**Enhanced sensitivity in land EM by using an unconventional source**

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**Summary**

We present a novel land EM source. By arranging 8 horizontal dipoles in a radial pattern an EM field can be generated that contains only the TM mode of the electromagnetic field. This results in a superior sensitivity towards resistive targets. Specialized equipment has been build to generate the TM mode source field. The methodology has been successfully tested on several oil reservoirs in Russia and the USA.

**Introduction**

Within the last decade Electromagnetic (EM) methods have drawn increasing attention within the oil & gas industry. This is primarily due to the introduction of marine CSEM as a tool to detect and delineate thin resistors not seen with more traditional methods like Magnetotellurics (MT).

While early euphoria and claims based on the direct hydrocarbon indication capability of the method were found to be not sustainable CSEM’s ability to detect thin resistors and the usefulness of EM methods in oil & gas exploration has been proven in many cases.

One key distinguishing factor between CSEM and other forms of EM methods is that the horizontal line source used in CSEM creates a field that comprises of TE and TM mode. Other methods like MT or TEM using a loop source basically create a horizontal eddy current pattern and mainly sense the horizontal resistivity of the subsurface. In a layered Earth such methods only create a TE mode. A thin resistive layer embedded in a conductive background is seen by horizontal currents as a parallel circuit of conductors and resistor in which the resistor contributes almost nothing to the overall resistivity.

This feature of TE mode based EM methods is typically described as detection of the transverse conductance rather than the individual conductivities of a particular layer. TE mode methods have been proven to be useful in basin characterization and background characterization for salt bodies. They however cannot provide resistivity information of the reservoir itself.

The field of the horizontal electrical dipole used as source by CSEM methods contains in the case of a layered earth TE and TM mode and the TM mode creates a vertical current flow. Contrary to the horizontal currents vertical currents see the sequence of 1D layers as a series of resistors and by that even a thin resistive layer may cause a measurable effect.

As the TM mode is superior in delineating thin resistive targets it is desirable to measure the TM mode in the absence of any additional TE mode. In a layered Earth such TM mode only field can be provided by a vertical electrical dipole or vertical elongated line (bipole) source. As the magnetic lines circumvent the vertical bipole only magnetic field lines and no electric field lines will be parallel to the layer boundaries.

The idea of using vertical bipole sources is not new. The basic principles have been described in the various publications on the MOSES experiments in the early 1980s see Chave. et al. 1991 Or in an even earlier Soviet Union patent from Nazarenko (1961). Numerical studies for the land case have
been published by Pellerin and Hohmann (1995). While the earlier studies focus on low frequencies or DC, more recent work uses transient vertical sources in the marine environment (Barsukov et al., 2005). For such a system an analysis of the sensitivity towards resistive layers has been carried out by Scholl and Edwards (2007). They come to the conclusion that a downhole to seafloor array that uses a vertical bipole source inside a borehole will have superior lateral resolution and is therefore preferable in a production monitoring scenario.

While a vertical dipole source can be realized in the marine case by using the dipole in the water column, the land case always requires a well and therefore puts a strong limitation on the method. In the following chapter we will introduce a TM mode only source that creates the equivalent of a vertical dipole in a land case and show examples of its use.

**Methodology**

As explained in the introduction the EM field of a vertical electric bipole will only have magnetic components circumventing the bipole. In a 1D Earth only the B component will be present. The electrical field however will have only Er and Ez components. No E component will be present. The DC current distribution of an elongated vertical line is shown on figure 1.

![Figure 1: Current direction inside a homogeneous half space (xz plane) as caused by a vertical line. Length of the vectors is chosen constant for display reasons and does not represent the current density.](image)

As can be seen on figure 1 the current flow on the surface is radial only. There is no angular current component. Thus creating an electrical field on the Earth surface that consists of a perfectly symmetrical, radial component only will result in the desired TM source. Such source has been developed in by Mogilatov (1996) and Mogilatov and Balashov (1996). It is called Circular Electrical Dipole (CED).
Figure 2: Left: View onto an ideal CED in the XY plane. Right: Approximation of the ideal CED using 8 dipole lines.

Figure 2 shows an ideal CED as well as an approximation using 8 horizontal dipole lines. In both cases current flows radial from the red center electrode to the blue ring electrode or the blue electrodes on the outer perimeter. For the case of an ideal vertical dipole (infinitesimal small) and an infinitesimal small CED the fields are exactly identical. Extensive modeling and experimental studies have been carried out to determine the best compromise for a practical CED. The shown setup using 8 horizontal lines results in a reasonable good TM field while still being practical from a field operation point of view. The DC current distribution of the practical CED is shown on figure 3.

Figure 3: Current direction inside a homogeneous half space (xz plane) as caused by a practical CED. Length of the vectors is chosen constant for display reasons and does not represent the current density. Compared to figure 1 the direction of current flow is reversed.

While being slightly different in the immediate vicinity of the dipoles the current pattern generated by the CED is remarkably similar to the one of the VED shown on figure 1. After switching off the primary current both sources create toroidal eddy current systems in the subsurface with a magnetic B component in the xy plane.
Figure 4: Left: CED transmitter with power control for 8 dipoles. Right: Center electrode arrangement for the middle of the CED.

To generate the desired TM mode field it is essential to maintain identical current in all 8 dipoles. To do this a specialized transmitter is needed that individually regulates the current in each of the dipoles so that even in cases of different grounding conditions the symmetry of the current is maintained.

Using the transmitter shown on figure 4 measurements over oil fields in Russia and the USA have been performed. Figure 5 shows a measurement result obtained over a known oil deposit in Tatarstan, Russia.

Figure 5: Contours of dBz/dt component over a known oil deposit in Tatarstan, Russia.

The dashed line shows the reservoir boundaries as derived from drilling and other information. Originally the reservoir was assumed to be oval shaped. However a well drilled to the east of the northern CED was dry.

Conclusions

By arranging 8 horizontal dipoles in a radial pattern on the surface of the Earth the EM field of a VED can be mimicked. The CED allows creating a TM mode source without the need for a transmitter installation inside a well.
References

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