Passive and active airborne electromagnetics – separate and combined technical solutions and applicability

Alexander Prikhodko
Expert Geophysics Limited
Units 3 & 4, 16 Mary St.,
Aurora, ON, L4G1G2, Canada
alexander@expertgeophysics.com

Andrei Bagrianski
Expert Geophysics Limited
Units 3 & 4, 16 Mary St.,
Aurora, ON, L4G1G2, Canada
anrei@expertgeophysics.com

Petr Kuzmin
Expert Geophysics Limited
Units 3 & 4, 16 Mary St.,
Aurora, ON, L4G1G2, Canada
petr@expertgeophysics.com

Andrew Carpenter
Expert Geophysics Pty Ltd
12/110 Inspiration Drive,
Wangara, WA 6065, Australia
andrew@expertgeophysics.com

SUMMARY

Airborne electromagnetic methods are divided, by primary field sources, into 'active' (with controlled primary field sources) and 'passive' (without the ability to control the primary field). Each has pros and cons related to the depth of investigation, bandwidths, sensitivity, resolution, terrain clearance requirements, and parasitic effects. Expert Geophysics Limited has developed AEM systems utilizing active and passive principles, separate and combined. The MobileMT system is an entirely passive system using a remote reference technique. The system provides low-noise broadband data extracted from natural field audio frequency (AFMAG) and a very-low-frequency (VLF) power spectra. In addition to the passive field data, but with limited broadband, the TargetEM system measures time-domain data with an active and focused source of the primary transmitting field. The combined (active and passive) airborne electromagnetic system records broadband streaming data used to extract AFMAG, VLF, and time-domain components. The natural field data, even in a limited frequency range, is valuable in filling the gaps when the time-domain method is limited – at mapping highly resistive geological terrains, in detecting superconductors, during surveys in rugged relief conditions, and at parasitic effects appearance. In this paper, we present the combined "active-passive” system.

Keywords: Electromagnetics, AFMAG, VLF, time-domain.

INTRODUCTION

Using airborne electromagnetic time-domain systems (ATDEM) is applicable across various exploration purposes. High spatial resolution, focused transmitting field, depth of investigation exceeding the frequency-domain method several times, and well-developed interpretation theory and tools make the airborne EM method popular in exploration programs. Regardless of their popularity, the ATDEM systems have several limitations in data acquisition. ATDEM capabilities in mapping resistivity are limited in the range higher than 1000 ohm-m (Annan et al., 1996). However, depending on a system’s noise level, they can vary in some limits. Conductive target detection seems the best application for ATDEM, but most common off-time systems “fail to detect or adequately discriminate targets of high conductance” (Witherly, 2007). As for any controlled field source method, ATDEM data quality and informativeness are highly dependent on terrain clearance which is especially critical in areas with rugged relief (Allard, 2007). Induced polarisation (IP) and superparamagnetic (SPM) effects are not exotic in ATDEM data (Kratzer & Macnae, 2012; Mutton, 2012) and are often considered parasitic and destroy the induction response (IP effect) or create false “late-time” anomalies (SPM effect). The depth of investigation (DOI) of time-domain systems is not always capable of reaching exploration goals and is very limited in conductive conditions (Allard, 2007).

MobileMT, the latest development in airborne passive field methods, overcomes all the limitations inherent to ATDEM (Prikhodko et al., 2022). The technology has comparable detection capabilities with three other airborne EM principles, including VLF, time-domain, and a predecessor in the natural field domain, but covering the entire depth range beginning from the near-surface (Moul & Witherly, 2020).

Figure 1 demonstrates the limitations of a time-domain system (400k NIA, trapezoidal waveform, 30 Hz base frequency) over a resistive geological terrain. The ATDEM detected only near-surface moderately conductive alluvium sediments, whereas MobileMT recovered resistivity differentiations in the range of thousands ohm-m with a greater depth of investigation. Another example in Figure 2 shows combined ATDEM and MobileMT data along a line crossing a known KL-22 kimberlite pipe in northeastern Ontario (McClenaghan et al., 2008). The off-time dB/dt ATDEM data is heavily impacted by the IP effect excited, most likely by the documented surficial till layer. A complete resistivity picture is recovered from MobileMT data since the IP effect does not destroy it, and MobileMT is sensitive to a broader range of resistivity differentiations.

These examples demonstrate that natural field data can be a very supportive addition to time-domain data. Combining multiple techniques in one system is an attractive solution for applications in a wide range of conditions. The technique of extracting multiple electromagnetic components from recorded, streaming data in the presence of a controlled current pulse source has been under discussion and development since 1997 (Lane et al., 1998). The latest investigations (Sattel and Battig, 2018, 2018a, 2021) achieved decent results in extracting and modelling passive EM tipper responses from accessible streamed time-domain data but with noted inadequate S/N levels and poor quality of extracted AFMAG data.

Expert Geophysics Limited introduced a system that measures natural-field and VLF EM data, acquiring three-component airborne magnetic-field data while monitoring the horizontal electric field at a base station used as a field variations reference. (Sattel et al., 2019). The same technology can be combined with active source time-domain measurements.

Passive MobileMT technology and its combination with the active TargetEM system

MobileMT passive airborne EM technology utilises natural audio frequency electromagnetic fields to measure simultaneously: 1) variations of the magnetic field along three orthogonal axes (airborne receiver) over survey areas (Figure 3) 2) variations of the electric field associated with telluric currents using two grounded horizontal orthogonal dipoles (Figure 4). All seven data streams are synchronised and recorded in the same frequency band at a 73,728 Hz sampling rate. The ground electric sensor system calibrates the airborne sensor system and extracts denoised and unbiased data. The electrical admittance of the subsurface for each frequency window is calculated by processing the airborne inductive receiver XYZ data and the ground electric field sensor system XY data using the calibration data. In general, differences between calibration parameters and the ratio between the magnetic field strength and the electric field strength at different positions on the survey lines indicate geoelectric differentiations along the lines. The calibration coefficients are calculated as the ratios but in the vicinity of the magnetic and electric components. Previous developments in airborne AFMAG lack the advantages of a remote reference technique (Ward, 1959; Barringer, 2002; Morrison & Kuzmin, 2005; Kuzmin et al., 2012).

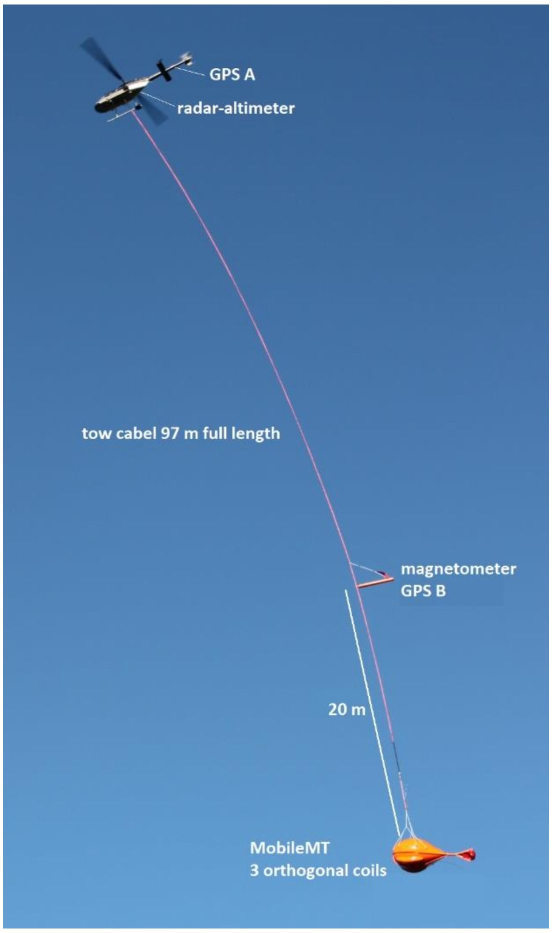

Figure 3. MobileMT magnetic field variations receiver with auxiliary sensors under a helicopter

Figure 4. MobileMT electric field variations remote base station

The TargetEM system (Figure 5) is a time-domain system that when synchronized with the electric field base station (Figure 4); in addition to time-domain EM data, also provides natural field apparent conductivities (AFMAG) and VLF data.

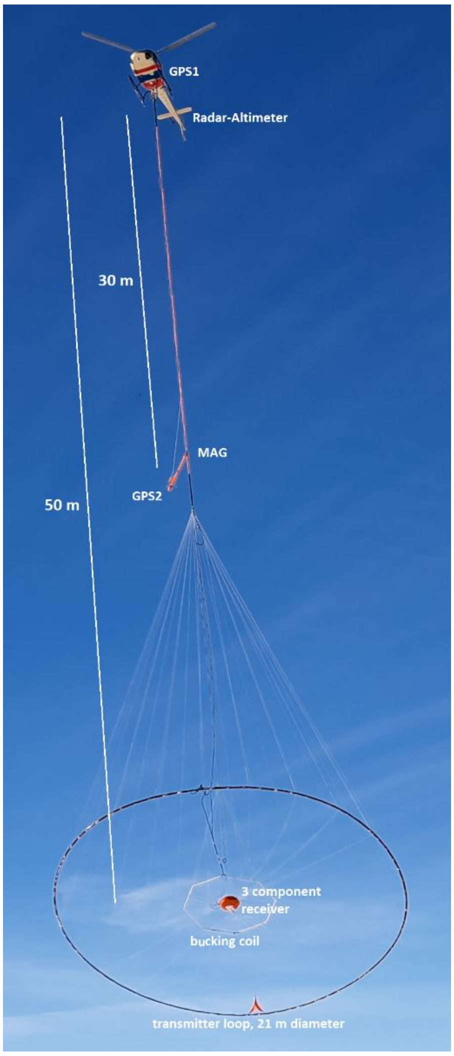

Figure 5. TargetEM broadband passive and time-domain active system with auxiliary sensors under a helicopter

Specifications of the TargetEM system:

- Transmitter loop diameter – 21 – 26 m
- Number of turns – 4 - 6
- Peak transmitter current – 230 A
- Dipole moment – 320,000 – 700,000 NIA
- Transmitter bipolar pulse shape – rectangular
- Transmitter pulse width – selectable, typical 6 ms
- Turn-off time – typical 1 ms
- Base frequency – 25/30 Hz
- Receiver – 3 orthogonal inductive coils (X, Y, and Z)
- Number of turns – 120
- Z coil diameter – 1 m
- Full waveform recording at a digitising rate of 73,728 Hz
- Very high signal-to-noise ratio
- Two time-domain EM data output formats: raw streaming data; stacked and processed time-domain data.

Synchronized electric and magnetic variations time series recordings (streamed data) include eight channels: 3 orthogonal magnetic variations components, two pairs of horizontal electric components, and transmitter current. The time-domain active source EM data is derived by thresholding, stacking, windowing, and filtering standard procedures on the raw streaming data. The VLF radio-field signals (15-30 kHz) are identified and extracted based on comparison with the electrical base station data. The extraction and processing of natural field AFMAG data correspond to the MobileMT data processing scheme (Prikhodko et al., 2022). In the case of TargetEM, the natural field frequency range with informative data depends on the controlled primary field source base frequency and the current waveform duty cycle. For this reason, apparent conductivities derived from TargetEM data cannot be equal to MobileMT due to a limitation in the frequency range.

The single platform combination of time-domain active source, natural field AFMAG, and VLF radio-field data processing and extraction has been successfully tested over conductive structures in northern Ontario.

CONCLUSIONS

The airborne time-domain active field source method has several limitations under certain circumstances, regardless of its progressive improvements and inherent advantages. The limitations are associated with a narrow range of resistivity sensitivity, strict requirements for terrain clearance, depth of investigation, particularly in a conducive environment, and susceptibility to parasitic IP and SPM effects. Natural field AFMAG and complimentary VLF radio-field data can be a valuable addition to the active source EM data, especially with simultaneous recording. Combining streamed time series recordings over survey lines and recordings from a synchronized reference base station provides high-quality natural and radio fields electromagnetic data. The jointly acquired data recordings and processing (active-source EM, natural field AFMAG, and VLF frequencies), combined with a remote reference technique for providing high-quality data, are realized in the TargetEM system.

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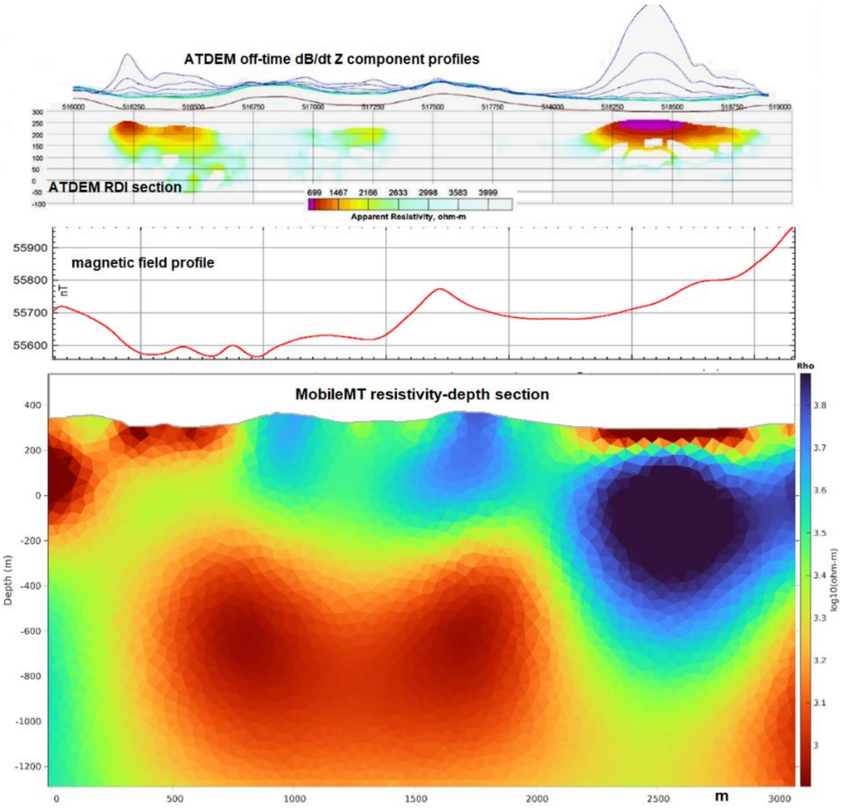

Figure 1. A MobileMT and ATDEM survey line in a resistive environment (Northern Ontario). From top to bottom: dB/dT time-domain off-time Z component profiles; ATDEM Resistivity-Depth image; magnetic field profile; MobileMT resistivity section (2D inversion).

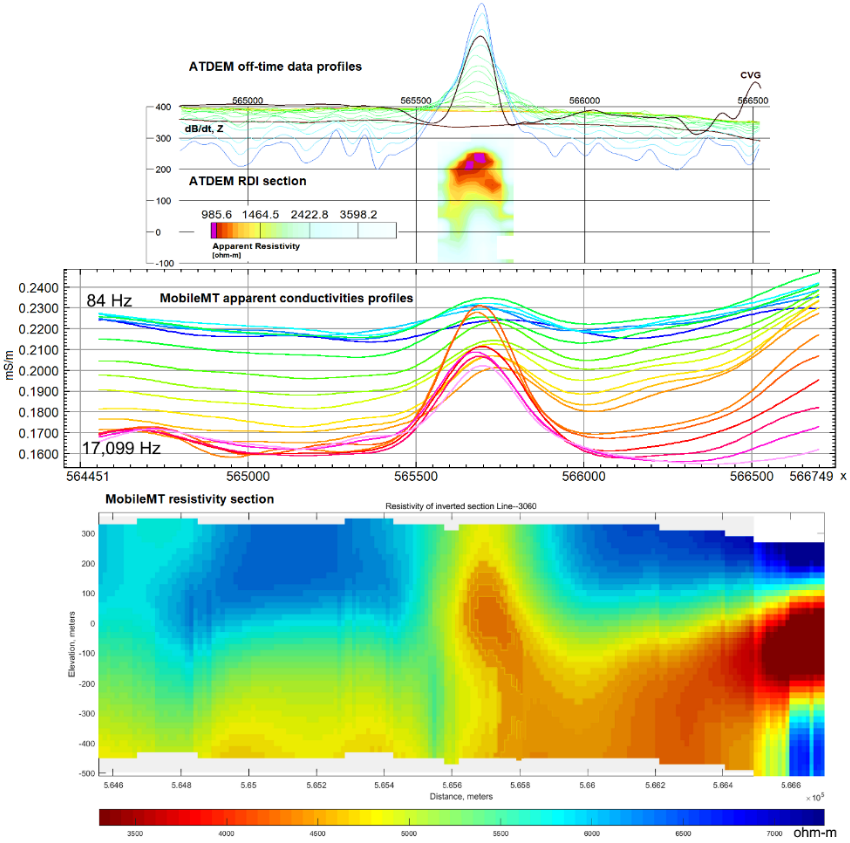

Figure 2. A MobileMT and ATDEM survey line over a known kimberlite pipe KL-22 (Northern Ontario). From top to bottom: dB/dT time-domain off-time Z component profiles; ATDEM Resistivity-Depth image; MobileMT apparent conductivity profiles; MobileMT resistivity section (1D inversion).