Algorithms in EMIGMA

Electromagnetic Algorithms

There are a number of different algorithms in EMIGMA for EM. This is because it is difficult to simulate all of the scattering processes under all geological and geotechnical situations. We will try to summarize the different algorithms, their purpose and situations in which each is suitable. You will find a variety of technical papers on our website which discuss the algorithms more extensively.

Sphere: This solution can be very useful for studying EM scattering in either FD or TD as it is a very general solution but limited to a sphere in a wholespace and excited by a magnetic dipole. Sphere and background may have arbitrary conductivity, susceptibility and electric polarizability and even very high frequencies well above 1MHz may be used.

This solution was initially proposed and developed mathematically by Debye early in his career as a solution of the differential equation in spherical harmonics and shown to be convergent. There were numerous people who developed numerical solutions for a few harmonics including Wait (1953) and Harrington (1961). Groom (1993) attempted to solve for a convergence series but was unable to ensure convergence as for higher orders the coefficient calculations became unstable but found that generally a few coefficients did not provide even reasonable results as the converged solution required much higher number of harmonics. At the time T. Habashy suggested a technique to derive stable solutions by a unique method for this problem but used in other spherical harmonic problems. Groom (1994) was then able to develop a numerical solution for up to 200 harmonics which was stable and generally convergence for most situations.

This approach is has been included in EMIGMA and implemented for time and frequency domain problems. It has been generalized for magnetic or electric sources as well as electric and magnetic point receivers.

However, it must be understood that we do not know whether this complete set of orthogonal functions represents all EM scattering. For example, we do not know if this solution represents reflections at radar frequencies from a highly conducting surface.

Plate Solutions: The term plate algorithm means the model is not the shape of a dinner plate but rather a rectangular body which has no thickness. Instead of a thickness it is defined in terms of its integrated conductivity thickness and this is given as conductance in units of Siemens (S). The purpose of these algorithms is to represent the inductive response of the plate due to excitation from the primary magnetic field of the source. This type of algorithm has a long history and includes developments by Annan, Lamontagne, Lee, Lajoie, Raiche, and Walker. The use of these algorithms was historically developed for mining applications for conductors using a magnetic source.

There are 2 plate algorithms in EMIGMA, FSPlate and VHPlate.

The freespace algorithm is based on the mathematics of Annan. This was first developed as a useful algorithm by Bloore and Dyck. This solution computes a distribution of currents on the plate due to a magnetic source in terms of eigenvalues sometimes termed eigencurrents. We have re-developed the algorithm to provide more stable solutions and for more eigencurrents. The solution is almost always stable to 11 eigencurrents but sometimes for more. The solution is quite different of MultiLoop III and Maxwell in that the currents have more than a dipole solution and the currents may migrate over the plate. The solution is only for magnetic sources and magnetic receivers but is available in EMIGMA for both TD and FD. Additionally, we have provided the solution in TD in 2 processes. First, directly in TD assuming a theoretical infinite bandwidth system response and secondly by computing a practical band limited system response in FD and then transformation to the time domain. In addition, we have included a background response which is superimposed on the plate response allowing for interpretation which represents both the background and target response. The plate aspect ratio can be quite varied and can rotate about 3 axes. Multiple plates may be used but no interaction is computed.

The second plate algorithm is modified from the formulation and algorithm of Walker but we still give it the original terminology of VHPlate. This algorithm is more general than the FSPlate in several important aspects. First, both a magnetic and an electric source (current bipole) can be utilized and secondly, both magnetic and electric field receivers may be utilized. More importantly the computed response includes not only the inductive response due to the primary source field but also the effects due to the induced currents in the background (i.e. current channelling). The formulation also includes the interaction between these two scattering processes. The model consists of both the plate and a layered background which may be polarized but no effects due to susceptibility are computed. The solution is computed in the frequency domain (FD) and then transformed to the time domain (TD) if required. Multiple plates may be utilized but no interaction is computed which is a limitation when compared to MultiLoop. An additional, restriction is a limitation on the aspect ratio (Length: Width) generally for a ratio of no more than 6. An important issue for interpretation is that this algorithm is much slower than FSPlate.

3D Integral Equation Solutions: There have been many algorithms for computation of controlled source EM for 3D problems using Finite Difference, Finite Element and Integral Equation techniques. Historically, some of the best known are the IE codes of Hohmann and a number of his students developed from the 1970’s until into the 1990’s and the codes of Raiche and his students from the 1980’s into the present century.

All of these versions of these software codes and many others suffer from some important issues. Speed of computation was, of course, a major problem in the past for all of these techniques for 3D models for controlled source. This problem can be resolved today by arrays of processors but this becomes an expensive proposition and not suitable for day to day interpretation by practicing geophysicists. Another major issue was the inability to compute solutions near the anomalous structures, on the surfaces of the structures and inside the structures. High gradients of the source fields were also a problem as well as contrast ratios. Another issue was the lack of proper interaction between bodies. For example, in the last versions of the Hohmann et al codes, a significant failure could be viewed by computing a simple model of a cube in a halfspace then dividing this model in two and making one half only slightly more conductive. The results of the 2 models were vastly different. This pointed to a common issue in these codes and this was the self interaction terms of cells dominated everything else. This is quite predictable in the sense that these terms are the largest and thus the other interaction terms are lost in the noise of the numerical computations without some specific method to maintain these terms.

It was for these reasons that another technique which was based upon a variety of analytic solutions was proposed in the early 1990’s at SDR labs by T. Habashy and R.Groom. These techniques have been developed and extended by a variety of workers at Petros Eikon including principally Groom, Walker, Murray, Alvarez and Jia.

LN (Localized Non-Linear): This is an Integral Equation (IE) technique. This technique was originally developed for three specific purposes. First was to provide a fast technique to solve the IE equation electric field problem, second to provide a solution with fast convergence and third to provide a solution in which electric and magnetic fields could be calculated close to the scatterer and conversely when gradients of the source field were high. The first algorithm was originally developed and tested for a sphere at SDR by Groom and Habashy. Later the technique was extended for a prism by Groom and later for high frequency by Alvarez and then for an arbitrary polyhedra by Alvarez. For a prism for a wide range of single target models, for a wide range of frequencies and for a variety of sources, the technique matches the results of Hohmann, et al. as long as the source gradients were not too large, the receivers too close to the model and the frequencies too high when the Hohmann code would be begin to break down. Also, of critical issue was the reproduction of the response of resistive models another issue which tended to fail in the historical codes.

The technique was extended for a variety of purposes including models both conductive and magnetic and for conductive and resistive models which are also polarizable under a Cole-Cole model for both magnetic and electric sources. But, the important issue that we were able to accomplish with this technique was interactions between bodies. An important issue in IE techniques is when a body plunges between two different strata. The source and induced currents will excite both the top and bottom of these bodies and currents should flow between them. Most codes can be shown to only produce superposition of the top and bottom response with no current flows between them. We have been able to produce the correct current flow with one type of interaction technique. Another important issue is when 2 bodies are separated but the fields from one body additionally excites the other. We have been also able to produce this type of interaction.

Another critical issue was the use of extended electrical sources and receivers. Even today, most CSEM codes use point receivers and some point sources. Important issues in many surveys are the true geometry of extended sources as in grounded sources which terminate in the borehole, large sources which cannot be laid out in a straight line due to logistical reasons and measurements which require voltage readings with large distances between electrodes to provide sufficient signal strength. This technique allowed for the development of all of these capabilities and even more not mentioned here.

ILN (Inductive Localized Non-Linear): This is also an Integral Equation (IE) technique. The generation of EM solutions for non-plate conductors to include both inductive and galvanic effects has long been problematic for any type of solver. The LN technique proved to be a very rapid and accurate solution and extensions to this technique had been suggested. One such approach was the ILN technique proposed and developed by us. A brief description of the approach is given on our download pages in the papers by Murray *et al.*

Up to that time, there were no 3D solutions which provided anything but a weak inductive response. So, our intention was not to provide an accurate solution but an approximate solution. It is critical to understand if using this technique that it is not a convergence solution in the number of sample points and it normally is only a reasonable approximation when the source fields over the targets do not have high gradients and the targets cannot have to high a contrast with the background. While, this was a useful solution in 2000 at the time of its release in EMIGMA, we have never returned to this solution to try to improve it. Some users found it useful but there was limited market demand for such a product as the mining industry reverted back to old dipole plate solutions. If you would like assistance in trying to use this algorithm, please contact us.