Generalized Scattering Matrix Computation Based on 2-D and 3-D Higher Order FEM and Mode Matching for Underground Mine Tunnel Modeling

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This paper presents our ongoing studies related to the generalized scattering matrix (GSM) computation of waveguide structures using a three-dimensional (3-D) finite element method (FEM) with a mode matching (MM) technique for computation of the boundary conditions at the waveguide ports. A principal benefit of this computation is that once a solution of a model is obtained, at a certain frequency, the results can be reused or combined through the GSM as a part of a computationally larger structure. The large structures can be divided into smaller domains that are connected into a system through GSM ports. Each domain is modeled separately and the final solution is obtained by connecting the GSMs of all domains into the large structure. An excellent example for application of this methodology is constituted by the wireless propagation analysis through underground mine tunnels, where multiple tunnels or tunnel sections can be analyzed separately and their GSMs can be stored, so a larger structure as a composition of tunnels and sections can be solved using GSM concatenation. Once the solutions for all modes at all ports of the domains are known, electric field values can be obtained at the points of interest, e.g., for some aspects of evaluation of wave propagation in an underground mine.

The GSM results for one domain are computed using higher order large domain 3-D FEM where the structure is discretized using generalized Lagrange-type curved parametric hexahedra of higher geometrical orders while the electric field unknown is approximated by higher order curl-conforming hierarchical vector basis functions. The boundary conditions at the ports of domains are introduced by invoking modal expansion method. The tangential electric and magnetic fields are expanded as linear combinations of the incoming and outgoing waveguide modes and the domain's GSM is computed as a relation between all outgoing and all incoming modes from ports of the domain. At a given frequency, all propagating modes are included into the modal expansion; however, computation of some of the evanescent modes is also important so the reflections close to the ports can be accurately modeled.

Modal expansion at an arbitrarily shaped waveguide port is, in a general case, computed as an eigen problem solved using a 2-D FEM, where it is assumed that the waveguide is infinitely long and that the fields and geometry vary only in two dimensions. Transformation of the unknown is used so the final equation to be solved is real and symmetric. This problem is a good candidate to be solved by shift and invert Lanczos algorithm. The updating of the shift is also implemented for a better accuracy of the solution, because it is well known that the smallest eigenvalues (i.e., the solution closest to the shift) converge most rapidly.

Characteristic results and analyses are presented to illustrate this approach. Limitations of the approach as well as hybridization with other approaches as applied to wireless propagation modeling of underground mine tunnels are discussed.