Controlled source radiomagnetotellurics: a tool for near surface investigations in remote regions

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SUMMARY

Features of the controlled source radiomagnetotelluric sounding method (CSRMT) and developed equipment RMT-C are considered. A horizontal electric dipole is used as a source in the RMT-C system. Specific features (wave effects) of EM field of high frequency electric dipole with account of displacement currents in the air are analyzed. The CSRMT method is intended for near surface investigations in remote regions where there is a possibility to measure VLF radio transmitter's signals only and to realize profiling surveys using standard RMT instruments. The application of the CSRMT method with the RMT-C system permits us to fulfill soundings in wide frequency range 1-1000 kHz, thus an important for near surface investigations gap between such EM sounding methods as TEM and GPR is filled. By using ungrounded (capacitive) receiving electric lines the measurements in different grounding conditions in summer time (on asphalt, concrete, gravel) and in winter time (on frozen soils, snow and ice) are realized. An example of the CSRMT method application in remote regions is presented.

Keywords. Radiomagnetotelluric sounding. Controlled source. Horizontal electric dipole.

INTRODUCTION

The radiomagnetotelluric (RMT) sounding method based on measurements of radio transmitters electromagnetic fields in frequency range from 10 up to 250-1000 kHz provides geological sections study in the depths interval from 1-2 to 30-50 m. Last years a quite big experience the RMT method application at the solution of near surface geophysical tasks has been obtained (Tezkan 2008).

An advantage of the RMT method is the possibility of primary field approximation by a plane wave. For this model methods and software tools for data interpretation ensuring reliable soundings results have been developed.

At works in remote regions there is a possibility to measure signals of VLF radio transmitters only. It allows us to carry out profiling surveys that reduces an informative value of the method. The controlled source radiomagnetotelluric (CSRMT) sounding method is developed for such conditions.

Features of the CSRMT method, developed equipment and an example of application are considered in this paper.

CSRMT METHOD

The application of RMT method is the most effective in populated areas, where there is a possibility to measure signals of radio transmitter's signals in wide frequency range from 10 up to 1000 kHz. Usually signals of 20-30 radio transmitters are confidently measured, that allows receiving sounding curves suitable for inversion and geoelectric sections deriving.

An example of auto spectra of horizontal components of electric and magnetic fields for frequency ranges 10-100 kHz and 100-1000 kHz measured in Denmark is shown in Figure 1. Data quality is controlled on values of mutual coherence between orthogonal components of electric and magnetic fields. At the coherence level higher than 0.8 the data quality is considered as suitable for soundings. In Figure 1 the coherence level exceeds a threshold level on 33 frequencies.

An example of the registration of radio transmitter signals in a remote area (Yakutia) is shown in Figure 2. For this example the coherence exceeds the threshold level 0.8 in frequency range 20-25 kHz (VLF radio transmitters) and on frequency 50 kHz (radio transmitter of exact time, Irkutsk).

Signals of three radio transmitters are registered in frequency range 100-1000 kHz however these measurements are not reliable. It is not enough for realization soundings, and works in these conditions can be carried out only in the profiling variant on one of the VLF frequencies or 50 kHz. For realization of RMT soundings in such conditions the use of a controlled source working in wide frequency range up to 1 MHz is necessary.

The first works on development of the controlled source RMT equipment Enviro-MT have been fulfilled at the University of Uppsala (Sweden) (Bastani 2001). Thus the basic purpose was to increase depths of the geological sections study up to 100-150 м using the decreasing of lowest limit of frequency range from 10 up to 1 kHz.

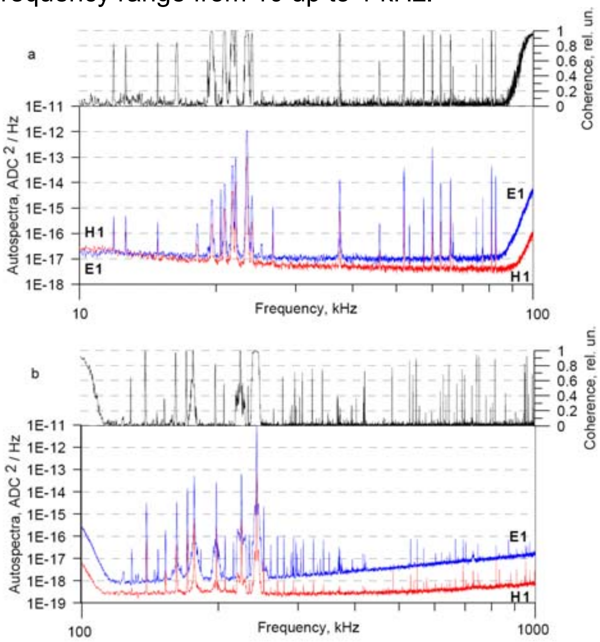

Figure 1. Auto spectra of electric and magnetic field signals of radio transmitters in frequency ranges 10-100 kHz (a) and 100-1000 kHz (b) from data of measurements in Denmark.

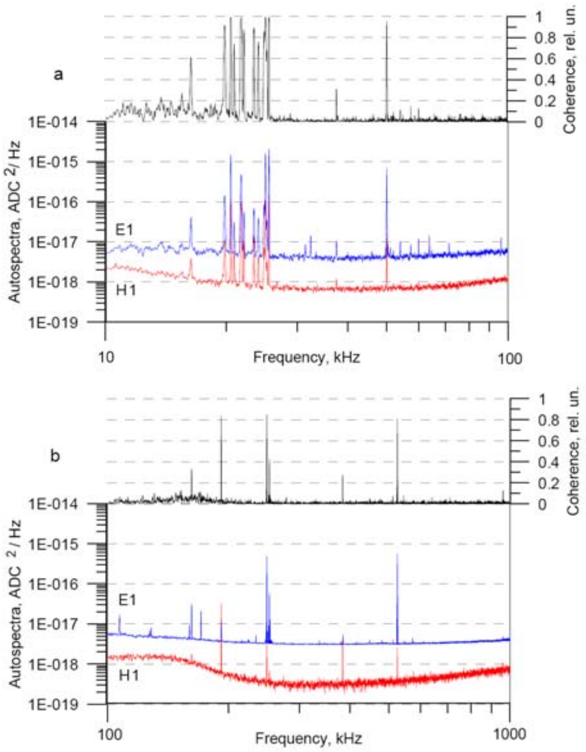

Figure 2. Auto spectra of electric and magnetic field signals of radio transmitters in frequency ranges 10-100 kHz (a) and 100-1000 kHz (b) from data of measurements in Yakutia.

As sources of EM field in the equipment Enviro-MT two mutually orthogonal vertical loops (horizontal magnetic dipoles) are used. Sources of such type have some advantages - compactness and possibility of tensor measurements realization. However, limited range of working frequencies 1-12 kHz and small long range action, no more 600-800 m, limits prospect of their application.

The use of a horizontal electrical dipole (finite length cable) as a source in the CSRMT method has better prospects. The first works on testing of such variant have shown a possibility of measurements realization on great, up to 3-4 km, distance from a source (Simakov et al 2010).

EQUIPMENT RMT-C AND MEASUREMENTS TECHNIQUE

Developed RMT-C system includes a recorder, receiving electric lines and magnetic sensors, a transmitter with an electric dipole as a source and data processing and interpretation software tools.

As a receiver in the RMT-C system is used the four-channel recorder RMT-4, created in 2002-2006 within the framework of the fp5 EU project of "Copernicus" by the St. Petersburg State University, MicroKor Ltd (Russia) and the University of. Cologne (Germany) (Tezkan Saraev 2008) or five-channel recorder RMT-5, created at the modernization of the equipment in 2012.

The recorder RMT-5 has five channels of synchronous measurements with 16 digits ADC in each channel (two electric and three magnetic channels). Frequency range of the recorder is 1-1000 kHz, volume of the built-in memory is 8 Gb (enough for 200-300 soundings). The measured data are transferred to an external computer on the Ethernet channel. The registration of time series of signals of magnetic and electric fields with data storage in the built-in memory is fulfilled. The recorder has four frequency sub ranges: D1: 1-10 kHz, (sampling frequency of input signals 39 kHz), D2: 10-100 kHz (312 kHz), D3: 10-300 kHz (832 kHz) and D4: 100-1000 kHz, (2 496 kHz).

Measurements of electric field are carried out with grounded or ungrounded (capacitive) receiving lines, that enables of works performance in summer time in adverse conditions for grounding of electric lines (asphalt, concrete, gravel) and winter time on the surface of snow or ice.

Transmitter GTS-1 is intended for the creation of two-polar signals of the rectangular form in frequency range 0.1 Hz - 1 MHz with adjustable pulse ratio on a loading with the resistance 10 - 1000 ohm. A feed voltage and frequency are 220 V and 50 Hz. Output voltage - up to 300 V, output current - 100 mA - 7.5 A, output power on a loading 100 ohm - up to 1 kW (Saraev et al 2011). At realization of works by the RMT-C method as a source is used a horizontal electric dipole (grounded at the ends a cable of 400 to 1000 m length).

The works by the RMT-C method are carried out in frequency range 1-1000 kHz. The measurements rate are significantly raised using measurements of basic signals and their odd sub harmonics. As it is seen from Figure 3, for the basic signal frequency 1 kHz in spectra of electric and magnetic fields signals 9 odd sub harmonics with the coherence level above 0.8 are visible. As the result for the overlapping of the full frequency range 1-1000 kHz the signals of 3 basic frequencies and their sub harmonics are used. Time of measurements at one sounding station does not exceed 2-3 min. The measurements rate makes about 70-80 sounding stations per day (10 times faster, than at works by the VES method with similar depth of investigations).

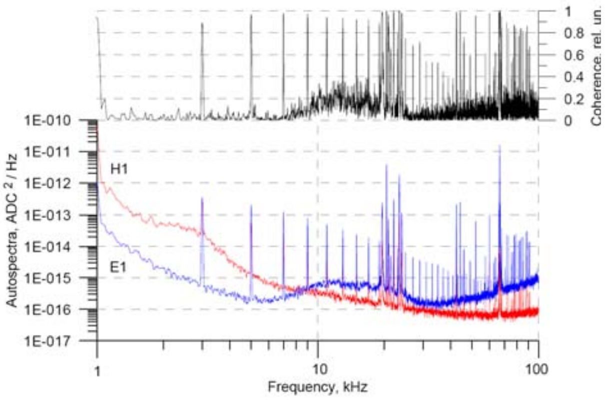

Figure 3. Auto spectra of electric and magnetic field signals of a controlled source and radio transmitters in frequency range 1-100 kHz.

Curves of apparent resistivity and impedance phase on data of measurements of a controlled source and remote radio transmitter's signals are shown in Figure 4. Curves well coincide, that confirms a possibility of the use of sub harmonics at soundings by the RMT-C system.

Frequency ranges and depth intervals for TEM and GPR in comparison with the CSRMT are shown in Figure 5. Thus the CSRMT method provides receiving of more reliable sounding results in the interval from 5 up to 15 m, where GPR does not has sufficient depth of investigations and TEM results are insufficiently authentic in connection with difficulties of data interpretation for small times.

On frequency (time) range and investigated depths the CSRMT method fills existing gap between the most widespread methods of near surface EM soundings – TEM and GPR.

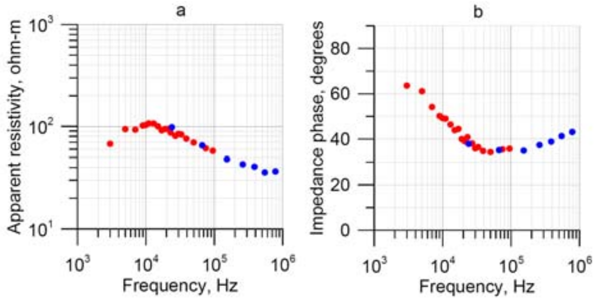

Figure 4. Curves of apparent resistivity (a) and impedance phase (b) on data of measurements of controlled source signals (red dotes) and remote radio transmitters signals (blue dotes).

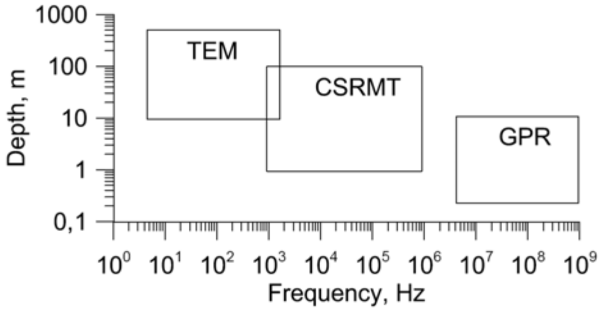

Figure 5. Frequency ranges and investigated depths of methods TEM, GPR and CSRMT.

FEATURES OF THE HIGH FREQUENCY EM FIED OF HOROSONTAL ELECTRIC DIPOLE

For high frequency sources it is necessary to take into account the displacement currents in the ground and in the air. The influence of the displacement currents in the ground are analyzed in a number of recent publications (Kalscheuer et al 2008; etc.).

We have considered the influence of the displacement currents in the air. The quasi-stationary and wave zones have been allocated for the high frequency horizontal electric dipole. The following wave effects are appeared in the wave zone:
- the amplitudes of the electric and magnetic fields decay more slowly than in the quasi-stationary approximation;
- the directional diagram of the source is changed in the wave zone: the maximum radiation is observed on the axis of the dipole;
- the configuration of the working area is changed in the wave zone: the most favorable area is located in the axial area of the source;
- the electric and magnetic fields become elliptically polarized (Figure 6);
- the major axes of the polarization ellipses are turned relatively to the direction of linear polarization of the quasi-stationary field.

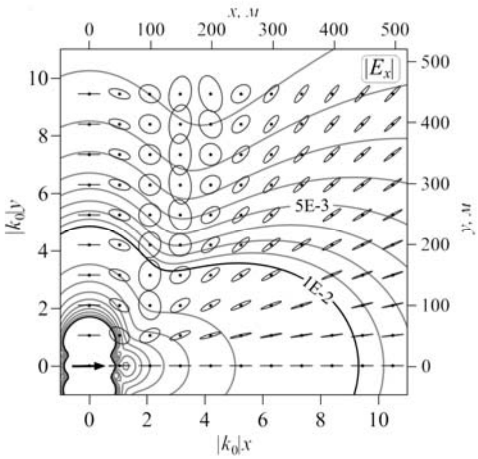

Figure 6. Polarization ellipses of the electric field for *f* = 1 MHz shown together with the isolines of |*Ex*|.

AN EXAMPLE OF APPLICATION

Works by the CSRMT method have been fulfilled at a site of construction of ore-dressing enterprise in Chukotka. Tasks of the works were the section study up 15 m, allocation of rocks varieties, allocation of underground ice-filled zones and mapping of tectonic zones.

During measurements VLF radio transmitter's signals in frequency range of 11.9 - 25 kHz and controlled source signals (the main frequencies 50, 105 kHz and their odd sub harmonics) have been registered. The controlled source (cable of length 630 m) has been settled down at a distance about 1 km from sounding stations. Geoelectric section obtained from results of 2D inversion is shown in Figure 7.

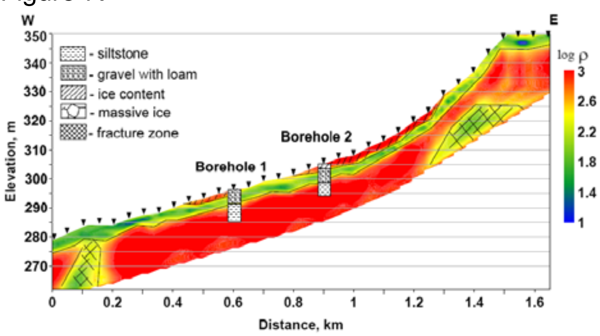

Figure 7. Geoelectric section from data of the CSRMT and its comparison with drilling data. Ratio of horizontal and vertical scales is 10:1.

In the top part of the section a layer of fragmental rocks with thickness of 4-5 m is confidently allocated by lowered resistivity values (50-150 ohm-m), and also lenses ice-bearing rocks. In western and eastern parts of the profile tectonic zones of lowered resistivity (50-150 ohm-m) have been revealed on a background of high-resistivity (700-1000 ohm-m) siltstone basements. Sections of boreholes 1 and 2, drilled after soundings, have confirmed results of the CSRMT.

CONCLUSION

The controlled source radiomagnetotelluric sounding method with a horizontal electrical dipole as a source realized with the developed equipment has good prospects at near surface investigations. Features of electromagnetic field of the high frequency horizontal electric dipole with account of displacement currents in the air should be considered at field surveys and data interpretations. The CSRMT method can be applied for soundings in remote regions, where at works using standard variant of the RMT method there is a possibility to measure VLF radio transmitter's signals only and carry out profiling surveys.

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