Making use of the horizontal magnetic dipole transmitters to improve AMT data quality within the 500 Hz – 5 kHz dead band

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Summary

Due to the properties of natural high-frequency EM fields there is an inherent problem of obtaining high-quality AMT data in the frequency band from about ~500 Hz to ~5 kHz. To solve this problem, we propose to use an additional artificial signal source when carrying out measurements using the AMT method. The source must be in the far-field zone and include several EM field polarizations. In this case, it becomes possible to obtain better data quality while remaining within the framework of the regular AMT method.

In the course of this work, we have developed an EM field source consisting of two horizontal magnetic dipoles oriented in the cardinal directions and creating several field polarizations, which allows tensor AMT measurements. The main features of the proposed transmitting system include the ease of its deployment, the relatively low required power of the generated signal, synchronization of the generated signal with the working schedule of the AMT station, and a fully automatic signal generation mode that does not require operator intervention during surveying. Field tests of the system have shown its effectiveness and superiority compared to horizontal electric dipoles in relatively conductive regions with resistivities of about ~100 Ωm or less.

Keywords: magnetotelluric, control-source, horizontal magnetic dipole

Introduction

One of the serious problems of the AMT method is the weak natural signal within the frequency band from several hundred Hz to several thousand Hz. In midlatitudes the problem of a weak EM signal in this frequency band is especially visible in the winter months. In this time of the year the natural magnetic field induction could be much less than 1 fT – the signal level, which could not be properly detected at the present moment. In this regard, this frequency range is also known as the AMT dead band.

To get high-quality AMT data in the dead band one can use an artificial source of EM signal. In order for this source to be equivalent to the natural EM field source of the AMT method, it must be located far enough from the survey sites (in the “far zone”) and create several (at least two) EM field polarizations.

The above approach is actively used in the CSAMT method. The most common type of source in this case is a pair of grounded orthogonal horizontal electric dipoles (HED). This source type requires a powerful current transmitter with the output voltage of about ~1 kV and power of ~ 5-10 kW. Organizing long grounded lines with sufficiently low electrode contact resistance is also labor intensive. Thus, if the task is just to create additional EM field in the AMT dead band, then using the HED sources could be too difficult and expensive.

In this situation, an easier-to-use source is needed, such as the horizontal magnetic dipole (HMD). The feasibility of using HMD for this task is supported by a number of its distinct features. Firstly, the rate of the HMD magnetic components attenuation does not depend on the properties of the medium (Svetov 2008), thus, knowing only the dipole moment and the equipment internal noise floor, one can estimate the maximum distances from the source at which surveying is possible. This is very convenient from a practical point of view. Secondly, the HMD source field is less sensitive to highly resistive layers in the medium, hence the far-field condition could be met closer to the HMD source than to the HED source, which allows using less powerful generators.

Transmitting HMD system layout

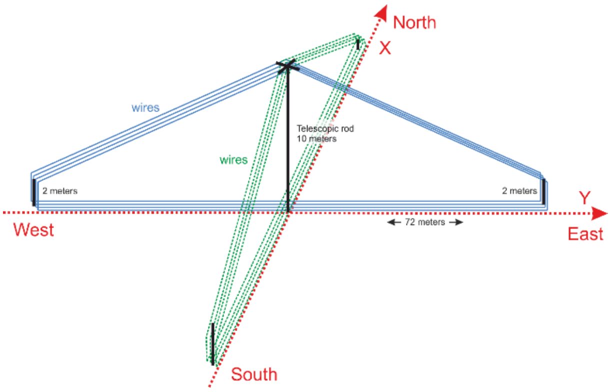

Figure 1. Transmitting HMD system layout

Figure 2. Transmitting HMD system deployed near MSU geophysical camp in Aleksandrovka, Russia

In the course of this work, we have developed a transmitting HMD system consisting of eight loops. The first 4 loops are stretched in the north-south direction forming a magnetic dipole source oriented along the *x* axis. Another 4 loops are stretched in the west-east direction, forming a magnetic dipole source oriented along the *y* axis. The layout of the resulting HMD system is shown in Figure 1.

Figure 2 shows some photos of the HMD loop wires deployed in Aleksandrovka geophysical camp of Moscow State University in Kaluga region, Russia (Aleksanova et al., 2018).

We have chosen the length of each loop segment to be about 150 m as a trade-off between the moment of the resulting dipoles and the complexity of system deployment. A distance of ~50 cm is kept between all adjacent loop segments in order to reduce their mutual inductive influence (Rosa and Grover 1911), and hence to reduce the resulting HMD impedance at high frequencies, as shown in Figure 3.

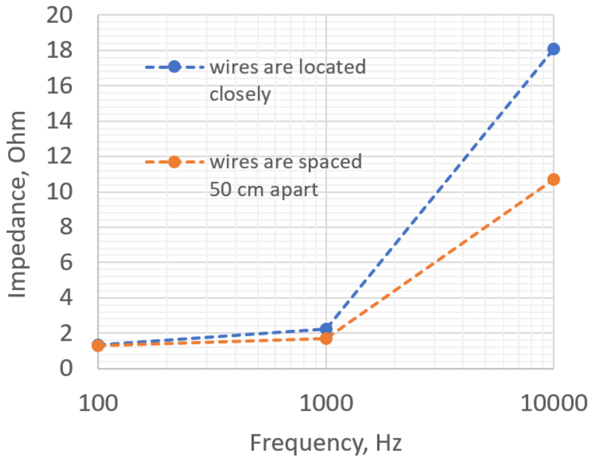

Figure 3. Input impedance of a single loop in the HMD system. Blue curve shows the impedance values for the case when all loops are close to each other. Orange curve shows the impedance values for the case when the HMD loops are kept ~50 cm apart.

Current transmitter

During this work we also developed a prototype current transmitter with 8 channels: 4 channels for each direction of the HMD system. Each channel has the output voltage of 30 V and is able to transmit the currents up to 30 A (the impedance of a single loop is just about ~1 Ohm at lowest frequencies). Transmitter prototype is shown in Figure 4.

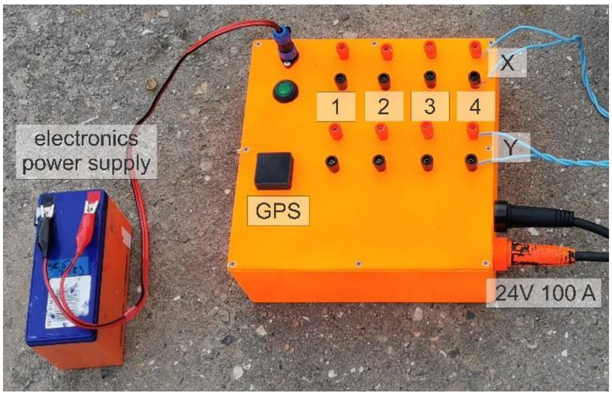

Figure 4. Prototype current transmitter for creation EM signal in the AMT dead band

The transmitting unit has a built-in GPS module for synchronization with the receiving unit schedule. To perform AMT measurements in this work we used the MT receiver NORD (Epishkin et al. 2022). High-frequency continuous data with the sampling rate of 78 125 Hz were collected for 1 s per each 10 s. Low-frequency data with the sampling rate of 150 Hz were collected continuously. To preserve the battery power in the transmitter, it was turned on only at the moments when the NORD unit was collecting data.

The transmitter generates square-wave current at several frequencies within the 500 Hz – 5 kHz band, according to a predefined schedule, one frequency transmitted at a time. Also, for each given frequency the transmitting system makes one switch between the *x*-oriented HMD and *y*-oriented HMD sources to create different field polarizations.

Field tests

The field testing of the transmitting HMD system was carried out at Aleksandrovka geophysical field camp of MSU in Kaluga region, Russia. During the field works, a series of measurements were carried out at different distances from the source, varying from 300 m to 3 km (Figure 5). Measurements have shown that the use of the HMD source is possible in most part of the employed range of distances. At distances less than 1 km, the far-field approximation begins to break down and the CSAMT results at low frequencies are no longer consistent with what we observe with natural source (Figure 6).

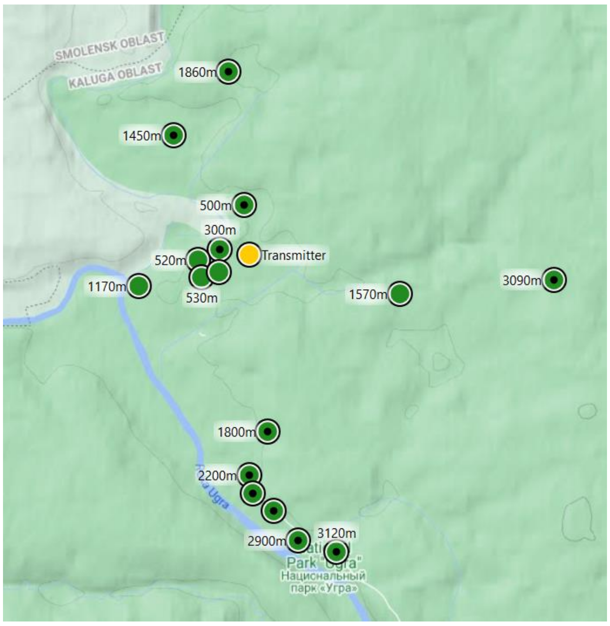

Figure 5. Map of measurement sites. Yellow point denotes the transmitter location, green points show the receiver locations and their distances from the transmitter.

The obtained data were processed with the help of EPI-KIT software (Epishkin, 2016). All data were processed using two approaches.

In the first case, automatic mark-up of time series was used. For each frequency were determined the intervals in which it was transmitted. Then, the impedance tensor was calculated for these intervals. In this case, narrow bandpass filters were used, aimed precisely at the generated frequency.

In the second case, processing was carried out in standard AMT mode, when no frequency mark-up was carried out and the entire recording was processed at each of the required frequencies. The first approach gives the best results when we are relatively close to the source and the amplitude of the generated signal is tens of times higher than the noise level (Figure 7, top). At larger distances, the second approach works better (Figure 7, bottom).

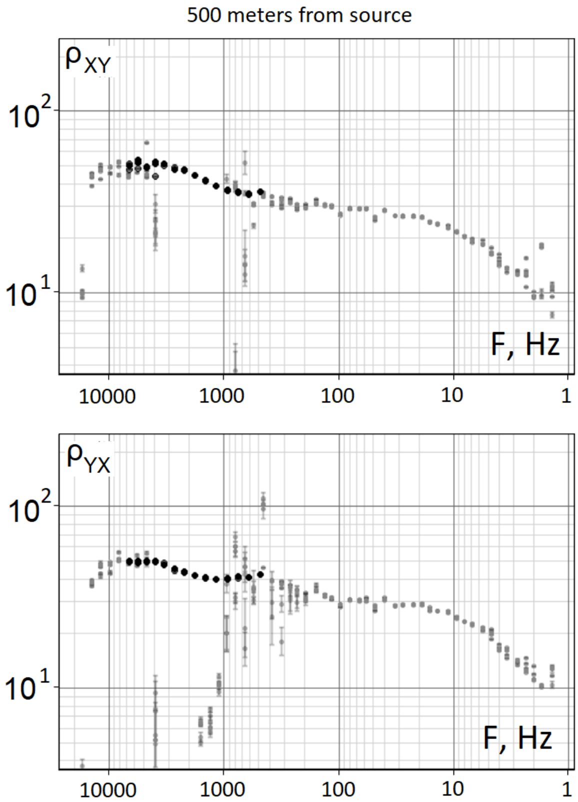

Figure 6. Apparent resistivities at the distance of 500 m from the source. Gray dots – AMT result obtained with natural source, black dots – CSAMT results obtained with the proposed HMD source.

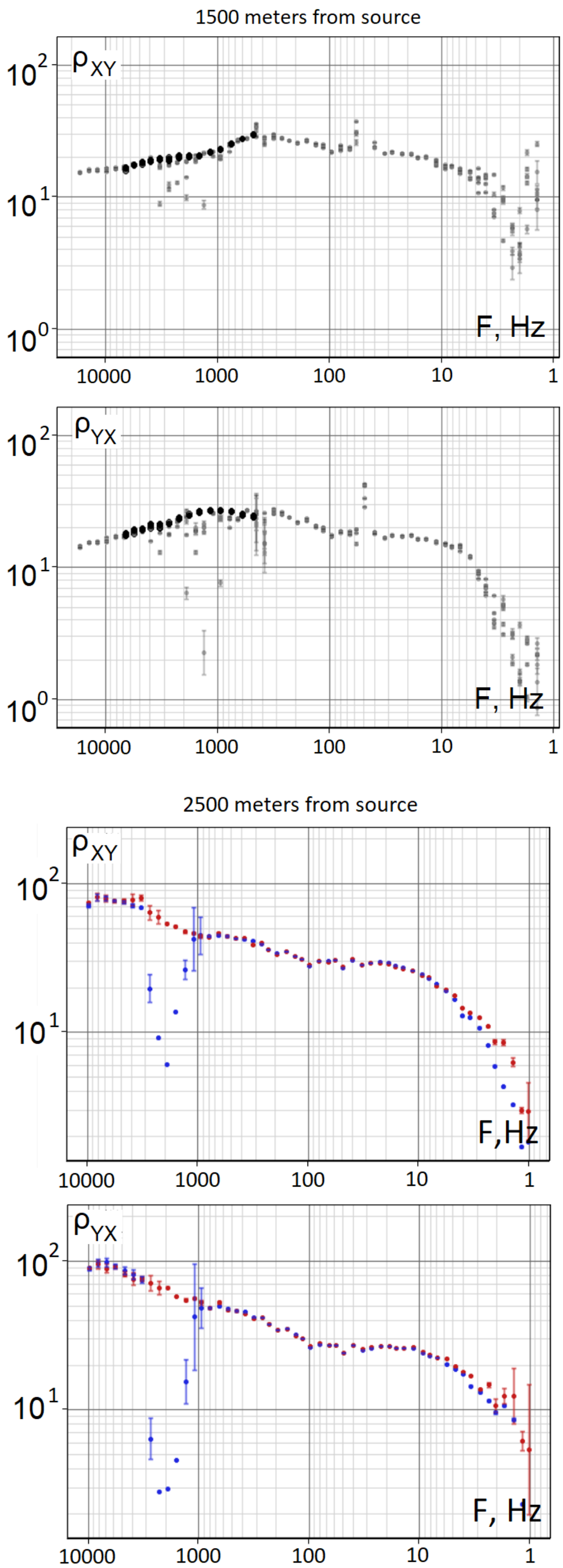

Figure 7. Apparent resistivities at 1500 m (top) and 2500 m (bottom) from the source. Gray and blue dots – AMT with natural source, black dots – CSAMT processing results, red dots – classic AMT processing result then transmitters are working

Conclusion

We have developed a transmitting HMD system to create EM signal within the AMT dead band. The maximum distance to carry out AMT measurements with this system is about ~3 km. This distance does not depend on the resistivities of the Earth. The minimum distance depends on the average Earth resistivity. As tests have shown, with resistivities of about 30 Ωm, it is possible to use the proposed HMD source up to minimum distances of ~500 m. At these distances, the obtained CSAMT data are consistent with the regular AMT data obtained with natural source.

An important feature of the developed system is that the transmitter works synchronously with receiver, which reduces the system's power consumption.

The proposed system can be used most effectively when the average Earth resistivity is less than several hundreds of Ωm, but it can be used in fairly resistive (about ~1 kΩm) media as well.

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