Introduction

For mining, groundwater exploration and geological engineering, it is often necessary to combine several electroprospecting methods for a complete solution to subsurface mapping task. Typically, hardware and software for different geophysical methods are manufactured by different companies with different ideology. In addition to the inconvenience associated with the use of several hardware and software platforms, there is also a serious drawback associated with the price indices for both customer and service contractor. The idea of developing a multifunction EM instruments supporting numerous ground EM methods with a common data processing and interpretation ideology has been held by geophysicists from the 1980s of the last century. At the turn of the 1980s and 1990s several manufacturers managed to achieve positive results (Fox, 2008, Ingerov, 2011). Developers of innovative multifunction EM instruments took into account positive features of these devices as well as their more recent clones to design modern set of super multifunction electroprospecting equipment (Ingerov 2016, Ingerov and Ermolin, 2018). The engineers set themselves objective to effectively implement in one set of equipment all known ground electroprospecting methods (except GPR). For basic concept adopted were technical requirements for systems supporting MT and AMT methods which include high sensitivity, low noise level, wide frequency and dynamic range. An important new requirement was flexible configuration of magnetic and electrical channels. In parallel with portable EM receivers designed were wideband geophysical current sources, low-noise non-polarizing electrodes, high sensitive wideband induction coil sensors of magnetic field components for AMT, MT and Broadband MT, precision tripods for accurate installation and alignment of magnetic sensors on any soil or terrain, set of accessories for the field work and software for the operation of equipment, processing, and interpretation of field data.

Broadband multifunction EM receivers

Receivers are produced with 4 or 8 channel options (Figure 1a, c). To provide a convenient interface, the latest devices are equipped with touchscreen that allows for quick and easy selection of EM methods and data acquisition parameters. The signal and all essential operational information is entered onto a removable SD card, which ensures a quick transfer of data to a computer for processing and interpretation. The magnetic and electric channels are interchangeable on both receivers by a command from the screen. This provides flexibility in selecting field installations for recording EM fields. Electroprospecting methods deployed by the device are grouped according to similar properties:

- Natural source methods;
- Control source methods consisting of geometrical soundings and induction soundings (both frequency and time domain).

a) b) c)

Figure 1 *Multifunction EM instruments - a) 4-channel broadband EM receiver GEPARD-4; b) Broadband current source AT-100; c) 8-channel broadband EM receiver GEPARD-8.*

Devices are equipped with a GPS receiver, which allows for the automatic registration of survey site coordinates, as well as time stamps and synchronization of unlimited number of units when recording time series. Devices also have a flexible selection of data sampling rates, which gives field researchers a convenient instrument for identifying useful signals and suppressing EM field noise.

Broadband current source

The portable generator AT-100 (Figure 1b) has a 100W output and a range of constant current functions in the interval of 0.001 - 1.0 A. The current function is selected automatically based on load resistance. The generator has a dense grid of generated frequencies in the range of 0.001 – 50,000Hz. The frequency grid consists of 5 rows, derivable from: 1Hz, 1.22Hz, 1.33Hz, 1.5Hz, 1.66Hz. The frequency is changed by multiplying the respective row by 2^n, where n can have a negative or a positive integer value. Individual frequency or frequency table can be selected manually from transmitter GUI or prepared frequency table can be loaded from removable SD card. In this case, the transmitter will operate in an automatic mode.

Sensors of EM field

To measure the electric component of the EM field, 1-100m long electric lines grounded using low-noise non-polarizing or steel electrodes are used. These electrodes have hermetic housing with a custom-formed porous membrane and contact wire, to which soldered is a metal rod encased in a special gel containing the salt of the given metal. Three models of electrodes (Figure 2) are produced - copper, lead, and silver. The silver electrodes are the most stable and environmentally friendly, however they are renowned by a relatively high cost and the complexity of manufacturing. The large effective area of membrane allows for low resistance grounding, which promotes high-quality measurements. For measuring alternating magnetic field in frequency domain several types of induction coil magnetic sensors are used. Each coil has a magnetic core, a multi-turn coil, a coil gauge, an electric shield and a low-noise wideband preamplifier board. Coils are connected to the device using noise-immune cables. Four sensors of different construction (Figure 2) are produced cover the entire frequency range:

- AMS-15 - frequency range 50 000 – 1Hz;
- AMS-27 - frequency range 1 000Hz – 0.0003Hz;
- AMS-37 - frequency range 500 – 0.0001Hz;
- AMS-47 - frequency range 10 000 – 0.0001Hz.

The sensors are hermetically sealed and can be buried in the ground, however more effective installation is with specialized precision tripods. To measure the derivative of the vertical component of the magnetic induction by time, airloop sensors equipped with a preamplifier are used (Figure 2).

a) b) c) d) e) f)

Figure 2 *Low-noise non-polarizing electrodes - a) ACE-84 (copper), b) ALCE-84A (lead), c) ASCE-84AG (silver); Induction coil magnetic sensors and airloops - d) AMS-15, e) AMS-37, f) MTEM-200 airloop sensor.*

Precision Field Tripods

Precision field tripods are a unique instrument that appeared at the beginning of this century. This tool enabled a significant expansion of AMT, MVP, MT, CSAMT methods scope of application, as well as, in some cases, to significantly increase the productivity of field surveys (Ingerov 2005, Ingerov and Ermolin, 2017). 3-component tripods are the most effective, and could be quickly and easily transformed from portable to working mode and vice versa (1-3 minutes), as well as could be easily installed on any terrain. Single component tripods (Figure 3) can be used as effectively, however productivity increases derived from these are not as significant.

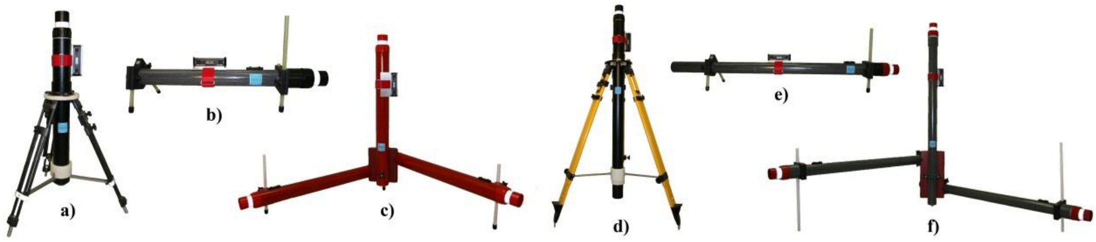

Figure 3 *Precision field tripods for induction coil magnetic sensors - a) TRI-1/30; b) TRI-1/30/1; c) TRI-3/30; d) TRI- 1/50; e) TRI-1/50/1; f) TRI-3/50.*

Examples of integrated EM methods application

One of examples of the integrated EM methods application is the pilot project completed in south-east Asia with Median Gradient, SIP and FDEMS methods (Figure 4 and Figure 5). For Median Gradient method, completed were 3 profiles with 8 sites per profile (MN size – 20m, AB size – 490m, depth of investigation – 60m). The SIP method profile and MN size coincide with the central profile of the Median Gradient method. Induced polarization effect was investigated in 512 to 0.125Hz frequency range using dipole array. The FDEMS profile and MN size also coincided with the central profile of the Median Gradient method. Data acquisition was done in the 32768 to 8Hz frequency range using equatorial array with 240m spacing. As can be seen from Figure 4, there is a close correlation between the results of all three (3) methods. Two regions are clearly distinguished: the eastern high-resistivity area with background polarization values and the western one with reduced resistance and increased polarization. This pattern is confirmed by the resistivity of the Median Gradient and FDEMS methods, as well as by the polarization of the Median Gradient-IP and SIP methods.

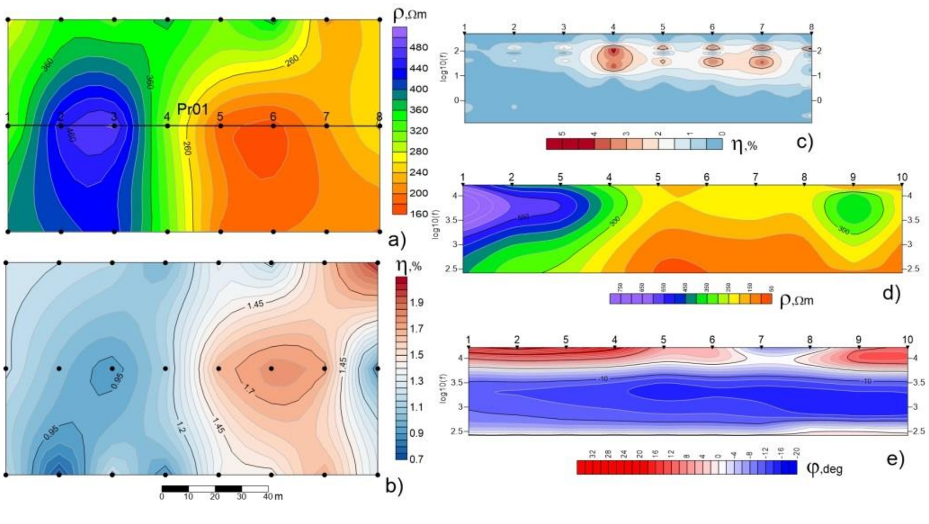

Figure 4 *a) Median Gradient-IP map of apparent resistivity; b) Median Gradient-IP map of apparent polarization; c) results of SIP and FDEMS methods; d) apparent resistivity cross-section; e) FDEMS phase cross-section.*

Figure 5 *Application of broadband multifunction EM instruments for data acquisition with AMT, MT, BMT, MVP and TC methods.*

Conclusions

- High sensitivity, compact, portable multifunction EM data acquisition system is designed and produced;
- The system includes all the required elements for conducting field work, processing field data and its interpretation;
- The system is distinguished by 4- and 8-channel receivers with a flexible configuration of magnetic and electric channels;
- Implementation of one or three-axis precision tripods for magnetic sensor installation allows to increase accuracy and productivity of field surveys on any terrain and any season of the year;
- The system permits the use of the overwhelming majority of known electroprospecting methods.
- Examples of integrated EM methods application confirm the effectiveness multifunction EM system application for solving various geological mapping and mining exploration tasks in wide depth intervals.

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