BEM, Broadband Electromagnetic Smart Method, phenomenology, theory, applications

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ABSTRACT

In this study a novel electromagnetic method, called BEM, is presented for investigating underground layers and anomalies. This method works in broad band frequency range of signals to transmit a pure magnetic field through the soil and receive an electromagnetic response using a wide range frequency domain receiver, in addition to being effective in detecting conductive targets, covers the present weak electromagnetic methods in recognition Non-conductive targets. Although, it is possible to use a time domain receiver which in that case, using a FFT transform the received signals can be monitored in frequency domain (Paal, 1965). . In this paper after a brief review of shift phenomena and theoretical schemes, a comparison between BEM method and other approaches on synthetic data are described. Ultimately and two real case studies are presented for a better vision .

Keywords: (BEM, EM, Electromagnetic, Broadband, Machine learning, Airborne, Synthetic, Smart Exploration)

INTRODUCTION

Due to the physical properties of materials such as dielectric constant, electrical and magnetic susceptibility, density, and etc., their radiated electromagnetic field will be polarized differently. So as a result, the reflected wave from the material in shape and energy dependently will differ. If the non-linear properties of dielectric and also the dependence on the frequency of the incident wave to be considered, due to energy considerations, and the amount of radiation at frequencies close to the frequency of the incident, wave will be reflected with different energy and shape. Measuring the reflected waves whose shape has been changed relative to the primary signal of the incident characteristics like the shape difference, the amplitude and phase of the signals, we can retrieve a precise knowledge of the materials structure, such as polarization, dielectric type, electrical resistivity, amount of the dielectric constant of materials, the type of reflective layer, it's shape and depth (Hummel, 1932), (Seigel, 1959). These all are useful in realizing the need of introducing frequency shift phenomena, by solving Maxwell equations analytically and considering machine learning in order to interpret the inversion outputs model. Accordingly, high quality results are gained on both artificial model and real data. This method can produce three outputs (dielectric coefficient, conductivity and resistivity) which are helpful in exploration procedures and even identifying the type of material .BEM technology has a very good result on both electrically conductive and nonconductive, magnetize and non-magnetize materials.

Method and Theory

In order to determine the dielectric properties of the constituent materials or layers of the earth, it is necessary to illuminate a variable field (with specific changes) on the earth's surface and measure its dependent changes. From the changes created in the phase and intensity of the reflected wave, the average electrical conductivity can be obtained. Furthermore, due to the different layers of the dielectrics and according to the process of absorbing and reflecting the waves, several different frequency shifts (more than one shift) are observed (Sato, 1960), (Reynolds, 1997), (Abdullaev, 2004). Similar to the Wait model (Wait, 1982), a layered model can be achieved using Mundry (Mundry, 1984) approximation. On the other hand, calculations can be a little more precise and the wave equation can be solved after digitally solving it numerically for real data. For this purpose, it is considered a pure magnetic field. Thus, under

Maxwell's equations, a wave equation is obtained as follows in which H is a magnetic field (Jackson, 1999):

$$\nabla^2 H + k^2 H = 0$$

$$k^2 = \omega^2 \varepsilon \mu_0 - i\,\omega g\,\mu_0$$

Which g is environment conductivity and Ω is frequency. Solving wave equation in spiral in the cylindrical space, the answer appears as Bessel functions as follows:

$$H = \sum_n A_n J_n(\gamma_n \rho) e^{-i(\alpha z - \omega t)}$$

$$\gamma^2 = \omega^2 \varepsilon\, \mu_0, \alpha^2 = i\,\omega g\,\mu_0$$

Considering a time symmetry (frequency domain), the time sentence is removed and the answer, which has a fluctuating sentence and a weakening sentence, appears. In the first approximation, for a uniform environment we have:

$$H = AJ_1(\sqrt{\omega^2 \varepsilon \mu_0}\, \rho) e^{-i\frac{\sqrt{2}}{2} z\sqrt{\omega g \mu_0}} e^{-\frac{\sqrt{2}}{2} z\sqrt{\omega g \mu_0}}$$

Which ρ is the radial distance and z is the depth of the layer.

If we assume a layer model and generalize the equation for each layer by entering the coefficients of passage and reflection R and T, we will eventually have an equation that gives us the output wave of the model layers at the point of study. By sending a square wave packet with a specific center frequency, it is possible to obtain the shift. Inversion model uses this shift as a correction for frequencies thus the results of the forward and inversion model, written in this way, are in perfect agreement with the values obtained from the artificial data (Zhadanov,2009) (Telford,1990).

After data acquisition and before inversion phase, a few processing steps must be applied on the data. The first step is QC of recorded data to make sure that these data are recorded correctly and S/N ratio is good enough. Second step is using noise attenuation techniques on data to remove random noises without any effect on the data. After these steps, data is ready for inversion progress. The basis of the processing and interpretation of the data in this method is based on solving Maxwell equations for a forward model and then solving an inversion problem for the data with relative boundary conditions.

The final task is to obtain the precise values of the initial variables and afterward is the step of determining the precise values of the specific resistance, the coefficients of electrical permeability and magnetic susceptibility of the environment, and finally the types of layers or reflecting points can be estimated. Initial values for inversion are determined using geological information, previous studies and report of the field observation. As it is mentioned above, BEM device consists of a transmitter and a receiver which work in broad band frequency range (Broad band Frequency Domain Electromagnetic Device). Of course they can work in time domain too. Transmitter can transfer several frequencies simultaneously. It is a point that makes it possible to analyze received data in several frequencies which belong to different depths and after that comparing results with each other can help researchers find a better vision of what’s going on, in different layers. BEM transmitter is 14 kg and its 50*50cm receiver has 10 kg weight. The NS for transmitter is 800 and for receiver is 1200. The receiver is high sensitive (-140db) which is able to work with frequency range from 100 Hz to 40 KHz and separate subsurface layers based on resistivity. As well as being sensitive to nonconductive layer, it is able to increase power of intensity to investigate deeper sections.

Here is a comparison of BEM method with the smoothness-constrained inversion algorithm CRTomo introduced by Kemna (Kemna, 2000) and used by Robert & Caterina (Robert, 2012) (Caterina, 2013). BEM method is used to create a synthetic dataset with an offset of 9 meters. The number of frequencies components in the electromagnetic signal is 15.figure 1 is shown synthetic fractured resistivity model representing sharp lateral contrasts of electrical resistivity between different rock formations that are more or less fractured (Robert *et al*. 2011 – site F5). The inversion Result of the BEM Method is shown in figure 2. As it is observable, The thickness of all layeres in the inversion of the frequency domain data in BEM method can be determined with an accurate approximation, which has not been determined.In CRTomo method. Resistivity of some layers exactly is compatible with synthetic model although in other layers is not seen. Also in separation of layers with different resistivity, BEM method has a better result. In conclusion BEM method has a better result in comparison to CRTomo method.

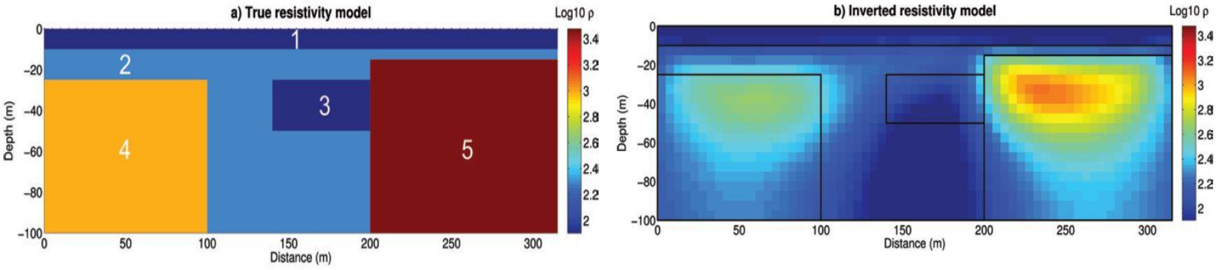

Figure 1. a) True resistivity model, b) inverted resistivity model. This synthetic model is based on a real case study (Robert *et al*. 2011 – site F5).

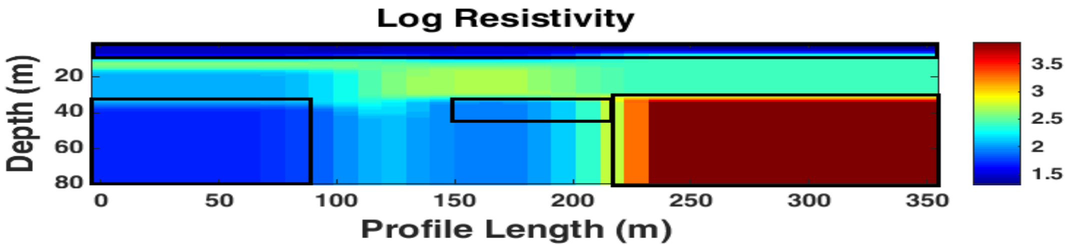

Figure 2. Inverted Resistivity Model Using BEM Method

First Case study: (A playa case for potash in Khoor and Biabanak in Iran)

Figure 3 is shown that the flatness of clay under playa which has very small changes: (this data is about well number 8 to 4 which were stablished in the area)

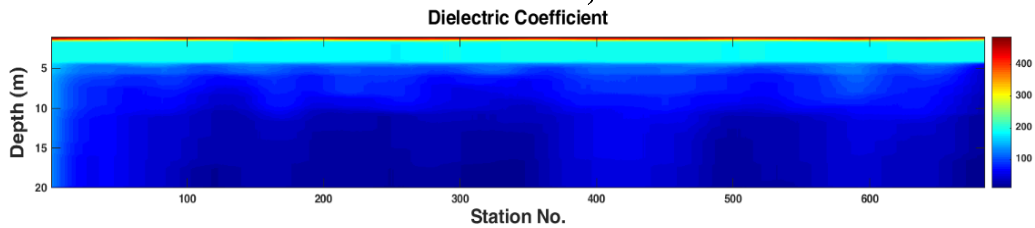

Figure 3. playa case study for long range data acquisition

Figure 4 is shown the 2nd profile was carried out over the unknown well which after the exam it appears that the salt thickness in that well is near 7.7 meters.

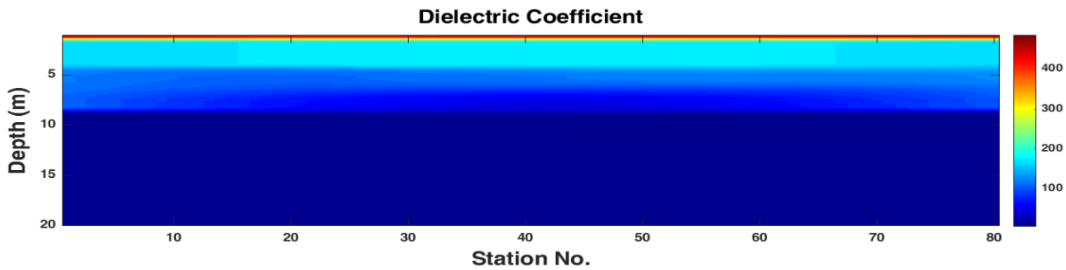

Figure 4. playa case study on exam well which shown average 7.5 meters of salt

Second Case study: (Chromite)

Using BEM method to investigate chromite ore by interoperating the dielectric constant of bed rock is shown in figure 4.

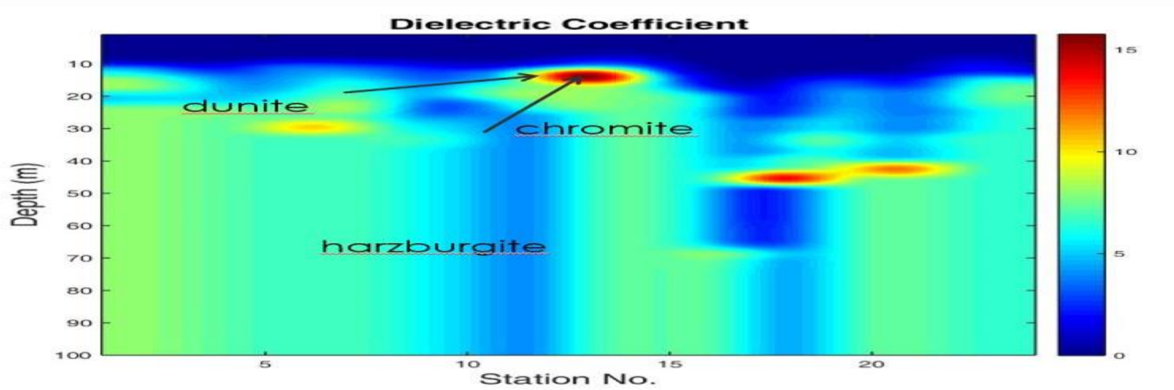

Figure 4. Chromite in harzhurgite medium in Olang Sabzevar in Iran

CONCLUSION(S)

BEM technology is a unique and creative geophysical technique that investigates subsurface structures by analyzing the reaction of layers components to the electromagnetic waves in frequency domain. According to what presented in this paper, BEM method outputs are developed comparing to conventional EM technologies, which can be observed in playa and chromite case studies. Working with EM methods in playa environment is hard because of lack of current and wave penetration in these places. On the other hand, geophysical techniques are not suitable for chromite because of similarity between bedrock and mineral. But as it is shown here, BEM method by combining the results of dielectric and resistivity outputs is able to reach more accurate results. It is notably that using geological data as the input of this method, not only BEM is not a geophysical approach, but also it is a useful and trustworthy exploration one. This technique helps researchers to perform water exploration, metallic and nonmetallic exploration, fault detection and to identify any anomaly that exists in subsurface in both shallow and deep parts, all around the world. In places with hard accessibility like mountains that are dangerous for human to reach or in complicated regions, in separation of layers with different resistivity, BEM method has a better result. The sub-layer with low resistivity is determined in BEM result, also dielectric constant output of BEM method can give us a better understanding and resolution in determining underground anomalies.

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