New abilities of quadrature EM systems

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ABSTRACT

It can be said that quadrature systems failed the competition with powerful time-domain and towed rigid-boom frequency-domain systems. It seems that there is no place for them but they continued to be in use for a long time and the reasons are: first, in contrast to time-domain systems quadrature systems could be applied in weak conductive environment. But one of them, namely, EM4H is still widely used for survey – about 100 000 line kilometers in a year. Experience has shown that new advantages of EM4H have improved essentially survey results and noticeably risen the potential of frequency-domain systems with large receiver-transmitter separation.

In the paper basic features of the EM4H system are described and illustrated by survey results. Particular attention is paid to estimation of effectiveness for searching conductive target depending on distance.

Key words: quadrature, EM4H, frequency domain.

INTRODUCTION

Quadrature systems play an important role in the history of airborne electromagnetics (AEM). Even the birth of this branch of exploration geophysics is associated with successful test flights conducted with Stanmac-McPhar fixed-wing AEM system during the summer of 1948 and with first INCO AEM surveys in 1949 (Palacky and West, 1991).

The term 'Quadrature' is commonly refers to frequency-domain AEM systems with transmitter mounted on an aircraft and receiver placed in a bird towed with long cable. This term origins from the way these systems measure the signal: separating component that is in-phase with transmitter signal from quadrature component, i.e. out-of-phase. Response from conductive geologic objects influence on both components, but in contrast to in-phase component, which could not be separated from transmitter field at that time, quadrature component can be measured directly by synchronous detection method with corresponding initial phase. And this property was used to detect conductive object.

Between the 1950s and 1970s quadrature systems were widely and successfully used in exploration geophysics together with towed rigid transmitter-receiver systems and time-domain systems. But already in the mid-1960s their number noticeably decreased and in the mid-1970s only F-400 (McPhar, Canada) and DIP-A (TSNIGRI, USSR) were used (Fountain, 2008).

The principal aim of AEM surveys at that time was the location of large sulphide ore bodies. And quadrature systems lost their popularity because they were unable to register a response from very conductive objects, which is concentrated mostly in in-phase component.

At that period 'Rigid-boom' systems became dominant among frequency-domain systems. These systems are among the principal tools of mineral exploration up to now. Their main advantage is measuring of in-phase component of a response due to stable geometry, which allows primary field signal compensation. These systems showed good results for subsurface structure investigations (Smith et al., 2008).

It can be said that quadrature systems failed the competition with powerful time-domain and towed rigid-boom frequency-domain systems. It seems that there is no place for them but they continued to be in use for a long time and the reasons are: first, in contrast to time-domain systems quadrature systems could be applied in weak conductive environment. Second, higher transmitter position and large footprint allow regional surveys to be conducted with greater distance between routes. To the end of 1990s the only quadrature system was still in use: DIP-4A (Aerogeophysica, Russia), but it surveyed hundreds of thousands line kilometers.

Specialists of Geotechnologies developed a new quadrature-like frequency-domain system named EM4H (Volkovitsky et al., 2008).

PROPERTIES OF UP-TO-DATE QUADRATURE SYSTEM

Main objectives of the developments were to improve measurements quality and accuracy, survey performance and to extend applications of quadrature system for exploration in different geoelectric environments including location of large conductive ore bodies. During the development important technical results were obtained:

- Not only high sensitivity but also accuracy and stability of wideband three-axial receiver measuring characteristics were achieved due to high-precision digital signal registration, signal processing and special methods of continuous amplitude-and-phase calibration and stabilization.
- Additional field sources and special algorithms (Pavlov et al., 2010) allowed continuous high-precision receiver-transmitter positioning. Not only distance between receiver and transmitter but also angles of their relative orientation are measured;
- In-phase component measurement became possible. It is known for a long time that in-phase component can be obtained by quadrature system in resistive environment (Palacky and West, 1991), but in EM-4H the method of receiver-transmitter positioning is applied, which provided the solution for in-phase response from conductive targets.

Experience has shown that these new advantages of EM4H have improved essentially survey results and noticeably risen the potential of frequency-domain systems with large receiver-transmitter separation.

RESULTS

Influence of 'geometry noise' in traditional quadrature systems always raised doubts in their effectiveness. Uncontrolled variations of receiver-transmitter-earth geometry usually led to strong distortion of measurements. This forced to use low-frequency filtration and smoothing in processing decreasing mapping detail level.

EM4H has a built-in system of relative electromagnetic positioning that allows spatial and angular parameters in receiver-transmitter geometry to be measured after necessary calibration. So corresponding corrections of electromagnetic measurements can be done and also these parameters can be used for interpretation. After this 'geometry noise' influence is considerably compensated.

The charts (Figure 1) show effectiveness of geometry control for the purpose of 'geometry noise' elimination. The values of apparent resistivity for one of operating frequency are calculated twice: on the base of the same electromagnetic data with and without corrections for system geometry (a). The charts of difference between transmitter and receiver altitudes measured by relative electromagnetic positioning system (b) and transmitter altitude above ground level (c) are given to illustrate the influence. It can be easily seen that negative influence of unstable geometry is well compensated by corresponding corrections.

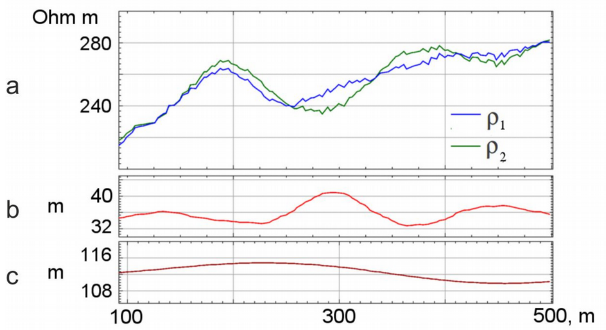

Figure 1. Receiver positioning results: a) apparent resistivity calculated using actual bird position (ρ_1) and using average offset (ρ_2); b) vertical bird offset – affects ρ_2 deviation about 10%; c) aircraft altitude – no influence on apparent resistivity

The control of receiver-transmitter relative orientation is very important as well. Accurate measurements allow the influence of natural noise or 'spheric noise' (Palacky and West, 1991) to be reduced. This result is achieved by transformation of measurements to vertical projections of response vector because noise caused by thunderstorms at short and long distances is horizontal usually.

Another traditional prejudice against quadrature systems is their inability to measure in-phase component. As consequences they have reduced ability to locate conductive target and interpretation complexity in areas with thick mid-conductive overburden. Palacky and West (1991) described the principle possibility and the method of in-phase component calculation but in practice it was impossible for high conductive geoelectic environment. Geometry control, amplitude and phase stability allows this problem to be solved also.

Figures 3 and 4 demonstrate EM4H effectiveness for location of conductive objects. The target was salt lake (resistivity value is about 0.08 Ωm). Test flights were performed over the lake at different altitudes to estimate the effectiveness. For given object parameters (two-layered section $\rho_1 = 0.08$ Ωm, $h_1 = 4$ m, $\rho_2 = 200$ Ωm) signal level was modeled (Figure 2) for in-phase (a) and quadrature (b) components at different flight altitudes. It can be easily seen that the effectiveness is much better when we measure full response. Practical results (Figure 3) correspond well to preliminary calculations.

The parameters by themselves are important also: at altitudes lower than 500 m resistivity values are measured correctly.

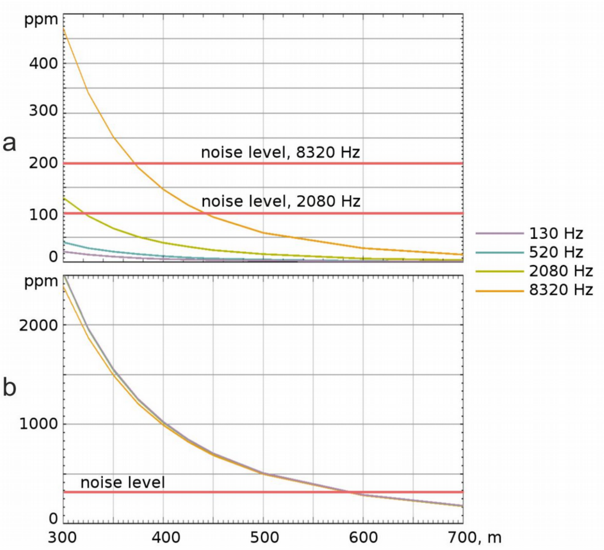

Figure 2. EM4H sensitivity over salt lake: response modelling data as a function of altitude (water: 4 m, 12.5 S/m; basement: 10 mS/m). a) Quadrature response – altitude limit for noise level is 380 m. b) In-phase response – altitude limit for noise level is 600 m

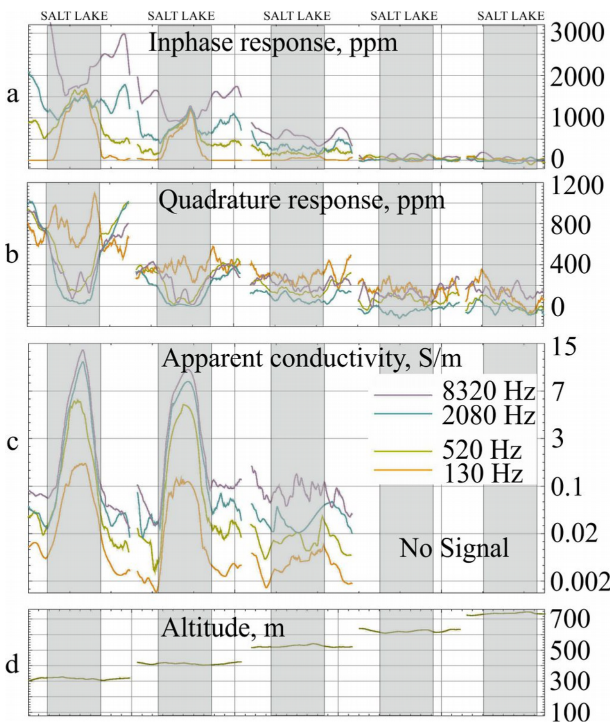

Figure 3. EM4H sensitivity over salt lake (marked in grey): flight data as a function of altitude. a) In phase response; b) Quadrature response; c) Apparent conductivity: lake is not detected at 500 m, ground is not detected at 600 m and higher; d) Altitude.

Additional information about geological structure and refinement of geological maps are important aims of AEM surveys. For these applications powerful systems with towed receiver (MEFATEM, GEOTEM) are successfully used. But it's important to note that these systems are not so effective in resistive environment. Described EM4H advantages make the system sufficiently effective for mapping in resistive areas. Figure 5 shows survey results obtained for mapping purposes and refinement of geological information (Figure 6).

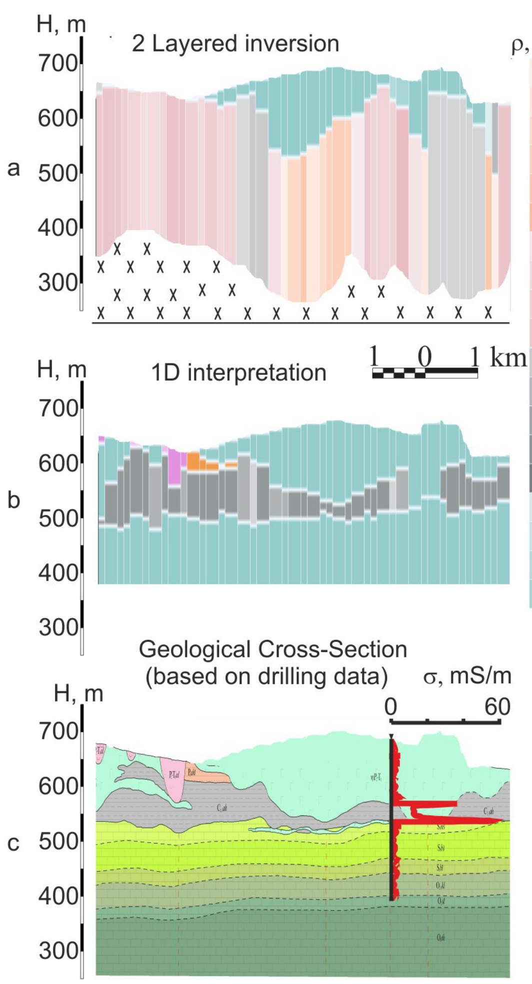

Figure 4. EM4H interpretation: a) 2 layered inversion; b) 1D interpretation; c) geological cross-section with conductivity log results (red chart)

EM4H ability to measure full response vector allows serious advantages of interpretation. Suffice to say that wide range of traditional interpretation methods become available. For example, structure of obtained data turned out to be suitable for AirBeo software. Specific effective interpretation software tools were also developed by Geotechnologies.

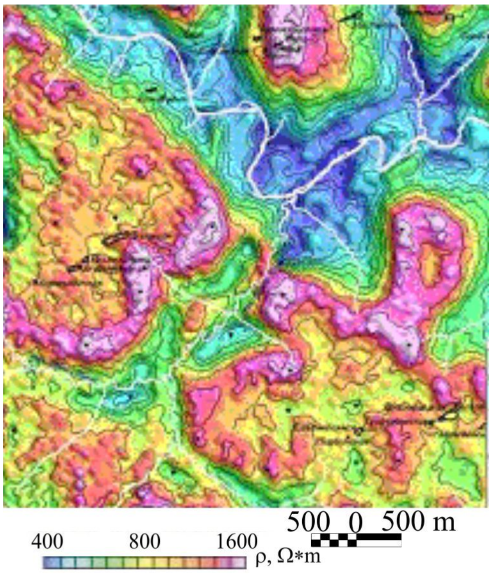

Figure 5. Apparent resistivity map at 520 Hz.

CONCLUSIONS

The main conclusion of given results is that traditional 'quadrature' systems have been phased out but this doesn't mean that frequency-domain systems with large receiver-transmitter separation are living their last days. They not only survive but their development goes on and they are irreplaceable for wide range of mapping and exploration tasks.

Moreover, it's important to note universality of technical results obtained during EM4H developing: algorithms and methods of measuring characteristics stabilization and monitoring of system geometry. It can be expected that realization of these results in AEM systems of different types involves their effectiveness.

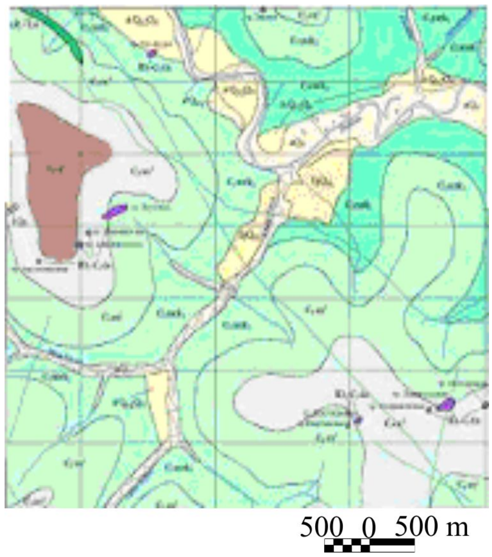

Figure 6. Geology map.

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