Magnetotelluric system NORD

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SUMMARY

This work presents the testing results of a new magnetotelluric system NORD. The key features of the system are: wireless operation with options of real-time data processing and quality assessment, measuring complex impedance of electric lines, low self-noise, low power consumption, light weight, compactness, reliability, robust data processing algorithms. The receiver has a built-in calibration system as well as telemetry that allows to monitor the status of the device and identify common problems. At the moment, the NORD allows to obtain high-quality MT data in the range from 50 000 seconds up to 20 000 Hz. We carried out a large number of field tests and comparisons with equipment from leading manufacturers, which showed excellent performance of the system. Also in recent years, a few large-scale production works have been carried out using this system.

Keywords: instrumentation, self-noise, testing, data processing

INTRODUCTION

The use of high-quality modern equipment is one of the important components of the successful implementation of magnetotelluric (MT) work. A number of review papers and textbooks discuss land MT instrumentation (Kaufman and Keller 1981; Simpson and Bahr 2005; Ferguson et al. 2012). Other reviews are focused on magnetic (Poliakov et al. 2017) and electric (e.g. Perrier et al. 1997; Lu et al. 1998) field sensors.

At present, a number of requirements are imposed on magnetotelluric systems. The system should have low level of self-noise, wide frequency range, the receiver input impedance should be sufficiently high to minimize the distortions of electric signal associated with poor grounding conditions. The equipment should be reliable, robust and able to operate in various climatic conditions; it also should be as simple as possible to use. We focused on these requirements when developing the station.

The NORD magnetotelluric system consists of 3 main parts: 1) 5-channel receiver 2) magnetic and electric field sensors 3) software for communication with the station and for data processing. This work describes the distinctive features of the NORD system and presents the results of testing.

MAIN FEATURES OF THE SYSTEM

The NORD system has a number of features that distinguish it from other magnetotelluric systems.

An innovative feature of the NORD receiver is that it has the ability to measure the overall complex impedance of the grounded dipoles, which include the capacitive effects in the wires. This allows taking less biased electric field measurements in the regions with poor grounding conditions.

The station has the ability to process data in real-time without stopping the record. It is also possible to view telemetry, time series, spectra and coherences in real-time, which allows you to quickly estimate the quality of the data.

All interaction with the station is carried out via Wi-Fi, which increases the reliability of the device in the field. Operation of the system is carried out by any Android / iOS / Windows / Linux – based device with a Wi-Fi module and an Internet browser.

The small dimensions and weight of the receiver make it possible to adapt it for marine measurements (Epishkin et al, 2018).

For advanced processing (Epishkin 2016) of raw time series acquired by NORD system one should use EPI-KIT — a modern and universal software solution for processing of MT and CSEM data. This software can process data received by equipment from a number of manufacturers, which allows you to combine different types of equipment in one project.

Receiver

The first component of the NORD system is a modern digital receiving unit (Figure 1), specially designed to register the EM field signals in wide frequency range. The receiver has 2 electric and 3 magnetic channels, each one equipped with a separate 32-bit ADC with a base sampling rate of 2400 Hz and 24-bit ADC with a base sampling rate of 312.5 kHz for radio-magnetotellurics (RMT) or audio-magnetotellurics (AMT). It is possible to save the time series simultaneously at 5 sampling rates: 15 Hz, 150 Hz, 2400 Hz, 78.125 kHz, 312.5 kHz. The sampling rate schedule is easily configurable, and allows to control the final size of raw data files. High accuracy of the acquired MT or CSEM data is ensured by low internal noise level (~ 3.5 nV/√Hz for AMT frequency range) and modern ADCs of NORD receiver, combined with using robust data processing algorithm implemented in the EPI-KIT software. The main characteristics of the receiver are given in Table 1.

Figure 1. Receiver NORD

Parameter	**Value**
Number of channels	2 electric + 3 magnetic
Frequency range	DC – 35 kHz
ADC per channel	32 bit + 24 bit
Sampling frequencies	312.5 kHz, 78.125 kHz, 2.4 kHz, 150 Hz, 15 Hz
Input resistance	10 MΩ
Input capacitance	< 0.5 nF
Max. input voltage	E channels: ± 600 mV H channels: ± 2500 mV
Self-noise level	~ 3.5 nV/√Hz
Data interface	Wi-Fi 802.11n
Time synchronization	± 30 ns (RMS)
Integral solid-state drive	32 GB Industrial Grade (optionally up to 256 GB)
Power consumption	6 – 8.5 W
Power supply voltage	12 V
Weight	1.8 kg
Dimensions	20x10x13 cm
Temperature range	-40 … +85 °C

Table 1. Technical characteristics of the NORD receiver

Electric field sensors

Electric field measurement in the NORD system is performed with NW-4 sensors, which is a special type of compact, environmentally sound and relatively inexpensive non-polarizable graphite electrodes with low self-noise level.

Magnetic field sensors

NORD system set includes induction coils of the IMS series – low-noise magnetic field sensors with smooth and stable frequency characteristics. There are three types of sensors: IMS-5 – high-frequency sensors for AMT (0.1 Hz – 20 kHz), IMS-10 – classic MT band sensors (0.00002 Hz – 1000 Hz), IMS-15 – broadband sensors which allows obtaining a single AMT+MT (BBMT) curve without changing different types of sensors (0.00002 Hz – 10 kHz). The main characteristics of the IMS sensors are shown in Table 2. The amplitude-frequency characteristics of the sensors are given in Figure 3.

Parameter	**IMS-5**	**IMS-10**	**IMS-15**
Methods	AMT, CSEM	MT, CSEM	AMT+MT, CSEM
Operation frequency range, Hz	0.1 – 20000	0.00002 - 1000	0.00002 - 10000
Power consumption, W	0.96	1.2	1.7
Dimensions: length, cm	55	105	105
Dimensions: diameter, cm	6	7.6	6
Weight, kg	3	7	5.5

Table 2. Technical characteristics of the induction magnetic sensors (IMS series) used in the NORD system

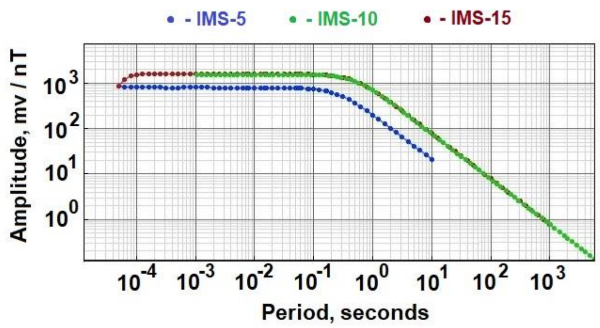

Figure 3. Magnetic sensors IMS-5, IMS-10, IMS-15 amplitude-frequency characteristics

TESTING RESULTS

Receiver self-noise

The measured internal noise level of the receiver is shown in Figure 2 in orange.

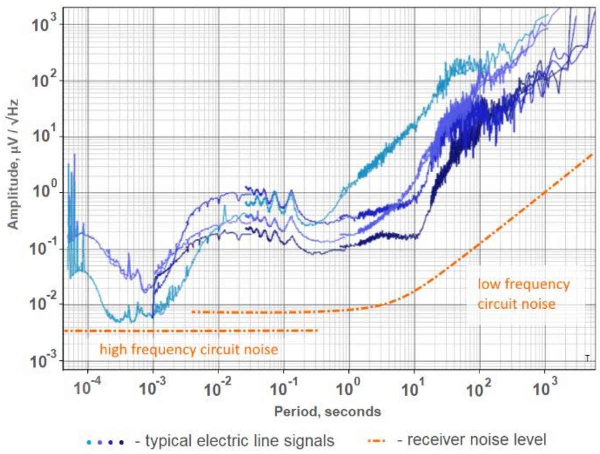

Figure 2. Self-noise of NORD receiver compared to typical electric line signals. There are different noise floors for high- and low-frequency receiving circuits.

Magnetic sensors self-noise testing

For all types of inductive magnetic sensors, we carried out numerous parallel tests, on the basis of which the self-noise of each sensor was calculated. Also, for some sensors self-noise measurements were carried out in a shielded camera. The noise levels obtained by both methods agree with each other. Tests have shown that the sensors have a stable and predictable noise level. Figure 4 shows results of self-noise measurements for different types of IMS sensors.

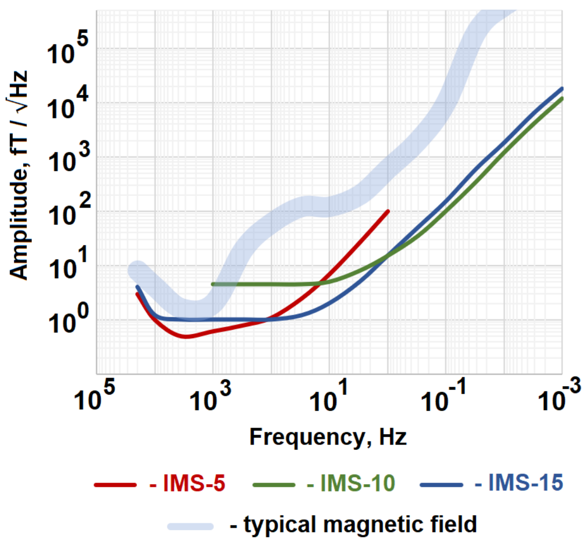

Figure 4. Self-noise of IMS sensors compared to a typical magnetic field

Synchronization testing

One of the important requirements for MT units is accurate time synchronization. To check the NORD receivers' synchronization accuracy we developed a special test. The same sinusoidal signal with a frequency f of several hundred Hz was applied simultaneously to several receivers, and for each moment of time the phase difference in degrees ($\Delta\varphi$) between the registered signals at the given frequency was calculated. Next, according to Equation 1, the time shift (Δt) was calculated:

$$\Delta t = \frac{\Delta\varphi}{360}\frac{1}{f} \quad (1)$$

Figure 5 shows an example of a two-hour observation of timing accuracy between two NORD receivers. During the entire observation period, the synchronization accuracy between instruments was better than 60 ns, which is sufficient for synchronous processing of time series at frequencies up to 100 kHz.

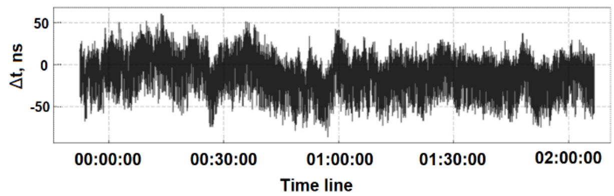

Figure 5. Time shifts (Δt) between signals from two NORD stations synchronized by GPS

Field testing

NORD system is being actively tested for several years, and dozens of pilot instruments have been already used in commercial MT and CSEM projects in Ural Mountains, Taymyr Peninsula, Siberia and Kazakhstan. To date, thousands of measurements have been carried out using the NORD system in various climatic conditions.

As a demonstration of the system's capabilities, Figures 6 and 7 show 2 measurement results.

The first result was obtained in Kamchatka (eastern part of Russia). The measurements were carried out in the MT mode. For 3 days of measurements, it was possible to obtain high-quality curves in the range from 0.001 seconds to 30 000 seconds.

The second result was obtained in the central part of the East European Plain. In this example, the recording was carried out in the BBMT mode. With 12 hours of data, high-quality results were obtained in the range from 0.0001 seconds to 1000 seconds.

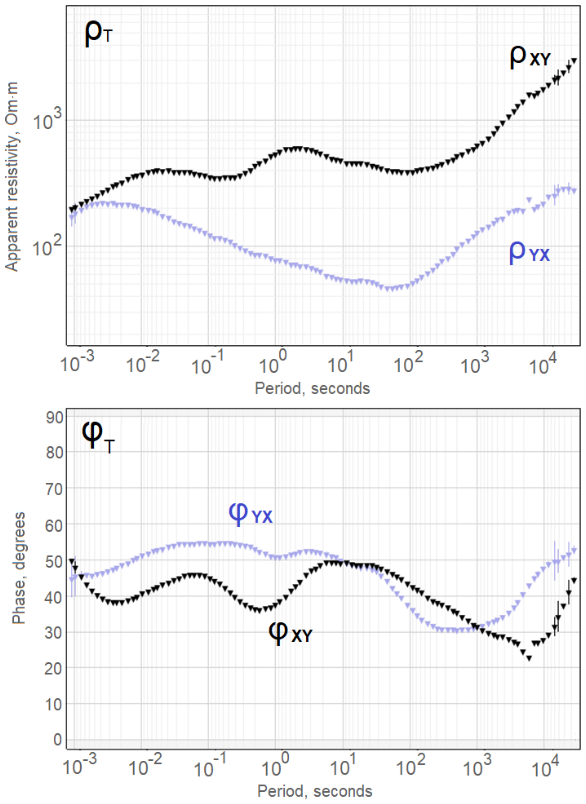

Figure 6. Processing result of 3-day record at Kamchatka region (East of Russia) with the IMS-10 magnetic coils in the MT frequency range

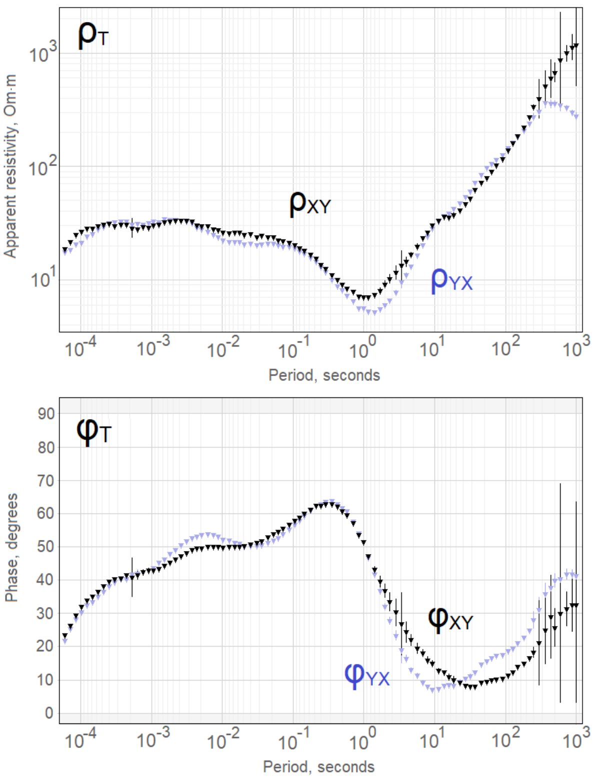

Figure 7. Processing result of 12-hours record at the East European Plain (Russia) with the IMS-15 magnetic coils in the BBMT frequency range

CONCLUSIONS

The conducted tests have shown that the receiver and field sensors work at a high level and meet the most modern requirements for accuracy and reliability. The new solutions applied in the Nord complex (measurement and accounting of the complex resistance of electrical lines, processing and quality control in real time, control through any device with a browser) improve the quality of the received MT and CSEM data and increase work productivity.

REFERENCES

Epishkin DV (2016) Improving magnetotelluric data-processing methods. Moscow Univ. Geol. Bul. 71(5):347–354.

Epishkin D, Palshin N, Yakovlev A, Yakovlev D (2018) Technology of marine magnetotelluric sounding in transition zone. In: Paper presented at the 24th EM Induction Workshop, Helsingor, Denmark, 13-20 August 2018. https://doi.org/10.13140/rg.2.2.33684.60808

Ferguson IJ, Chave AD, Jones AG, Mackie R, Rodi W (2012) Instrumentation and field procedures. In: Magnetotelluric method. Cambridge University Press, pp 421–479

Kaufman AA, Keller G (1981) The magnetotelluric Sounding Method. Elsevier, Amsterdam

Lu K, Macnae J (1998) The international campaign on intercomparison between electrodes for geoelectrical measurements. Explor. Geoph. 29: 484-488.

Perrier FE et al. (1997) A 1-year systematic study of electrodes for long period measurements of the electric field in geophysical environments. J. Geomagn. Geoelectr. 49: 1677-1696

Poliakov SV, Reznikov BI, Shchennikov AV, Kopytenko EA & Samsonov BV (2017) The range of induction-coil magnetic field sensors for geophysical explorations. Seismic Instruments 53: 1-18

Simpson F & Bahr K (2005) Practical Magnetotellurics. Cambridge University Press, Cambridge