Analysis of Tilted-Coil Well-Logging Tools in Multicylindrical Earth Formations by Vertical Eigenstates NMM with PML

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The numerical mode matching (NMM) method has been successfully used in the past to study the response of well-logging tools in multilayer earth formations. In the case of traditional tools employing horizontal antennas, only TE modes are excited. More recently, well-logging tools employing tilted-coil antenna arrays (TCAs) have been subject of much interest because of *i.*) their directional capabilities and *ii.*) sensitivity to formation anisotropy. Tilted-coil antenna tools excite both TE and TM modes. Here, we develop a NMM approach based on *vertical* eigenstates and combined with perfectly matched layers (PML) to study the response of this class of logging tools in uniaxial anisotropic formations.

Due to the fixed radius size of the tilted-coil antennas mounted around the steel mandrel of the logging tool, we choose to numerically expand the eigenmodes in the longitudinal (vertical) direction, i.e., parallel to the steel mandrel. TE and TM eigenmodes of the inhomogeneous anisotropic (uniaxial) formation are found by using non-uniform B-splines as basis functions. To simulate the radiation condition in the longitudinal direction, a cylindrical unixial perfectly matched layer (UPML) formulation is incorporated into the Helmholtz equation. The source is expanded in terms of the vertical eigenmodes by numerical integration and in terms of the azimuthal modes by Fourier series. The solution inside the source layer is then assumed to satisfy the radiation condition and the source condition. In order to include multicylindrical layered formations, the the tangential fields need to be known so that appropriate boundary conditions at the interfaces are enforced. The transverse field (ϕ) components are expanded in terms of the longitudinal field in a matrix form, and local reflection and transmission coefficients are found by imposing tangential field continuity across the boundaries. Multiple cylindrically layers can be included using a recursive algorithm to find *generalized* (i.e., multilayer) reflection and transmission coefficients. The transimpedance measured at the receiver antennas is also found by numerical integration.

Results from the present NMM algorithm are compared with brute-force 3-D three-dimensional numerical simulations using finite-difference time-domain (FDTD), and show very good agreement.