Tucker Compressed Muller-SIE for EM Analysis of Mine Communication Systems

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The Mine Improvement and New Emergency Response Act of 2006 requires that all mines are equipped with systems capable of two-way post-accident communication and tracking. Even during normal mine operations, reliable wireless sensing, tracking, and communication systems are critically important to ensure miners' well-being and operational effectiveness. Current mine communication and tracking systems leverage wireless mesh networks, leaky feeders, low-frequency through-the-earth communication systems, medium frequency radios, and combinations thereof (NIOSH, *Advanced Tutorial on Wireless Communication and Electronic Tracking*, 2009). These systems' design, deployment, and electromagnetic compatibility certification all benefit from advanced electromagnetic simulation tools.

Current simulation tools developed for this purpose are based on either approximate techniques or full-wave methods. Approximate techniques oftentimes only apply in limited frequency bands and do not allow faithful modeling of mine environments replete with mining equipment and cables. Full-wave methods, in contrast, are free from these restrictions but require excessive computational resources when applied to the analysis of realistic mine environments. To remedy this issue, we recently proposed a fast, full-wave, and memory efficient surface integral equation (SIE) simulator (Yucel et al., *USNC/URSI Nat. Radio Sci. Meeting*, 2014) that leverages Poggio-Miller-Chang-Harrington-Wu-Tsai (PMCHWT) and electric field SIEs to model scattering from mine walls and perfect electrically conducting (PEC) objects residing inside mine tunnels and galleries. The iterative solution of the SIEs is accelerated using a fast multipole method - fast Fourier transform (FMM-FFT) scheme (Taboada et. al., IEEE Antennas Propag. Mag., 51(6), 20-28, 2009). Unfortunately, for many practical mine environments, the iterative solution the discretized SIEs converges slowly due to well-known ill-conditioning of the PMCHWT SIE (Ylä-Oijala et. al., *Radio Sci.,* 40(6), 1–19, 2005).

This study proposes a new full-wave, memory and CPU efficient 3D SIE simulator that improves on the aforementioned solver in two ways: it leverages (i) Müller and combined field SIEs to account for scattering from mine walls and PEC objects, respectively. Additionally, it uses (ii) Tucker decompositions to compress FMM-FFT translation operator tensors to further reduce the memory requirements of the simulator (Yucel et al., *USNC/URSI Nat. Radio Sci. Meeting*, 2015). The Muller SIE yields a well-conditioned system of equations and its iterative solution converges very rapidly, typically 5-10x faster than the above PMCHWT-based simulator. The Tucker decomposition produces multidimensional low rank approximations of all translation operator tensors and oftentimes results in more than 90% reduction in the memory required for their storage. The accuracy and efficiency of the proposed simulator are demonstrated through its applications to the analysis of various practical mine communication systems, including leaky feeder, low-frequency through-the-earth, and a partial mesh wireless network systems in tunnels and galleries that are thousands of wavelengths long.