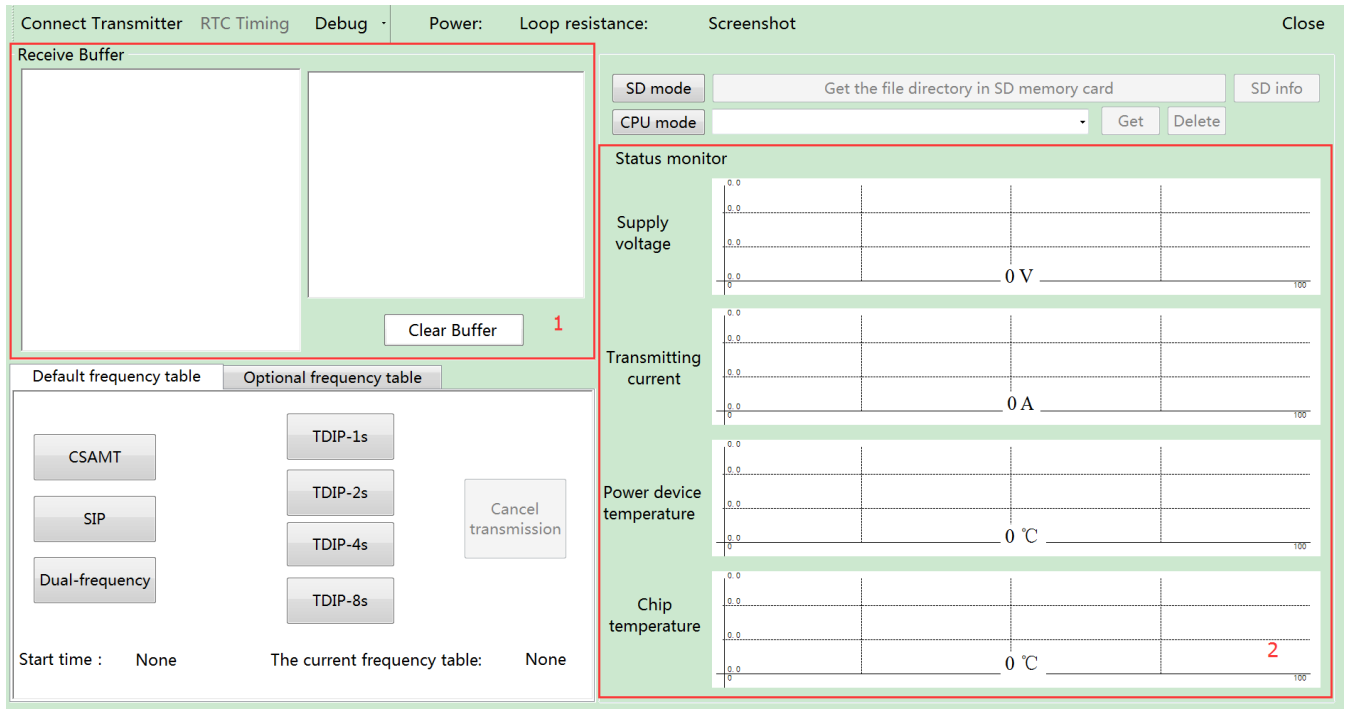
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Figure 1: Functional block diagram

Figure 2: System interface

3 Main function modules of the system

45   ### 3.1 Initialization

As the system is designed for wireless communication, 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 system is connected to, and communicates with, the transmitter via socket programming. After securing the connection, debug mode is performed to

50   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 on 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

55   synchronization reference signal to confirm clock agreement and initiate synchronization (Wang et al., 2009; 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

60   The single frequency tab is located in the drop-down menu of 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 frequency, but also the frequency entered in the text box shown in Fig. 3.

Figure 3: Signal frequency table

3.2.2 Frequency table transmission

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Frequency table control implementation is divided between the default frequency table and the optional frequency table tabs, as is 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,

70   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. The current desired waveform can be easily transmitted by clicking on one of the functions shown in the default frequency table tab

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shown on the left in Fig. 4.

Additionally, a function to prevent spurious triggering of the waveform is included that is necessary to ensure stable
75 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 can be seen, the users can select the appropriate
80 frequency table and set the transmitting mode and suitable timeframe. Therefore, it can be concluded that the proposed
system offers flexibility to users.
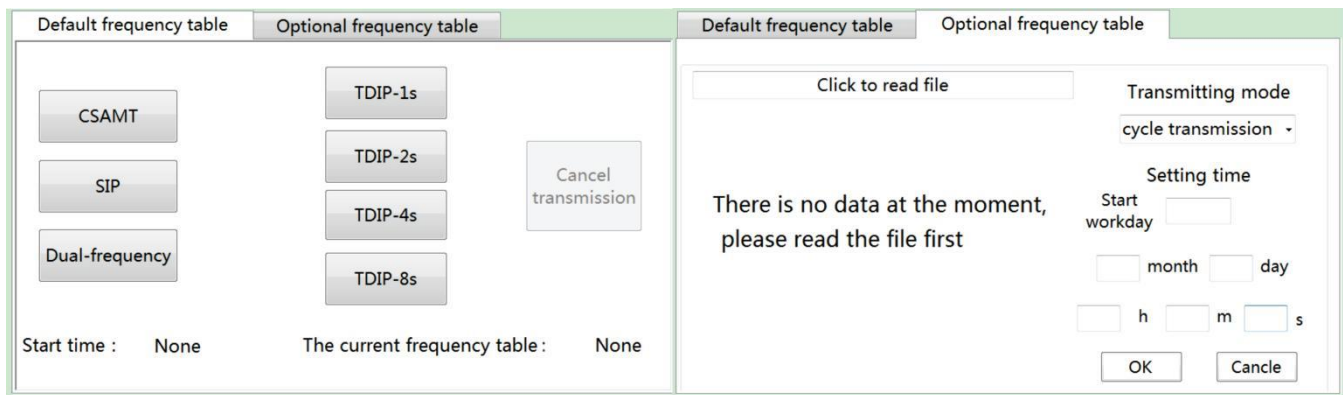
Figure 4: Frequency table interface

3.3 Display and storage

85 The system is designed with the ability to display data in real time, as is illustrated via 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
left white field, and the transmitter status information in the right white field; this information includes the corresponding
values for power supply voltage, transmitting current, power device temperature, space temperature, chip temperature, and
90 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
such that they can judge whether there are problems with transmitter operation.

The proposed system also incorporates a data storage function. Two files, which are respectively referred to as the duty file

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and log file, are initiated in the background of the system after a successful connection between the system and transmitter is

95   established. The two files record important information in real time in order to provide data for subsequent data processing. 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
```

100 **Figure 6: Screenshot of the log file**

3.4 SD memory card mode

The proposed system 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. The file stored in the SD memory card must be copied to the computer via wireless technology after completing the transmission. Because the data storage is updated every 105 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 formatting disorder in wireless transmission, a data check function is incorporated into the system. If there are errors, the system will send instructions to the transmitter, and the transmitter will subsequently send the corresponding correct data, thereby improving the accuracy of the wireless transmission.

4 Field testing

110 In order to verify the stability and reliability of the proposed wireless monitoring system, 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 System interface for field testing

A screenshot of the system interface implemented in the field testing is presented as Fig. 7. It can be seen that the current 115 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 as 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.
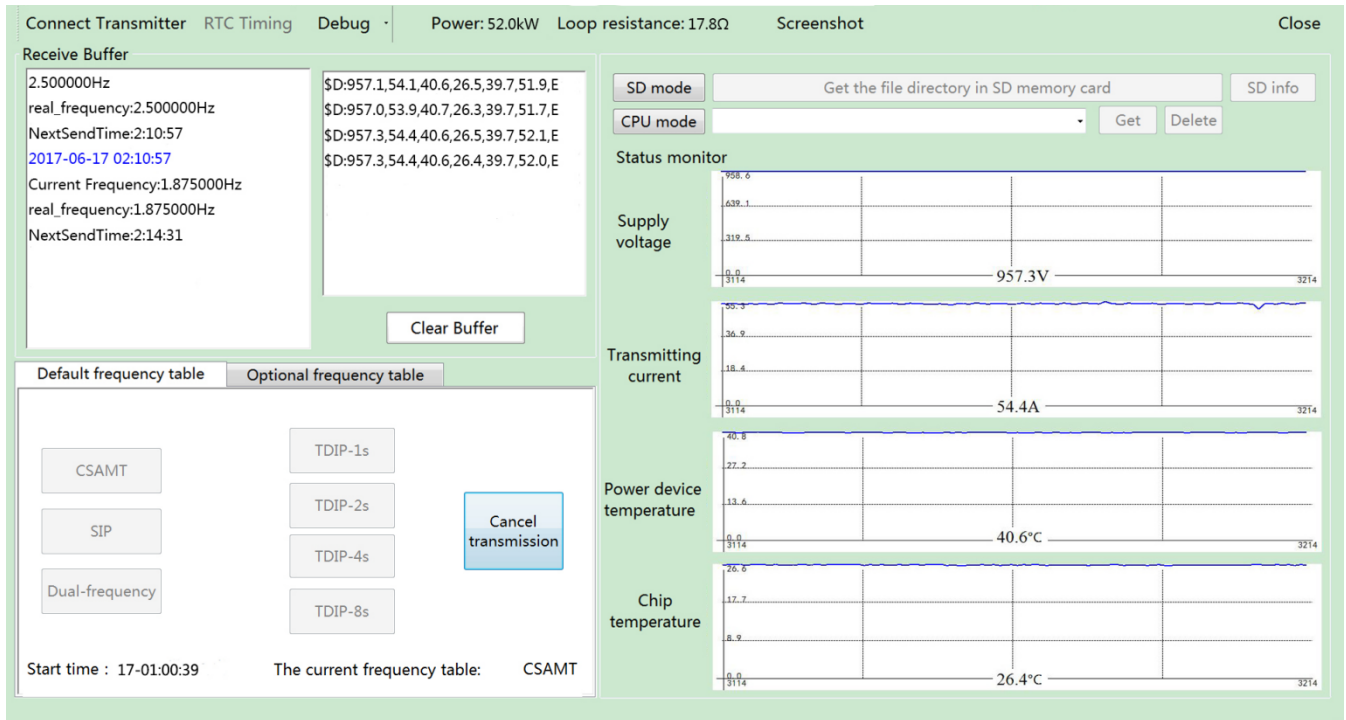
120 **Figure 7: Field experiment monitoring interface**

4.2 Data processing

The real-time data output graphs were derived as based on the data of the duty file (Fig. 8). The graphs were plotted by a data playback applet, which is designed based on MATLAB. The horizontal and vertical axes represent time and amplitude, respectively. It can be seen that the transmitter was in use for approximately 1 hour and 40 minutes, the maximum

125 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 system for a high-power borehole-ground transmitter.

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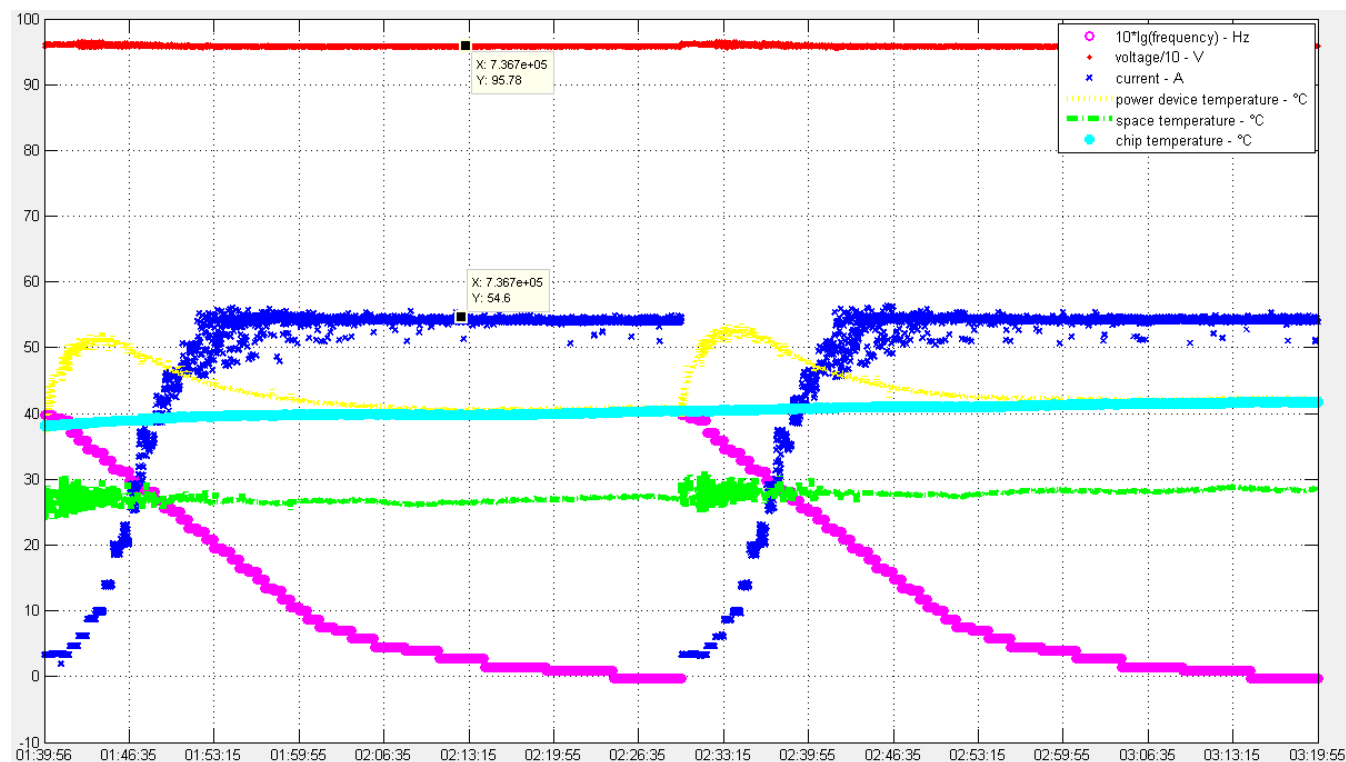
Figure 8: Graph of data playback

5 Conclusions

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

The results of several indoor and outdoor field tests indicate that the system is stable, easy to operate, and effectively monitors the operating status of an EM transmitter. The system offers two advantages, the first of which is high security. The system 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 test processing. The second advantage is simple operation. The system simplifies a series of configuration operations and enables transmitter control via clicking on a function button in the system interface. Finally, the wireless monitoring system affords convenience and can act as a reference for scientific researchers engaging in instrument development and electromagnetic prospecting.

145 **References**

Chen, G. Y., Deng, M, Jin, S., Wang, M., Wu, C. X. and Zong, F. Y.: Design of embeded human-machine interaction software of borehole-to-surface electromagnetic transmitter. Progress in Geophysics (in Chinese), 31(5):2319-2325, doi:10.6038/pg20160560, 2016.

Chen, K., Jin, S. and Deng, M.: Multifuncation waveform generator for EM receiver testing, Geosci. Instrum. Method. Data
150 Syst. Discuss., https://doi.org/10.5194/gi-2017-43, in review, 2017.

Chen, K., Deng, M., Wei, W. B., Jin, S. and Ye, G. F.: New progress in the design and development of AMT instruments. Geophysical and Geochemical Exploration, 37(1):78-81, 2013

Cheng, D. F., Wang, J., Li, X. P., Duan, Q. M. and Lin, J.: Development in the research of HSSMT instrument. Progress in Geophysics (in Chinese), 19(4):778-781, doi:10.39969/j.issn. 1004-2903. 2004.04.012, 2004.

155 Coïsson, P., Telali, K., Heumez, B., Lesur, V., Lalanne, X. and Xin, C. J.:Time-stamp correction of magnetic observatory data acquired during unavailability of time-synchronization services, Geosci. Instrum. Method. Data Syst., 6, 311-317, https://doi.org/10.5194/gi-6-311-2017, 2017.

Deng, M., Li, Z., Wei, W. B., Tan, H. D., Jin, S. and Deng, J. W.: Seafloor magnetotelluric synchronous acquisition technology with far reference measurement method. Geology and Prospecting, 39(5):77-80, 2003.

160 Geng, Q. L.: The latest multifunctional electromagnetic instrument and its development trend at home and abroad. Equipment for Geotechnical Engineering, 17(2):26-29, 2016.

Han, L.: Research and implementation of GPS time synchronization and data acquisition and processing system for SEP transmitter. Beijing: Beijing University of Technology, 2015.

Daniels, J. J. and Dyck, A. V.: Borehole resistivity and electromagnetic methods applied to mineral exploration,
165 Geoscience and Remote Sensing, IEEE Trans, 22(1):80-87, 1984.

Jin, S., Zhang, L. T., and Wei, W. B.: Magnetotelluric method for deep detection of Chinese continent. Acta Geologica Sinica, 84(6):808-817, 2010.

Johnson, I. M.: Spectral induced polarization parameters as determined through time-domain measurements, Geophysics, 49,
170   1984.

Liu, L. X., Liang, Z. S., Liang, H. Q., Yin, H. D. and Liu, Y.: A study on current stabilization technology of transmitter for controlled-source frequency electromagnetic sounding, in the Tenth International Conference on Electronic Measurement & Instruments (ICEMI), Chengdu, China, 16-19 Aug. 2011, 357-360, 2011.

Marshall, D. J. and Madden, T. R.: Induced polarization, a study of its causes, Geophysics, 24, 790, 1959.

175   Sandberg, S. K. and Hohmann, G. W.: Controlled-source audiomagnetotellurics in geothermal exploration, Geophysics, 47, 100-116, 1982.

Tang, J. T., Ren, Z. Y. and Zhou, C.: Frequency-domain electromagnetic methods for exploration of the shallow subsurface: A review. Chinese J. Geophys. (in Chinese), 58(8):2681-2705, doi:10.6038/cig20150807, 2015.

Wang, M., Deng, M., Jin, S. and Wu, K.: High-power Pit(Well)-Ground electromagnetic automatic sweep frequency
180   transmitter used for exploration of metal mine, in: 2011 Third International Conference on Measuring Technology and Mechatronics Automation, Shanghai, China, 6-7 Jan. 2011, 332-335, 2011.

Wang, M., Deng, M., Jin, S. and Wu, K.: The borehole-ground controlled source electromagnetic signal transmitter, in: 2011 International Conference on Electric Information and Control Engineering, Wuhan, China, 15-17 April 2011, 1782-1785, 2011.

185   Wang, M., Jin, S., Deng, M. Wei, W. B. and Chen, K.: Multi-function electromagnetic transmitting system for mineral exploration, IEEE Transactions on Power Electronics, IEEE Early Access Articles, 2017.

Wei, W. B.: New advance and prospect of magnetotelluric sounding (MT) in China. Progress in Geophysics (in Chinese), 17(2):245-254, doi:10.3969/j.issn. 1004-2903. 2002.02.009, 2002.

Zhang, Q. S., Deng, M., Luo, F., Qiao, D. X. and Chen, K.: Circuit drivers of signal-acquiring unit in seafloor
190   magnetotelluric system. Progress in Geophysics (in Chinese), 31(4):1845-1851, doi:10.3969/j.issn. 1004-2903. 2004.04.015, 2004.