MAPPING DIELECTRIC PERMITTIVITY AND RESISTIVITY USING HIGH FREQUENCY HELICOPTER-BORNE EM DATA

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ABSTRACT

Interpretation of helicopter-borne EM data is commonly based on the mapping of resistivity under the assumption that the magnetic permeability and dielectric permittivity are the same as those of free space (Fraser, 1978; Sengpiel, 1988; Huang and Fraser, 1996). However, EM data obtained from a multi-frequency EM system may contain information about the magnetic permeability and dielectric permittivity as well as the conductivity. Prior work has shown how the conductivity and magnetic permeability may be obtained from the EM data by transformation using a homogeneous conductive magnetic half-space model (Huang and Fraser, 1998).

With the high frequencies available with helicopter-borne EM systems, it is now possible to transform the EM data to yield information on the dielectric permittivity. Displacement currents become significant when their amplitude exceeds approximately 5 percent of that of conduction currents (Lytle et al., 1976; Sinha, 1977; Fraser et al.,1990). This situation can occur for the frequency of 56,000 Hz which is common to all DIGHEM helicopter EM systems. With the highest frequency of some DIGHEM systems being as high as 200 kHz, dielectric permittivity should not be ignored in resistive environments.

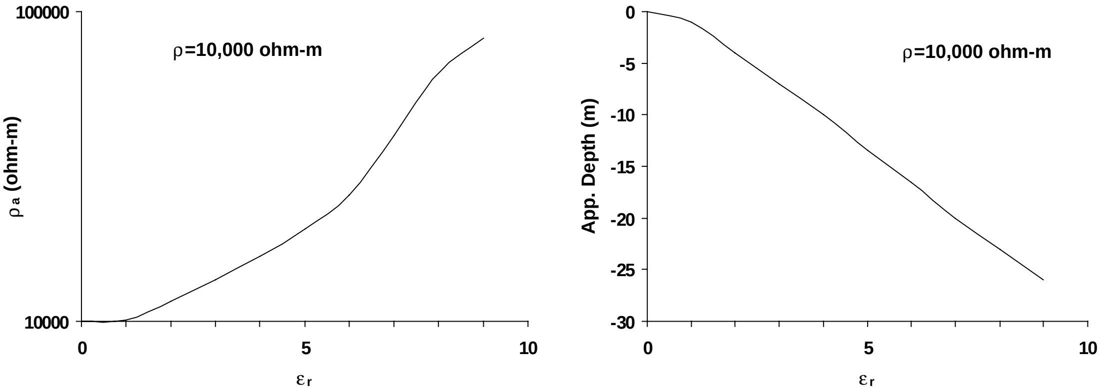

Fig. 1 The computed apparent resistivity and apparent depth, for the pseudo-layer half-space model, as a function of the relative permittivity, when the permittivity is neglected in computing them.

We evaluated the feasibility of dielectric permittivity mapping using a high frequency EM system in resistive areas. The model used in the study was a non-magnetic homogeneous half-space with variable resistivity and dielectric permittivity. Displacement currents have the effect of decreasing the inphase and increasing the quadrature, relative to what would be expected from the conduction currents alone. This results in an increase in the apparent resistivity and a decrease in the apparent depth, for the pseudo-layer half-space model (Fraser, 1978), if the permittivity is neglected in computing the apparent resistivity as shown in Figure 1.

An algorithm based on a homogeneous half-space model has been developed for transforming the inphase and quadrature into the apparent relative permittivity and apparent resistivity. For closely coupled transmitting and receiving coils, the secondary magnetic field H_s can be approximated as,

$$H_s/H_o = (s/h)^3 [M + iN] \qquad (1)$$

in units of parts per million (ppms) of the primary field intensity H_o at the receiving coil, whereupon the measured inphase I and quadrature Q ppms may be represented as

$$I = (s/h)^3 M \qquad \text{and} \qquad Q = (s/h)^3 N \qquad (2)$$

M and N respectively are the inphase and quadrature components of the response function M+iN, and simply reflect the inphase and quadrature ppms scaled for variations in flying height h and coil separation s. Equations (1) and (2) are valid on the assumption that $s^3 << h^3$. This *superimposed dipole assumption* (Grant and West, 1965) is generally valid for surveys flown with all commercial helicopter EM systems.

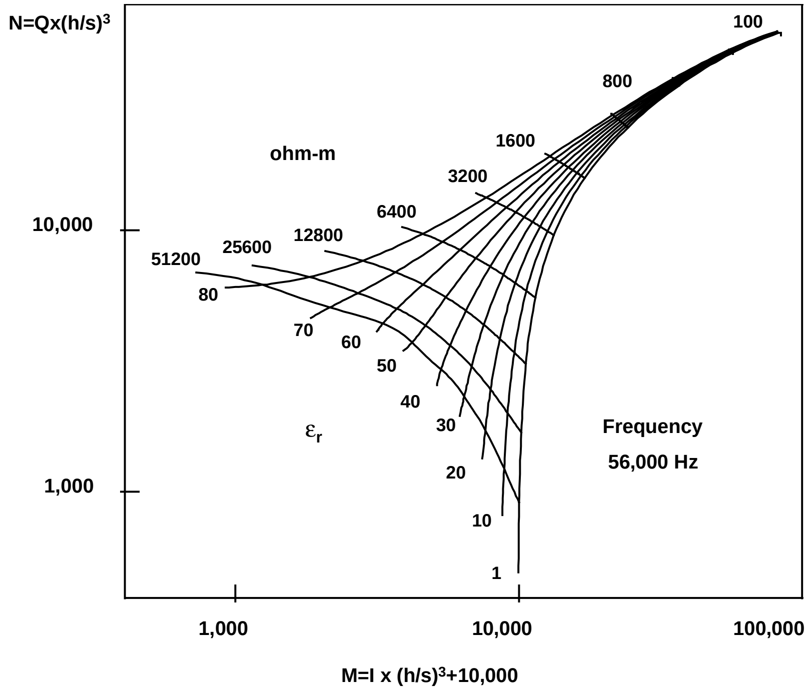

Fig 2. The diagram of the inphase M′ and quadrature N for the half-space model for several resistivities ρ and relative permittivities ε_r. In order to plot the diagram in log-space, M′ is taken as M+10,000 to ensure all inphase data are positive.

Figure 2 shows the diagram of the inphase M′ and quadrature N of the response function M+iN for the half-space model for several values of resistivity and relative permittivity. In order to plot the diagram in logarithmic space, M′ is taken as M plus a base value of 10,000. Thus, it is obvious that the inphase is a negative value if M′ is less than 10,000 on the diagram. The inputs to the algorithm are M′ and N. M and N are first obtained from equation (2) on the assumption that the bird height from the altimeter can be used in place of the unknown sensor-source distance, and then M′ is simply M+10,000. The outputs from the algorithm are the relative permittivity (dielectric constant) ε_r and resistivity ρ. If the earth is a true homogeneous half-space, the relative permittivity ε_r obtained in this way would equal the true relative permittivity. Otherwise, it would be the apparent relative permittivity. The permittivity can be well resolved in a resistive environment. The dielectric permittivity cannot be resolved when the resistivity is lower than an empirical threshold for a given frequency.

The behavior of the apparent permittivity and apparent resistivity is illustrated for several models. As an example, Figure 3 shows the apparent resistivity and apparent permittivity for a two-layer model where the thickness of the upper layer t_1 increases from left to right. The upper-layer permittivity is 2 and the basement permittivities vary from 2 to 50. The resistivity is fixed at 10^4

ohm-m for all media. The upper panel and middle panel show the transformed apparent resistivity and the apparent relative permittivity, respectively. The model is shown at bottom. When the upper layer has zero thickness, i.e., beyond the left side of the model of Figure 3, the earth is a homogeneous half-space with a true resistivity of 10^4 ohm-m and the relative permittivities are from 2 to 50. The computed apparent permittivities and apparent resistivities are equal to the true values. At the right side, where the upper layer is thick, the earth again tends to be homogeneous with a resistivity of 10^4 ohm-m and a relative permittivity of 2. Both the apparent resistivity and the apparent permittivity are equal to the true values. As can be seen, the apparent resistivity in the upper panel will be underestimated when $\varepsilon_r > 10$ in the transition zone even though the two layers have no resistivity contrast. The permittivity behaves well except for the undershoot for large permittivity contrast, as shown in the middle panel of Figure 3. It should be noted that the earth becomes a true homogeneous half-space when the permittivity of the basement is equal to 2 so that the apparent permittivity equals the true permittivity for all t_1. This also reveals that the depth of investigation for a dielectric polarizable layer may reach to 100 m in some cases for 56,000 Hz. The technique has been tested on survey data.

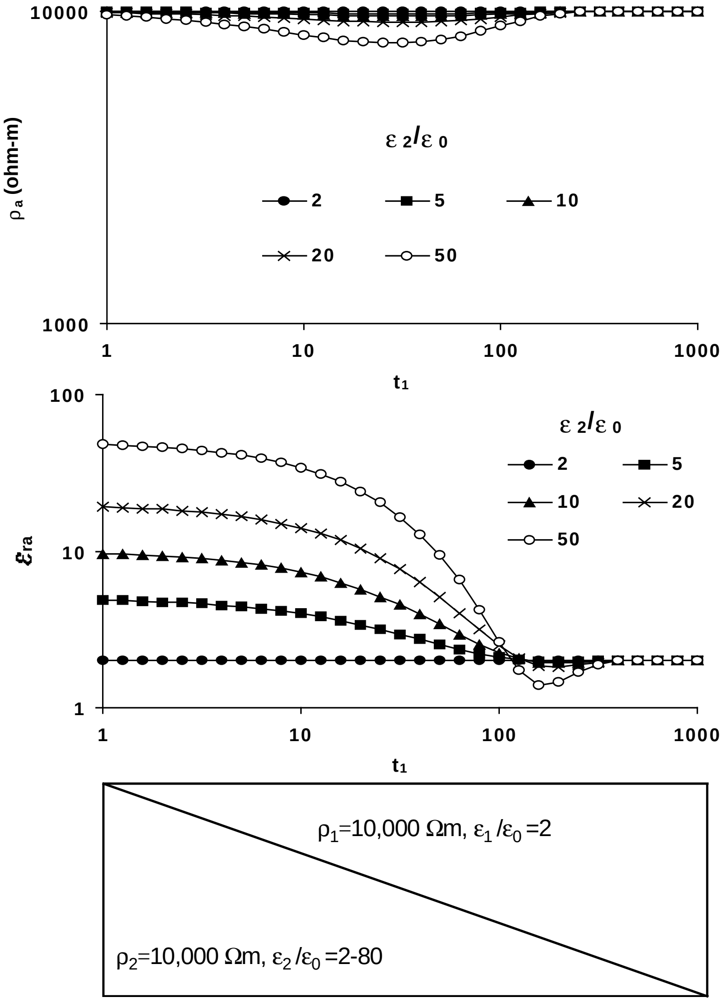

Fig. 3. The apparent resistivity and apparent permittivity for a two-layer model where the thickness of the upper layer t_1 increases from left to right. The resistivity of both layers is 10^4 ohm-m. The upper-layer permittivity is 2 and the basement permittivities are from 2 to 50.

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