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Geotomographic studies for ore explorations with the EMRE system

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ABSTRACT

A new geophysical borehole prospecting method has been taken into use at the Geological Survey of Finland (GTK), known as the radiofrequency imaging method (RIM). RIM is a high-resolution technique and useful for second-stage explorations and ore body delineations, assisting, e.g. with strategic mine planning and large rock building projects to determine the structural integrity of the rock in the area of interest. It is a computerised tomography method that is based on the radiowave attenuation between the boreholes, making it possible to reconstruct the attenuation distribution of the borehole section (tomographic image). Under certain conditions it may also be possible to convert the high p-domain attenuation to the electric conductivity and use it to determine the relative permittivity in the low p-domain. The system consists of a continuous wave (CW) borehole transmitter and borehole receiver. The transmitter and receiver deploy insulated dipole antennas to radiate and receive electromagnetic energy. The borehole transmitter of the system is the core where the four measurements frequencies (312.5, 625, 1250 and 2500 kHz) and the vital references frequency (156.25 kHz) are generated. The reference has its importance in the proper detection of phase difference and amplitude. This paper presents the first experiences with the RIM device in Finland, dealing with the technical characteristics of the instrument and comparisons with results measured by other systems (resistivity logging and transient electromagnetic method). Presently, the device is the main part of the borehole system known as EMRE (ElectroMagnetic Radiofrequency Echoing).

1. Introduction

The radiofrequency imaging method (RIM) is a geophysical technique where a bistatic antenna system measures the decayed or attenuated field from a dipole antenna between two deep boreholes at radio frequencies, 100 kHz to 5 MHz. A transmitter is fixed in one borehole while a mobile receiver takes readings in another borehole. The transmitter is moved between sets of receiver position. The survey is accomplished by transferring the transmitter and receiver in the boreholes. The technique is known as a full tomographic survey (*a two-way measurement*). RIM can be used e.g. to scan the subsurface faults and geological contacts, to delineate conductive mineralizations, in mine planning and in determining the structural integrity of the rock.

The first studies concerning electromagnetic wave propagation through the earth date back to the beginning of the 20th century. Sommerfeld and Weyl performed rigorous theoretical studies with vertical antennas, and their formulations are useful even today. Eve and Keys conducted measurements where the propagation of electromagnetic waves through earth materials was also established. The Russian scientist Petrowsky used buried antennas and managed to receive fields in the earth. He calculated the attenuation constants of porphyry and sedimentary rocks at several frequencies [1]. The work was

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continued by Lager and Lytle [2], Lytle et al. [3] and Somerstein et al. [4]. Stolarczyk and Fry [5] used RIM to detect faults in the continuity of coal seams, and this can be considered as the starting point of RIM. Russian experts carried out intensive studies using RIM with good results during the late 2000s [6]. They measured the decayed or attenuated field and compared it to the theoretically calculated field decay in a homogeneous medium to estimate the conductivity. The Miningtek Pluto-6 system was developed by the Division of Mining Technology of the CSIR [7]. The frequency synthesis ranges from 1 MHz up to 30 MHz, and the gain is effectively adjusted to maintain the power at 1 W. The JW-4 system was developed by the Chinese Institute of Geophysical and Geochemical Exploration (*IGGE*). The group used a technique where the cross-sectional image was reconstructed from the ratio of decayed fields at two frequencies [8]. In 2010, Geological Survey of Finland (*GTK*) took into a productive use a RIM system, known as the EMRE system.

RIM is based on the attenuation of electromagnetic signals in the region between two boreholes. The summary plot, where the received amplitudes are gathered in the same plot, is an useful and simple way to delineate the possible targets. Using a plane wave assumption (*far-field*), the measured amplitudes can be converted to the attenuation distribution of the section. Electrical resistivity logging of boreholes is an important exploration technique in identifying mineralised zones in a close proximity to a borehole wall. It is usually the first logging method used on a new borehole. The measurement of resistivity is related to the conductive rock materials near the borehole [9]. The transient electromagnetic method (*TEM*) is an electromagnetic method (*EM*) functioning in the time domain, in contrast to frequency domain methods (e.g. *RIM/EMRE*). Using TEM, the electrical resistivity of the underground layers can be measured down to a depth of several hundreds of metres. TEM has proved effective for detecting deep anomalies at distances of hundreds of metres from the boreholes [10].

A comparison of RIM and the resistivity logging method gives the same results under certain circumstances, the conductive zone near the borehole must be conductive enough to be detectable with RIM, but located a little further from the borehole, the logging loses its sensitivity but RIM's ability is even enhanced. When comparing TEM and RIM, the conductive anomaly can be located reliably by the both methods. However, when the distance from the boreholes increases over few hundreds of metres, TEM loses its sensitivity. The depth dimension can also be a restrictive issue with TEM if the loop size cannot be increased. On the contrary, RIM can be used all along the borehole and at the distances where the boreholes are separated by even one thousand metres. The results of the logging method and TEM are usually presented as curves but in RIM, the reconstructed attenuation distribution of a section can be presented as a visual and informative image of frequency dependent response of the subsurface materials to the propagating of electromagnetic waves at a used radio wave frequency band. Fig. 1 presents the main components of the EMRE system.

2. Continuous wave (CW) and superheterodyne technique

Electrical radio communication can be accomplished by two principal means, *radio and wire*. Electromagnetic waves are used in radio communication without any physical guiding path, but communication by wire requires conductors to carry the waves. Modern radio transmitters include continuous wave (*CW*), amplitude-modulated (*AM*), frequency-modulated (*FM*) types. The CW type was the first to be developed, and is still used in long-range communication. The narrow bandwidth, making it possible to use minor power supplies, is also one of its advantages [11]. The EMRE system consists of borehole devices that are based on the Russian inventions [12,13] (Fig. 2).

The main components of the transmitter (*CW device*) are an oscillator, a division circuit (*F/2-4-8-16*), amplifiers and an antenna (Fig. 3). The generator is the core, generating the required base frequency. The voltage and power amplifiers are the means to amplify the oscillations and the antenna is used to radiate electromagnetic waves.

Fig. 3 presents a block diagram of a CW device. The oscillator (e.g. *quartz crystal*) generates the radiofrequency (*RF*) carrier at the basic frequency of 2500 kHz, maintaining it accurately. The other measurement frequencies (1250–625–312.5 kHz) and the vital reference frequency (156.25 kHz) are generated from a basic frequency in a frequency divider circuit (*F/2-4-8-16*). The selection of measurement frequencies can freely be done by the jumper settings (*S*). The selected frequencies are conducted to the power amplifiers (*E*) through the buffer amplifiers (*B*). Applying a transformer circuit (*T*), the RF signals are sent to the antenna. Thus, the antenna's function is to serve as an interface between the generator and the surrounding environment.

It was the development of superheterodyne receivers that revolutionized the receiving technique. In the superheterodyne receiver, the incoming signal frequency is changed to a lower frequency, known as the intermediate frequency (*IF*) and the major part of the amplification takes place at IF frequency before detection. The antennas are the transducers between the device and environment, or together they form a transmission line. The receiver processes signals by performing certain basic functions such as reception, selection and detection having some general and important characteristics, namely sensitivity, low noise level, selectivity and fidelity. The sensitivity of a receiver is the minimum RF signal level that can be detected. The best way to improve the sensitivity of a receiver is to reduce the noise level (e.g. *reducing temperature*, *bandwidth*). Selectivity, receiver's ability to discriminate the wanted signals, is the most important feature for sensing small signals in the presence of strong interferences. Fidelity is a measure of the ability of a receiver to reproduce the original source information. The dynamic range of a receiver is the input power range over which the receiver is useful. The dynamic range of the EMRE receiver is <40 dB. It should be at the level of 60 dB that could easily be reached by a modern receiver solutions, thus being a limiting factor in the system. In principle, the EMRE receiver consists of