Application of Equivalence Principle in the Analysis of Buried Objects/Underground Power Transmission Cables

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One of the most important things I have learnt from Prof. Chalmers Butler, as his former graduate student and current colleague, is the understanding and application of equivalence principle in electromagnetics. In this paper, two examples are presented.

First, we present a hybrid integral equation formulation for determining the scattering from inhomogeneous cylinders buried below a planar interface separating two semi-infinite half-spaces of different electromagnetic properties. The inhomogeneous cylinders of general cross section are of infinite extent, and are illuminated by a plane wave excitation. The hybrid integral equations are formulated by employing both the surface equivalence principle and the volume equivalence theorem. In the formulation, attention is focused on minimizing the Sommerfeld-type integrals that are often encountered in the investigation of buried objects, and on reducing the number of unknowns. The Green's functions of all the volume integrals and part of the surface integrals involved are simply free-space Green's functions. Also, the hybrid integral equations formulated have less unknowns comparing to "pure" volume integral equation formulation.

Second, we present a two-step numerical technique for the investigation of magnetic fields produced by ELF sources enclosed by a ferromagnetic pipe. The first step is to employ the finite element method to solve the differential equations for the magnetic vector potential. From the solution of the magnetic vector potential, the electric and magnetic field can be computed. In particular, the fields on the outer surface of the pipe are obtained. Then, in the second step, employing the equivalence principle, a computational model equivalent to the exterior region is formulated. The equivalent currents can be determined directly from the electric and magnetic fields obtained in the first step. Based on knowledge of the equivalent currents, the magnetic field outside the pipe can be computed in a straightforward manner. To validate the two-step numerical technique, the numerical results of the magnetic field produced by an underground three-phase pipe-type cable are compared with existing measurement data. A good agreement is observed.