Z/H MEASUREMENT IN THE RADIO-FREQUENCY RANGE
(10 KHZ UP TO 1 MHZ)

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INTRODUCTION
Shallow subsurface explorations requires substantial and efficient geophysical methods. Among the geoelectrical techniques are the passive EM methods which use existing radio transmitters as the signal source. Consequently they can be set up very compactly, thus being versatile. Compared to the radiomagnetotelluric method (RMT), the well known VLF method is a contactless one, so that a high progress in measurement can be achieved. The Z/H method is a further development of the VLF method by using a wide frequency range, thus giving the possibility of a vertical sounding. The aims of the present work are as follows:

- calculating the magnetic transfer functions in radio frequency range
- increasing the frequency range to 10 kHz up to 2000 kHz.

DETERMINATION OF MAGNETIC TRANSFER FUNCTIONS
As the input channels $H_X$ and $H_Y$ are completely correlated, the usual expression of geomagnetic depth sounding

$$H_z = A_X H_x + A_Y H_y$$

cannot be used to calculate the magnetic transfer function $(A_X, A_Y)$ through a bivariate statistical analysis of time series. This problem has been solved by combining two radio transmitters of similar frequencies ($\omega_1 \approx \omega_2$) but different directions ($\phi_1 \neq \phi_2$). The extended formula is as follows:

$$H_{z1} = A_X H_{x1} + A_Y H_{y1}$$
$$H_{z2} = A_X H_{x2} + A_Y H_{y2}$$

This yields the following expression for the magnetic transfer functions:

$$A_X = \frac{H_{z2} - H_{z1}}{H_{y2} \left( \frac{H_{z2}}{H_{x2}} \right)^{-1} - H_{z1} \left( \frac{H_{z1}}{H_{x1}} \right)^{-1}}$$
$$A_Y = \frac{H_{z2} - H_{z1}}{H_{x2} \left( \frac{H_{z2}}{H_{y2}} \right)^{-1} - H_{z1} \left( \frac{H_{z1}}{H_{y1}} \right)^{-1}}$$

$A_X$, $A_Y$ obviously can be calculated out of four, if necessary, successively measured, transfer functions between two magnetic field components.

The parameters of the Z/H method (like dip angles, tipper, strike direction and skew) have been calculated from the magnetic transfer functions (Jupp et al., 1972). The induction arrows are a graphical representation of $A_X$ and $A_Y$ (Schmucker, 1970):
\[ c^r = \sqrt{(A_x^r)^2 + (A_y^r)^2} \quad \delta^r = \arctan \left( \frac{A_y^r}{A_x^r} \right) \] "Real" arrow

\[ c^i = \sqrt{(A_x^i)^2 + (A_y^i)^2} \quad \delta^i = \arctan \left( \frac{A_y^i}{A_x^i} \right) \] "Imaginary" arrow

**INSTRUMENTATION**

The four components of the measuring device are as follows (Figure 1):

- **Induction-coil magnetometer**: two aerial loops with 50 cm diameter.
- **Ultra low noise preamplifier**: $\Omega \cong 0.14 \text{nV/} \sqrt{\text{Hz}} \equiv 0.5 \text{fT/} \sqrt{\text{Hz}}$ at $1 \Omega$.
- **Heterodyne receiver**: the lack of fast and high resolving A/D converters required the use of this heterodyne receiver. This receiver selects an optional frequency range (bandwidth=4 kHz) between 10 kHz and 2.5 MHz. This signal will be set on a lower midfrequency (4 kHz) through multiplication with a monofrequent signal. Further processing of the resulting signal can be executed by using commercial A/D converters.
- **Computer**: the base of the calculation of the magnetic transfer functions are the recorded time series. The statistical procedure has been taken from the magnetotelluric method. Absolute value, phase and a confidence interval (statistical error) are calculated. Additional processing is executed only on the frequency that shows the highest coherence between the two channels. Usually, this is the carrier frequency of the selected radio transmitter.

**FIELD EVALUATION**

The practical testing has been carried out at Schöneiche. This area covers 300 m by 300 m and is located approximately 30 km south of Berlin, at the northern outskirts of waste dump Schöneicher Plan. Earlier geophysical investigations already had provided detailed information on the conductivity structures. RMT measurements were part of the pre-exploration (Fig.2). These measurements had been executed by Prof. I. Müller (Neuchatel, Switzerland). Having been measured under four different frequencies, the measured apparent resistivities represent distinct exploration depths between 3 and 12 meters.

Fig.1: Scheme of the Z/H instrument.
A north-to-south profile was chosen to carry out the dip-angle device’s proof and this coincides with RMT profile 100.

The calculation of the magnetic transfer function \((A_X, A_Y)\) requires four separate measurements. At first, all selected frequencies are measured through a northly aligned aerial configuration. Through this, the transfer functions between \(H_Z\) and \(H_X\) along the profile can be determined. And the end of profile, the aerial has to be turned east and to measure out \(H_Y\), the entire measurement has to be executed again alongside the same profile to determine the transfer function between \(H_Z\) and \(H_Y\). Finally, transmitters of neighbouring frequencies are used to calculate the magnetic transfer function \((A_X, A_Y)\). The field test has clearly shown that direction differences of 30° are sufficient.

Following Schmucker (1970), the „real“ arrow is directed to the poor conducting structures. Only the reach of approximately one skin depth has any influence on the arrow. Its length scales to the lateral resistivity contrast.

The results agree with the RMT results (Fig.3); the arrow points to the low conductivity structure: 0-40m: to East; 40-55m: to North-East; 55-130m: to South resp. South-East.

**FURTHER WORK**

Research is progressing on the following:
- 3-component superconducting magnetometer (SQUID)
- Digital receiver for simultaneous measurement of all frequencies
- RMT measurement up to 250 kHz
- Measurements below 10 kHz with controlled source
- Modelling and inversion of magnetic transfer functions

**REFERENCES**


Fig. 2: RMT measurements
The apparent resistivites at four different frequencies are shown. The exploration depth increases from top to bottom.

Fig. 3: Z/H measurements
Induction arrows (following Schmucker (1970)) along the profile 100.