3rd URSI AT-AP-RASC, Gran Canaria, 29 May – 3 June 2022

Efficient Electromagnetic Modeling of the Subsurface Reservoirs Using a Modified PMCHWT Scheme at Low Frequencies

Chaoxian Qi*(1), Donald R. Wilton(1), and Jiefu Chen(1)
(1) Department of Electrical and Computer Engineering, University of Houston, TX 77004, USA

1 Extended Abstract

Electromagnetic (EM) surveys are prevalent in reservoir fluid mapping, subsurface characterization, etc., due to their higher sensitivity to resistivity than the seismic approach. The EM fields-based technology can map the resistivity distribution due to high electrical resistivity contrasts between reservoir fluid and surrounding formation. To carry out the EM survey for reservoir monitoring, a crucial requisite is accurately modeling EM field response in complicated formations with reservoirs present. The reservoir modeling is cast into the problem of dielectric object modeling. A couple of approaches are available to perform EM modeling of dielectric objects, including PMCHWT (Poggio, Miller, Chang, Harrington, Wu, and Tsai) [1] and the combined field integral equation (CFIE) method. However, these formulations have been proven unstable at low frequencies without proper preconditioning. The issue is known as the low-frequency breakdown.

In this work, we propose to use PMCHWT formulation to model the dielectric object in the layered formation with a modified testing procedure. The PMCHWT equations are discretized with the method of moment (MoM). The continuous problem is converted into matrix form by discretizing the unknown surface currents $\mathbf{J}$ and $\mathbf{M}$ using the RWG bases $\mathbf{\Lambda}^{RWG}$ and the integral equations via appropriate testing functions. Here we follow the same testing procedure as the N-Müller formation described in [2]. The integral equations are tested by $\mathbf{n} \times \mathbf{\Lambda}^{RWG}$ function instead of $\mathbf{\Lambda}^{RWG}$ in a Galerkin sense. It has been proven that the modified formulation leads to a stable solution even at very low frequencies. Thus it is capable of modeling the dielectric object with high accuracy.

To extend the effectiveness of the modified PMCHWT method in subsurface sensing, we investigate the EM modeling of reservoir fluid in the underground formation. In practice, the EM transmitters or receivers are often deployed on the surface to ease the monitoring operation. Therefore, the low-frequency EM waves are employed to ensure considerable depth of penetration. The reservoir fluid is assumed to be homogeneous and placed in the lossy layered formation. The equivalent current densities $\mathbf{J}$ and $\mathbf{M}$ on the surface of the reservoir fluid are introduced to enforce the continuity condition of the physical electric and magnetic field along the surface. To capture the EM field responses in layered formations, we adopt the mixed-potential form of the layered media Green's function.

This work can lead to a fast and accurate numerical method for modeling the reservoir fluid in a subsurface formation. The modified PMCHWT scheme can be combined with EFIE to simulate the scattering problem of mixed conductor/dielectric objects. A target application could be monitoring the sequestered CO_2 via the energized casing, where a very low frequency is involved.

References

[1] R. Harrington, J. Mautz, and Y. Chang, "Characteristic modes for dielectric and magnetic bodies," *IEEE Transactions on Antennas and Propagation*, **20**, 2, March 1972, pp. 194–198, doi: 10.1109/TAP.1972.1140154.

[2] P. Yla-Oijala, and M. Taskinen, "Well-conditioned Muller formulation for electromagnetic scattering by dielectric objects," *IEEE Transactions on Antennas and Propagation*, **53**, 10, October 2005, pp. 3316–3323, doi: 10.1109/TAP.2005.856313.