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Excitation of a Half-space by a Radial Current Sheet Source

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Abstract—Some advantages and problems of the new geoelectrical prospecting method, i.e., vertical electric current soundings (VECS) are discussed. This method is based on using a new source, namely a circular electric dipole (CED). The source is installed by one of the transmitter poles grounded in the central point and the other pole uniformly grounded around with a radius determined by the depth of investigation desired. It can be defined as a noninductive source. The previous research was based on the diffusion approach. In this paper the author uses the solution with due regards for displacement currents in the frequency and time domain. A major disadvantage of the CED scheme is the need to provide a symmetrical grounding of the outer ring electrode. A possible way to avoid this requirement is to adopt an ungrounded CED array.

Key words: Electrical prospecting, vertical electric current soundings, circular electric dipole.

Introduction

Sometime ago a qualitatively new controlled source, a Circular Electric Dipole (CED), was described (MOGILATOV, 1992). It may be defined as a source having no magnetic field of its own at the earth's surface. Such a geometry of conductors with a current on the surface of the earth was proposed to reduce the magnetic field of each separate conductor. In other words, CED is a noninductive source.

The source is installed by grounding one of the transmitter poles in the central point. The other pole is uniformly grounded around with a radius determined by the depth of investigation desired (Fig. 1). Let us briefly illuminate the most interesting CED properties in the low frequency regime. CED is a source having no magnetic field of its own. Thus it is a pure galvanic source, which differs from a loop (a pure inductive source) and from a line. It is both galvanic and inductive (a "line" here refers to a cable or insulated wire grounded at its end points). The normal magnetic field on the earth's surface (and above it) of a horizontally layered medium is absent (within the quasi-static approximation), and only a radial electric component exists. A CED field is at right angles to a loop field and has an azimuthal symmetry (seen ideally. The real CED array has azimuthal periodicity).

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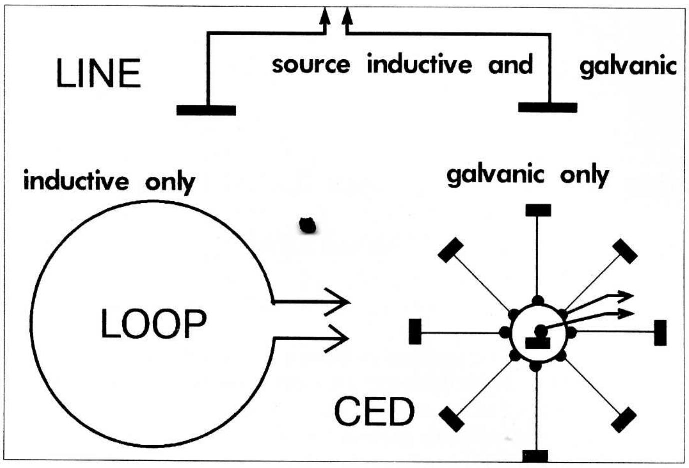

Figure 1
Three types of sources for the transient soundings.

The CED field is always defined by a vertical medium structure, at the latter transient stage as well, rather than by the total longitudinal conductivity. There is one interesting result: In marine electric prospecting a sea-water layer will not play such a fatal role when a CED is used as in applying a loop or a line. In medium with nonconducting basement the decay of the CED field is exponential. The transient process is faster than the transient process from a loop or a line. The CED can be also considered as a ground analogue of another known source namely, a vertical electric line. Finally we note that the CED as a pure galvanic source does not excite a long-term transient. Thus in all likelihood it will appear to be a new useful means to study IP processes. The CED is a *simple* source, whereas a line is *complex*. This fact should be kept in mind in studying such a complicated phenomenon as IP (Induced Polarization).

Considering a distinct vertical character of the currents under the central electrode and current circulation in vertical planes, we suggest an electric prospecting method using a CED to be named the method of vertical electric current soundings (VECS). There are the first field-test results for VECS. These assertions and previous research were based on the diffusion approach. In this paper we use the solution with due regard for displacement currents.

Field of CED in the Frequency Domain[2]

The model we adopt is very simple. As indicated in Figure 2 the radial current sheet $j_r(r)$ in A/m locates in the interface between two homogeneous half-spaces.

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[2] In fact this section is a private communication from James R. Wait, reproduced with his permission.

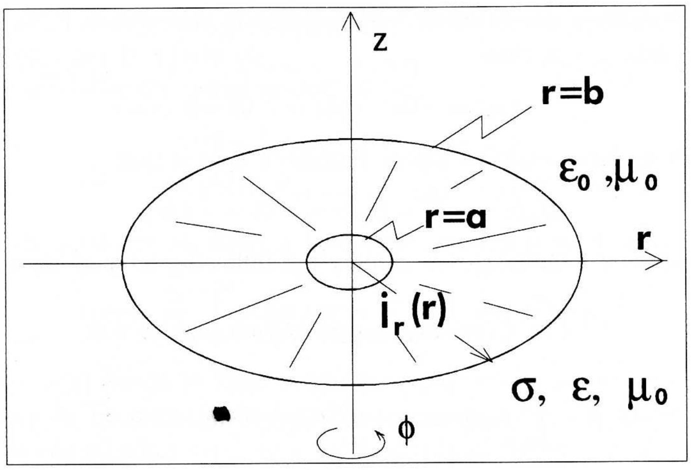

Figure 2
The model.

The upper region, for $z > 0$, which we refer to as the air, has the permittivity ε_0 and permeability μ_0. The lower lossy region, which we refer to as the earth, has the permittivity ε, conductivity σ and permeability μ_0. The objective is to deduce expressions for the fields everywhere in terms of the specified source current $j_r(r)$. A time factor $\exp(\mathbf{j}\omega t)$ is assumed where ω is the angular frequency.

Because of azimuthal symmetry, the fields can be derived from the vector potential which has only a z component. These are denoted A_0 for $z > 0$ and A for $z < 0$. Thus the nonzero field components are:

$$E_r = \frac{1}{\mathbf{j}\omega\varepsilon_0} \cdot \frac{\partial^2 A_0}{\partial r\, \partial z}, \quad z > 0; \tag{1}$$

$$E_r = \frac{1}{\sigma + \mathbf{j}\omega\varepsilon} \cdot \frac{\partial^2 A}{\partial r\, \partial z}, \quad z < 0; \tag{2}$$

$$E_z = \frac{1}{\mathbf{j}\omega\varepsilon_0} \cdot \left(-\gamma_0^2 + \frac{\partial^2}{\partial z^2}\right) A_0, \quad z > 0; \tag{3}$$

$$E_z = \frac{1}{\sigma + \mathbf{j}\omega\varepsilon} \cdot \left(-\gamma^2 + \frac{\partial^2}{\partial z^2}\right) A, \quad z < 0; \tag{4}$$

$$H_\phi = -\frac{\partial A_0}{\partial r}, \quad z > 0; \tag{5}$$

$$H_\phi = -\frac{\partial A}{\partial r}, \quad z > 0, \tag{6}$$

where $\gamma_0^2 = (\mathbf{j}\omega)^2 \varepsilon_0 \mu_0$ and $\gamma^2 = \mathbf{j}\omega\sigma\mu_0 + (\mathbf{j}\omega)^2 \varepsilon\mu_0$.