# Optimizing Electric Dipole Source, Transient Electromagnetic Data Acquisition Configuration Using Sensitivity Analysis


## Investigators

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## Introduction

In the past few years, there has been a growing interest in the electric dipole source electromagnetic (EM) method for both environmental investigations and petroleum explorations [1-3]. A primary reason for the recent interest in the method is based on the fact that the method can successfully distinguish between electrically conductive background media (e.g. aquifer environments and seabed) and resistive targets (e.g. sequestrated $CO_2$ plumes, petroleum/gas reservoirs, and organic fluids) [1-4].

Many active research studies are currently underway to improve the method in different ways. A particular goal of this research is to evolve this prospective technique from a simple profiling tool to a sophisticated imaging and monitoring tool for the thin resistors mentioned above. As a starting point for this research, this report organizes the basic steps that are necessary to determine its optimal data acquisition configurations for a given exploration scenario especially when multiple electric dipole sources are employed.

## Background

We have recently identified the important factors governing the sensitivity of a transient electric dipole to thin resistors and also elucidated the roles of multi-source configurations for better sensitivity. Readers are referred to [5] for details. However, despite the newly recognized importance of multiple source configurations for better sensitivity to thin resistors, there has been little research about how to position multiple electric dipole sources and receivers in an optimal manner.

Recent technological advancements in computerized electrical and EM geophysical equipments have made possible to employ multiple sources and receivers simultaneously in various acquisition geometries [6]. Among various electrical and EM geophysical tools, the electrical resistivity tomography (ERT) method seem to utilize the flexible and versatile nature of acquisition systems the most effectively. Although the borehole-based ERT application to imaging large-scale resistors mentioned above seems impractical because of excessive requirements for boreholes [7], its strategies for designing the optimum configuration give us useful insights into how to do the same thing for the surface-based electric dipole Transient EM (TEM) method. Therefore, in the following section, ERT approach to determining optimal survey parameters will be explicitly employed for this study.

## Results

A classic approach to determine the optimal survey parameters for a given exploration scenario is to formulate the sensitivity of a candidate source-receiver configuration to a specific subsurface volume in which a geophysical target lies. In order to derive an expression for the sensitivity of the electric field at **r** with respect to a change of electrical conductivity in a sufficiently small volume *V* at point **r’,** we start with the electric dipole source-receiver configuration shown in Figure 1 along with the time-domain integral equation [8]:

$$\mathbf{E}(\mathbf{r}, t) = \mathbf{E}_\mathrm{p}(\mathbf{r}, t) + \int_V \int_0^t \boldsymbol{G}(\mathbf{r}, \mathbf{r}', t - t')\mathbf{E}(\mathbf{r}', t')\sigma_\mathrm{a}(\mathbf{r}')\, dt'dv' \qquad (1)$$

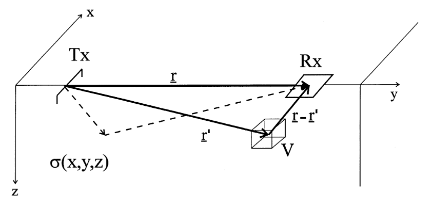


**Figure 1**: Geometry for calculating sensitivities [8].

**E(r,t)** represents the transient electric field measured at a receiver point **r** at time t. **E(r,t)** can be expressed as the sum of the primary field, $\mathbf{E_p}$ and the scattered electric field induced by the anomalous current in *V*. $\boldsymbol{\sigma_a}$ is the anomalous conductivity, and ***G*** is the electric field Green’s function that relates the current at **r’** to the electric field at **r**. If *V* is sufficiently small, both $\boldsymbol{\sigma_a}$ and the electric field can be assumed as constant values in *V*. With some minor mathematical manipulation of Equation (1) along the assumption above, Equation 1 reduces to

$$\frac{\mathbf{E}(\mathbf{r}, t) - \mathbf{E}_\mathrm{p}(\mathbf{r}, t)}{V\sigma_\mathrm{a}(\mathbf{r}')} = \int_0^t \boldsymbol{G}(\mathbf{r}, \mathbf{r}', t - t')\mathbf{E}_\mathrm{p}(\mathbf{r}', t')\, dt' \qquad (2)$$

The left hand side of Equation (2) can be thought of as the sensitivity for the measurement of the transient electric field at **r** with respect to an anomalous geo-electrical cell at **r’** [8]. Here, ***G*** is computed by placing a fictitious source at **r** and calculating the electric field at **r’**. This computation is performed over 2D/3D subsurface for a single source position and multiple receiver positions, producing successive sensitivity matrices over time. The sensitivity matrices will provide a full understanding of EM data acquisition process for a single source configuration in a quantitative manner. More importantly, the sensitivity matrices can be used as a building block to produce an additional sensitivity matrix for complex multiple source configurations via a linear combination. By adjusting weighting factors (e.g. source moments) in the linear combination, we can investigate sensitivity changes with different source combinations and determine the optimal multiple source configuration that produces the largest galvanic response for a resistive target in depth.

Another important factor we need to consider for a better sensitivity is the nature of an electric dipole source. The transient EM fields generated by an electric dipole consist of the two different modes: the transverse magnetic (TM) mode and transverse electric (TE) modes. The TM mode has vertical currents that interact with a resistor and produce anomalous perturbation in the background EM fields. However, the perturbation can be easily masked by the near-surface TE mode component (i.e. near-surface horizontal currents) at measurement points [5]. Note that the near-surface TE mode component does not have any information about the resistor in depth. Therefore, it is also of our interest to reduce the amount of the TE mode component as much as possible at least at the measurement points. In order to do so, we break the source field into its TE and TM components.

$$E_s(\mathbf{r},t) = E_s^{TM}(\mathbf{r},t) + E_s^{TE}(\mathbf{r},t) \qquad (3)$$

Here, we simply drop the TM source term in Equation (3) and have only the TE source term in a forward modeling scheme. The modified forward modeling scheme will compute only TE mode responses over a given subsurface model at multiple receiver positions [9]. This computation will produce a vector whose elements represent the positive/negative amplitudes of the TE mode responses at receiver positions for a given source position. Again, the linear combination of vectors of different source positions will allow us to determine the best multi-source configuration in which the near-surface TE components generated by multiple sources will be cancelled out each other as much as possible. Therefore, for a given exploration scenario, finding the final optimized multiple source configuration is to get the balance between the maximizing galvanic response at target depth and minimizing near-surface TE mode effect at measurement points.

## Progress

Optimal positioning of multiple electric dipole sources can improve the sensitivity of the surface-based electric dipole TEM method especially when a target is spatially localized in depth. In practice, its potential impact would be assessed by investigating whether or not the optimal multiple dipole source TEM data can resolve a deep localized target as sensitive as sparse-borehole EM data set [10] does.

## Future Plans

My future research will primarily focus on formulating 2D/3D time-domain finite element schemes. The procedures for determining optimal multi-source configurations will be implemented by modifying the new forward modeling algorithm.

## Publications

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