Full correction of the electric field data biased by the ECR-effects

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SUMMARY

Electrical exploration on frozen or stony soil is associated with high difficulties in achieving good quality of electrode grounding. In such conditions, the results of high-frequency electric field measurements are often biased due to the electrode contact resistance (ECR) effects, i.e., the capacitive leakage between wires and ground and voltage division at the receiver's input. In this paper we discuss a new method of full analytical correction of the ECR-distorted data.

Keywords: poor electrode contact, capacitive leakage.

INTRODUCTION

High contact resistance of grounded receiving dipoles can significantly distort alternating electrical field measurements in the ground (Vishnyakov and Vishnyakova 1974; Zonge and Hughes 1985). These distortions are mostly due to various kinds of capacitive effects in the receiving circuit, which increase with operating frequency. Thus, in the DC resistivity, induced polarization and magnetotelluric (MT) methods, electrode contact resistance up to 10-20 kOhm is usually considered to be acceptable, while in the audio-MT (AMT) and controlled-source EM induction (CSEM, CSAMT) methods it is generally recommended to achieve values less than 1 kOhm.

In many cases (for example, when working on ice, frozen, sandy and rocky soil), making a dipole with less than 10-20 kOhm grounding resistance is very labor-intensive, not to mention the almost infeasible values of 1 kOhm or less. Unfortunately, electrical explorations with the above methods are often carried out exactly in such unfavorable conditions, especially typical for the Polar Regions. Thus, better understanding of the electric field distortions caused by poorly grounded electrodes, as well as elaborating new ways to solve this problem, is a relevant task for EM scientists.

Below we present a novel approach of full analytical correction of the ECR-distorted electrical field data.

RECEIVING DIPOLE MODEL

To quantify the distortions associated with high grounding resistance, or, as called by Zonge and Hughes (1985), ECR (electrode contact resistance) effects, let us review the equivalent circuit of a grounded receiving dipole (Figure 1).

The following symbols are used in the figure: $R_M\ (R_N)$ is the grounding resistance of the electrode M (N); $C_M\ (C_N)$ is the capacitance between the cable M (N) and the ground; Z_0 is the complex input impedance of the receiver; D is the distance between the electrodes; E is the electric field in the ground; and U_0 is the observed voltage at the receiver's input. U_0 and E are related as follows:

$$U(\omega) = \left(\frac{0.5 + \frac{0.25}{1 + i\omega R_M C_M} + \frac{0.25}{1 + i\omega R_N C_N}}{1 + \frac{Z_{MN}(\omega)}{Z_0(\omega)}} \right) DE(\omega),$$

where ω stands for the angular frequency; i stands for the imaginary unit; $Z_{MN} = Z_M + Z_N$ is the complex contact impedance of the dipole MN; $Z_M = R_M/(1 + i\omega R_M C_M)$, $Z_N = R_N/(1 + i\omega R_N C_N)$.

Separating in this expression the coefficient K_{MN} due to wire-to-ground capacitive leakage from the coefficient K_0 due to voltage division at the receiver's input, we get:

$$U_0(\omega) = K_0(\omega) K_{MN}(\omega) DE(\omega), \qquad (1a)$$

$$K_0(\omega) = \frac{Z_0(\omega)}{Z_0(\omega) + Z_{MN}(\omega)}, \qquad (1b)$$

$$K_{MN}(\omega) = 0.5 + \frac{0.25}{1 + i\omega R_M C_M} + \frac{0.25}{1 + i\omega R_N C_N}. \qquad (1c)$$

For a perfectly grounded dipole Equation 1 yields $K_{MN} \equiv K_0 \equiv 1$, and the observed voltage U is related to the measured electrical field E with a simple expression:

$$U_0(\omega) = DE(\omega). \quad (2)$$

In a real grounded dipole, the voltage recorded by the receiver is always less than the expected value (2), and the degree of bias is governed by the values of complex coefficients K_{MN} and K_0.

CORRECTION OF BIASED DATA

A known way to deal with ECR distortions due to voltage division at the receiver's input is their partial correction based on the estimates of $R_{MN} = R_M + R_N$ values obtained *in situ* at each survey site. It is especially important for receivers with high input capacitance (and hence low input impedance values at high frequencies). For this, many modern MT/AMT stations are capable to autonomously measure the R_{MN} value, which is saved in the device memory and then taken into account at the stage of data processing by normalizing the results by $Z_0/(Z_0 + R_{MN}) \approx K_0$.

A natural development of the method of partial data correction described above is their full correction according to Equation 1 with *in situ* estimates of all necessary parameters – R_M, R_N, C_M and C_N. Such estimates can be obtained using a simple portable LCR-meter or a specially designed impedance meter using the "auxiliary grounding" technique (Bursian, 1972). For this purpose, it is required to ground an auxiliary electrode A at a sufficient distance from electrodes M and N and measure the impedance values Z_{MN}, Z_{AM} and Z_{AN} of the three obtained dipoles at two (at least) frequencies: ω_1 and $\omega_2 \gg \omega_1$. Then, using the following formulas, we estimate the impedance values of the half-dipoles M and N:

$$Z_M(\omega_i) = \frac{Z_{MN}(\omega_i) + Z_{AM}(\omega_i) - Z_{AN}(\omega_i)}{2}, \quad (2a)$$

$$Z_N(\omega_i) = \frac{Z_{MN}(\omega_i) - Z_{AM}(\omega_i) + Z_{AN}(\omega_i)}{2}. \quad (2b)$$

Then we solve with regard to the unknowns R_M, R_N, C_M and C_N the obtained determined (with $i = 1,2$) or over-determined (with $i = 1,2, \ldots$) equation systems:

$$Z_M(\omega_i) = \frac{R_M}{1 + i\omega_i R_M C_M}, \quad (3a)$$

$$Z_N(\omega_i) = \frac{R_N}{1 + i\omega_i R_N C_N}. \quad (3b)$$

Finally, for all operating frequencies, using Equation 1 and known complex input impedance of the receiver we calculate the distortion coefficients K_0 and K_{MN}, and then divide by them the obtained values of the electrical field after processing.

CONCLUSIONS

There are two principal ways of solving the problem of biased data in EM prospecting: 1) – to eliminate/minimize the distortion value in the field, and 2) – to correct the distorted data later at the processing/interpretation phase. In this paper we consider the second approach, which involves the *in situ* estimation of one or more parameters of the receiving dipole with further partial or full correction of the biased data during processing.

The proposed approach of full data correction may help to greatly expand the range of maximum permissible values of electrode contact resistivities for many EM methods with little additional effort. Note that in the capacity of an auxiliary electrode A one may use the central electrode of the receiver (if any) or, in MT/AMT methods – any electrode of the orthogonal receiving dipole.

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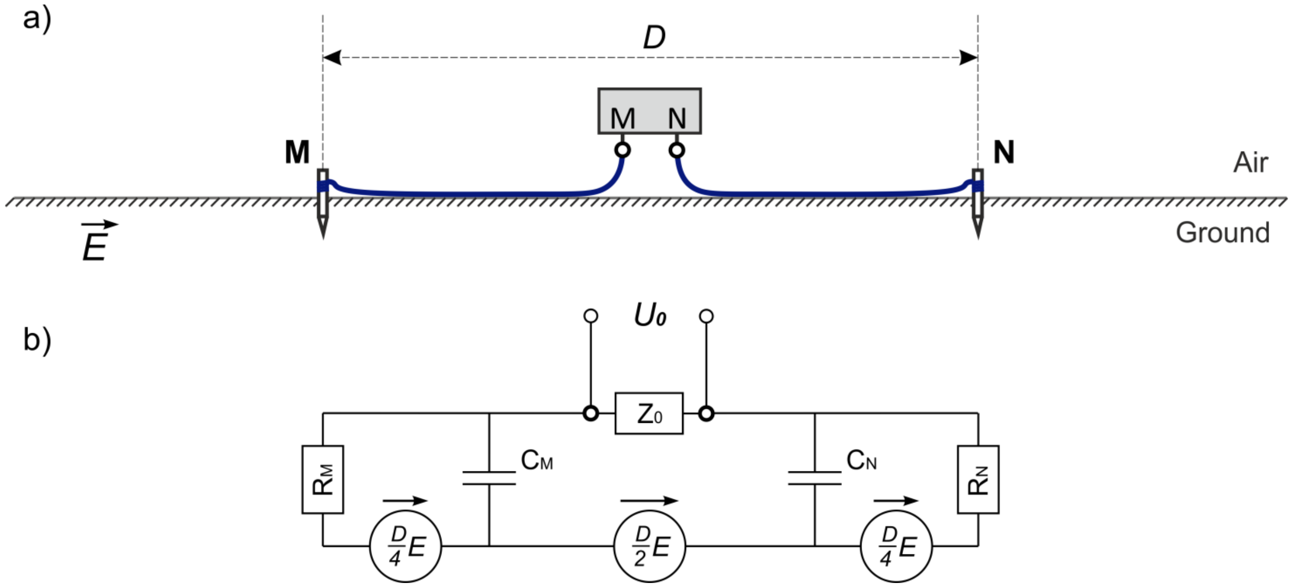

Figure 1. Classic receiving dipole (a) and its equivalent circuit (b).