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The UWB Beam Summation Scheme for RCS Calculations in the High Frequency Regime: The Numerical Complexity

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Exact numerical solvers for RCS calculations fail in the high-frequency regime due to their high complexity, hence the calculations are usually done by physical optics (PO) integration, by ray-based methods, or a hybrid combination of these approaches. Two major concerns are the scaling of the complexity of these algorithms with frequency and the additional cost of calculating the RCS at many frequencies over a wide frequency band. The long term goal of the present study is to formulate a robust UWB beam summation (BS) scheme for calculating the RCS of large complex targets, and to explore how it scales with frequency asymptotically.

In the BS approach, the incident field is expanded in a discrete set of beam waves. The field of each beam is then tracked through multiple interactions within the scatterer's domain until the beam emerges out and propagates to the far zone, where all the beam contributions are summed up to obtain the scattered field. The algorithm comprises several phases: the expansion phase; the beam tracking phase which is typically performed in the "beam coordinate" system; the near to far field transformation which requires a transformation to the "geographic" coordinate frame; and the final beam summation.

Several schemes for expanding time-harmonic source-excited fields in the terms of spectral beam waves have been introduced in the past (see review in [1]). For calculating the RCS, where the incident field is a plane wave, the appropriate strategy is the ultra-wideband phase-space beam summation (UWB-PS-BS) method, originally introduced in [2], where the incident field is expanded in a discrete phase space set of frequency independent iso-diffracting Gaussian beams. The key features of this method are: (*i*) the phase-space lattice of beam trajectories is frequency independent, hence it is calculated only once and then used for all frequencies. (*ii*) the formulation utilizes iso-diffracting Gaussian beams (ID-GB) whose propagation coefficients are frequency independent even in inhomogeneous medium, hence they need to be calculated only once and then used for all frequencies. (*iii*) the expansion parameters can be chosen so that the expansion set is "snug" (optimal) for all frequencies, leading to stable expansion (*iv*) utilizing a self-consistent multi-band approach [3], the method can be extended to accommodate effectively frequency bands that expand many octaves (in principle, up to infinity).

The present paper presents the application of this approach to RCS calculations in the high frequency regime. Then, to clarify the concept, we also explore the RCS calculation of a single sphere of radius a over a 4 octave frequency band. The method utilizes the same beam lattice and the same ID-GB propagators over the entire band. The Table below demonstrates that the number of beams needed to calculate the RCS of the sphere to a 1% accuracy does not increase with frequency (k being the wavenumber).

ka	1000	2000	4000	8000	16000
Number of beams	3029	1049	2493	1117	1589

1. E. Heyman and L. B. Felsen, "Gaussian beam and pulsed-beam dynamics: complex source and complex-spectrum formulations within and beyond paraxial asymptotic," J. Opt. Soc. Am. A, vol. 18, pp. 1588-1611, 2001.

2. A. Shlivinski, E. Heyman, A. Boag, and C. Letrou, "A phase-space beam summation formulation for ultra-wideband radiation," IEEE Trans. Antennas Propagat., vol. 52, pp. 2042-2056, 2004.

3. A. Shlivinski, E. Heyman, and A. Boag, "A phase-space beam summation formulation for ultra-wideband radiation – Part II: A multiband scheme," IEEE Trans. Antennas Propagat., vol. 53, pp. 948-957, 2005.