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A Complicate Response of Compact EMI Sensors over Shallow Local Conductive Targets

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SUMMARY

The paper presents a modeling of different type of compact EMI sensors response over a local conductive shallow depth targets. The target as well as Tx and Rx coils are approximated by the vertical magnetic dipoles. All the calculations are made under the model of uniform conductive space. Three types of coil configuration are considered. First is semi two coil device with fixed transmitter that carries out the sounding by the changing both the intercoil separation and frequency. The second type is three coil multi frequency sensor with fixed geometry. All the coils in previous configuration are arranged at the same plane. The last new type is multi frequency sensor with the receiver coils that placed at the line inclined to the horizon. A field example is considered as well. The theoretical and practical investigations show that shallow local conductive anomalies produce sophisticated response for compact EMI sensors with spaced coils. It yields from one to four anomalies over one target. The new proposed coil configuration produces the single anomaly

Introduction

Electromagnetic induction (EMI) surveying is a popular technique for shallow geophysical exploration, particularly for ecological, geotechnical, archaeological and agricultural surveys. Over the past several decades a number of single and multiple frequency electromagnetic (FEM) sensors have been successfully developed and widely applied (such as EM-31, EM-34, EM-38 produced by Geonics; GEM-2, GEM3, produced by Aeroquest; CMD – Explorer, produced by GF Instruments etc). All the mentioned above devices could be used to explore local conductive targets like an UXO or industrial waste. Some of them are able to perform parametrical soundings to resolve vertical structure of shallow ground as well. EMI equipment is designed by the different ways. Some of them use two coils, other – include third bucking coil. The sounding could be made by changing geometry or frequency. The coils may be coplanar or concentric. First usually intended to perform sounding or mapping, second – explore conductive targets. Here the first type of devices is considered.

The aim of this investigation is to study the response of EMI sensors with two and three coplanar coils over local conductive targets. The investigation is based on the synthetic results and field measurements.

Modelling

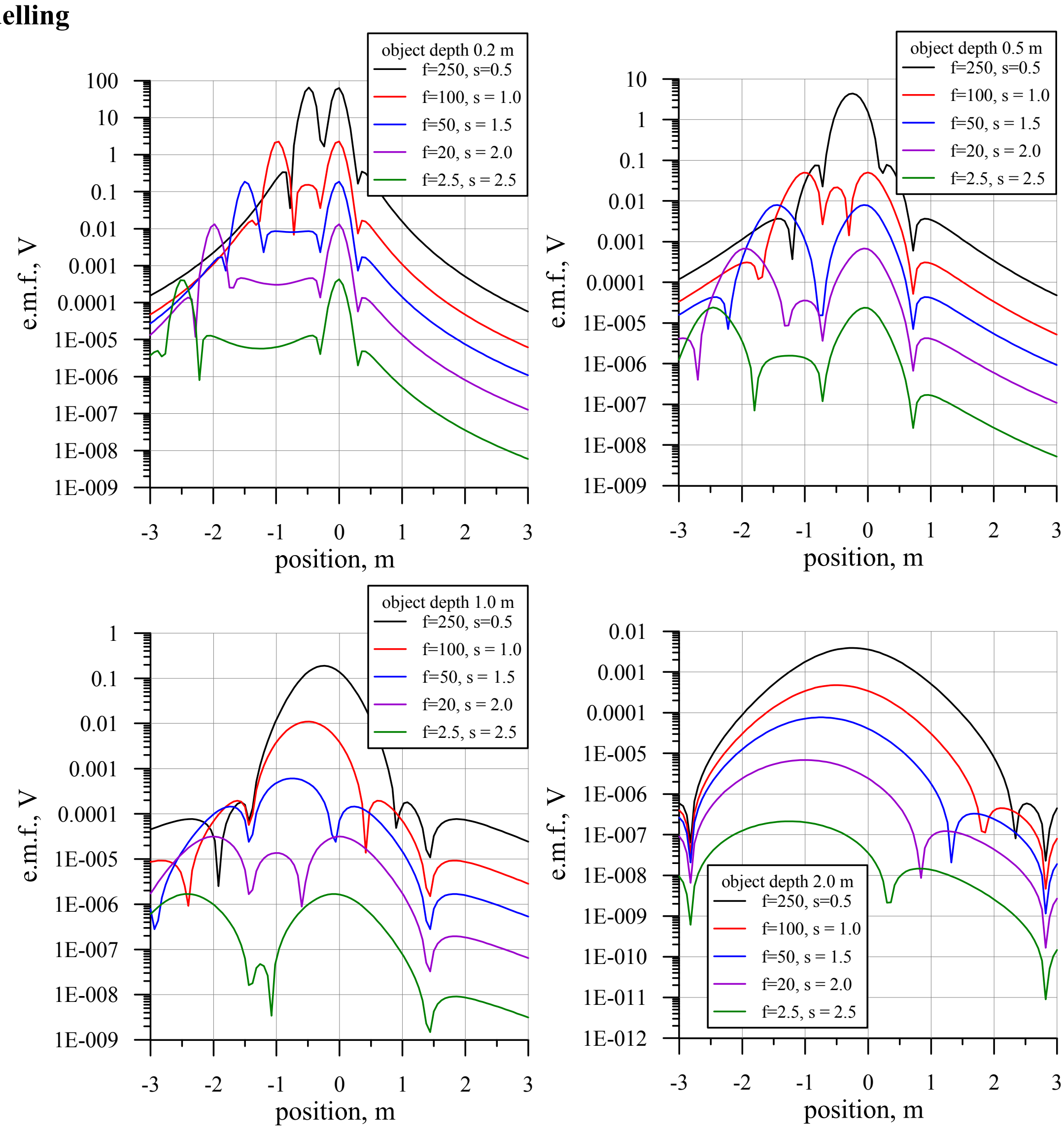

Figure 1 *Synthetic response for a two coil EMI sensor that uses five frequencies (2.5-250 kHz) and five Tx-Rx separations (0.5 m – 2.5 m) over a local conductive target that arranged at different depths (0.2, 0.5, 1.0, 2.0 m).*

Firstly the two coil EMI sensors are considered. The coils and the conductive target are approximated by the vertical magnetic dipoles. Formulation for response calculation in the uniform conductive space follows:

$$H_z^t = -\frac{I_t M_t}{4\pi R^3}\left(\frac{3r^2}{R^2} + \frac{3kr^2}{R} + k^2 r^2 - 2 - 2kR\right)e^{-kR},$$

where $k^2 = i\omega\mu_0\sigma$, r and R - cylindrical and spherical radiuses, I_t and M_t – current and moment of the transmitter, σ - conductivity of the space.

$$\varepsilon_d = i\omega\mu_0 M_d H_z(r_d),\ I_d = \varepsilon_d / Z_d,$$

where I_d, M_d, r_d, e_d, Z_d – current, moment, position, EMF, complex resistance of the target dipole.

Firstly the sensor transmitter induces electromagnetic force (EMF) in target dipole. Then using the complex resistance of the target we find the current induced in the target. Finally the target being the secondary source induces secondary EMF in the receiver coil. The results of modelling are presented in Volts (module of EMF, fig. 1).

The modelling was made for a device where the sounding is performed at five frequencies and intercoil separations. So the sounding is both geometrical and frequency like those that carried out by CDM explorer but with the single transmitter. Each of response curves has several extremums (fig. 1). At small depth (less than 1 m) the most of the curves has two peaks that correspond to conductive target. For such a case a lot of conductors would produce very sophisticated response that could not be interpreted. At the depth more than 1 m the response becomes to have the single peak.

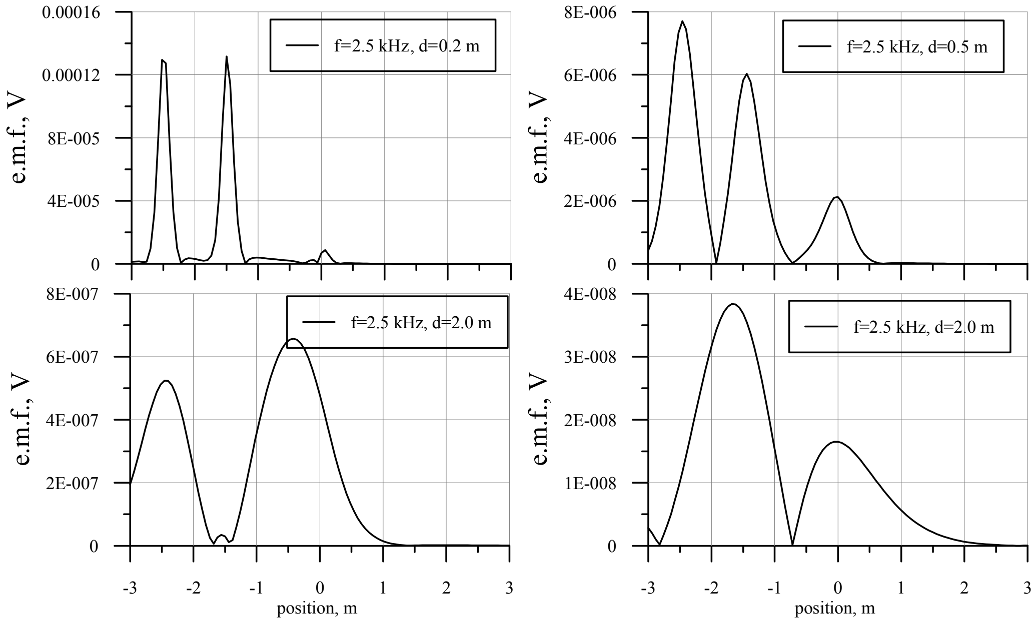

Figure 2 *Synthetic response for a tree coil EMI sensor at the frequency 2.5 kHz over local conductive target that arranged at different depths (0.2, 0.5, 1.0, 2.0 m).*

Next synthetic data was obtained for a three coil multi frequency device with fixed geometry NEMFIS (Balkov, 2009). It has the same principle as GEM2 sensor except the extended intercoil separation (1.5 and 2.5 m) and frequency band (from 2.5 kHz to 250 kHz). The response could be calculated by the formulas presented above applying to two receiving dipoles.

The response was calculated along the line for a single frequency. The results are presented at fig. 2. It can be seen that the response from the shallow target has three peaks, than it becomes to have two ones. At the depths larger than 1 m the single peak in the response dominates. It is shifted to approximately by 1.4 m from the transmitter.

Then the response was calculated at for an area of 2 buy 6 sq. m (fig. 3) with changing the target depth down to 2 m. The 2D and 3D representation (fig. 3) demonstrate the response behaviour over the target located at different depths. It also shows that shallow target produces a lot of anomalies that makes the interpretation more sophisticated. The target that placed deeper than 1 m produce single pronounced anomaly (peak).

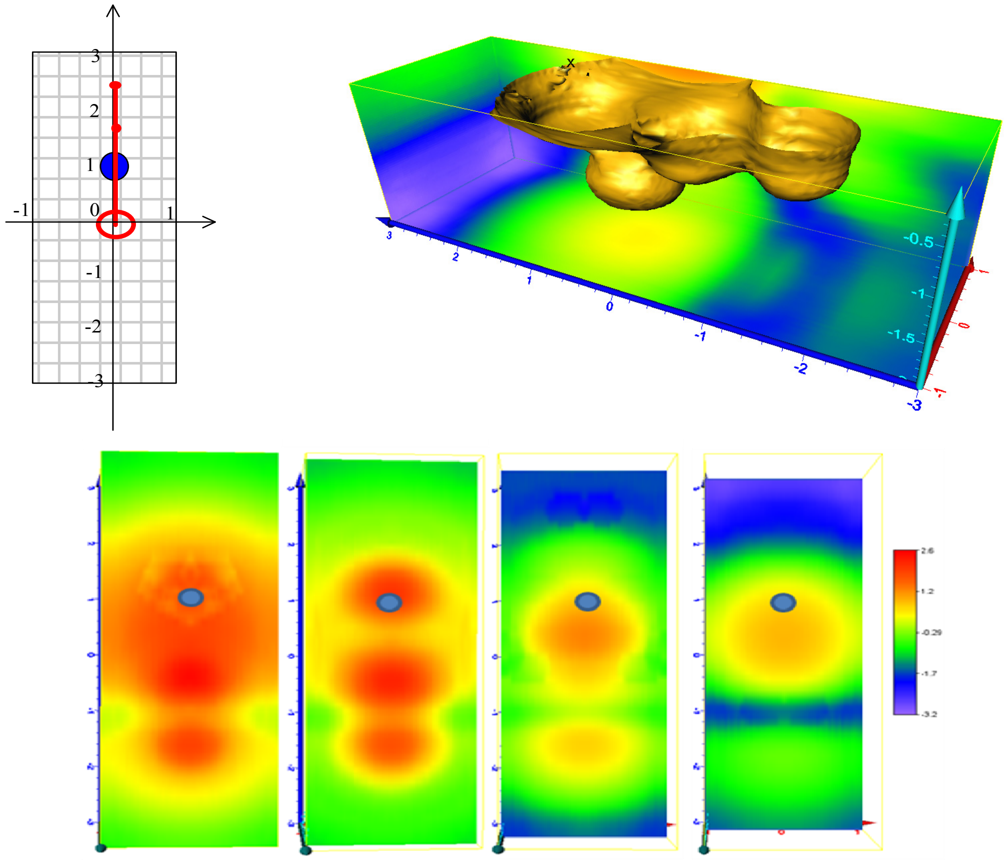

Figure 3 *Synthetic profiling (2 m by 6 m area) by a tree coil EMI sensor at the frequency 2.5 kHz over local conductive target that arranged at the depths down to 2 m. The maps correspond to the depths (0.2, 0.5, 1.0, 2.0 m).*

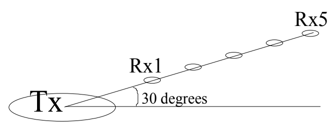

Figure 4 *Coils configuration.*

The last modelling section is performed for a two coil device with the receiver coil that placed at the line inclined to the X axis by the angle 30 degrees (fig. 4). Other coils parameters are considered the same as in the first modelling section. Such a configuration reduces the response that arises when the receiver coil is over the target. Thus all the response diagrams (fig. 5) have only one valuable peak. It makes such a coil configuration more favourable comparing to another considered above for detection of local conductive targets at various depths.

Field example

NEMFIS sensor was applied at the test site of the Institute of Geophysics (Novosibirsk, Russia). The results of profiling at the 2.5 kHz frequency presented at fig. 6. Five metal targets are arranged at different depth with various orientations. Since all the targets are not deeper than 1 m they produce several anomalies. Targets that oriented horizontally yield two or three peaks. It is consistent with presented above modelling results. Vertically oriented targets produce more sophisticated anomalies with a form of quadrupoles. Thus the interpretation of such a data must be interpreted subject to the synthetic and field modelling.

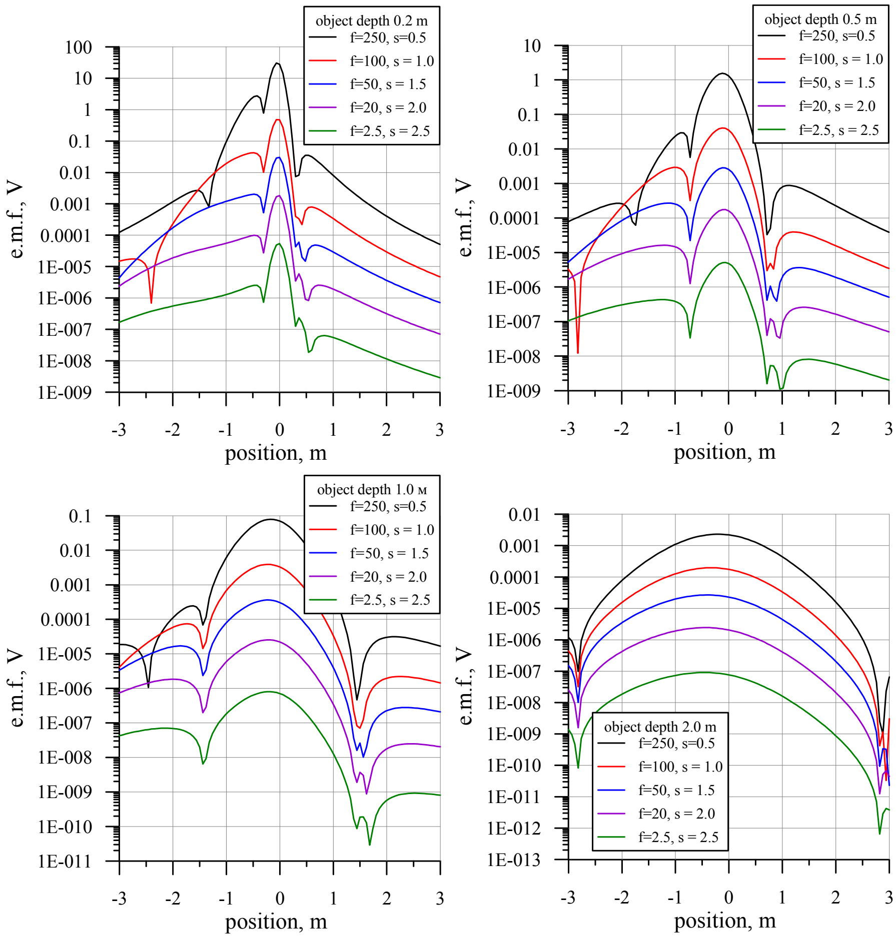

__Figure 5__ Synthetic response for a two coil EMI sensor with the receiver coil that placed at the line inclined to the horizon. It uses five frequencies (2.5-250 kHz) and five Tx-Rx separations (0.5 m – 2.5 m) over local conductive target that arranged at different depths (0.2, 0.5, 1.0, 2.0 m).

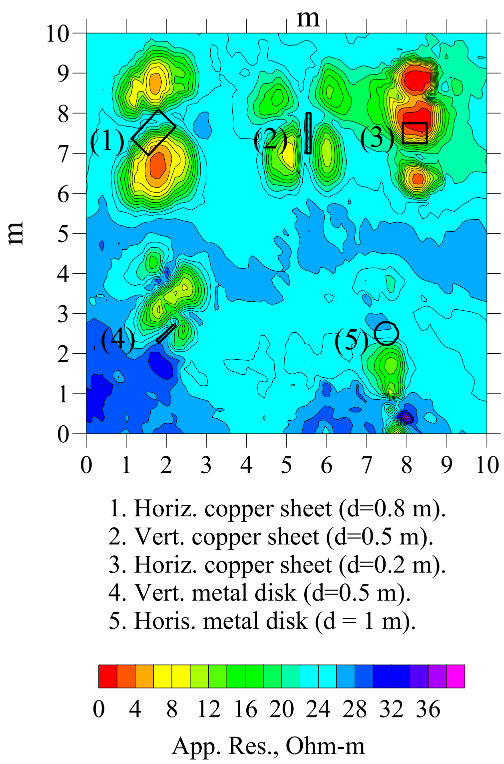

__Figure 6__ EMI profiling (NEMFIS sensor, 2.5 kHz). Resistivity distribution over metal targets.

Conclusion and Acknowledgements

The theoretical and practical investigations show that shallow local conductive anomalies produce sophisticated response for compact EMI sensors with spaced coils. It yields from one to four anomalies over one target. The new proposed coil configuration with the receiver coil that placed at the line inclined to the X axis by some angle produces the single anomaly.

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References

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