The role of RF source components in a whole device model

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For many years RF source modules have been employed as components within integrated simulation (e.g., within TRANSP [1]). Additionally the RF SciDAC program has produced both first-principles and reduced models for many aspects of simulating the application of RF power, with the goal of a predictive and robust tool for the coupled antenna-to-core system within reach. Considerable progress has been made on the validation of these RF source modules with the experiments. Several of these modules are now appropriate for integration with broader topical areas such as, turbulence, interaction with MHD instabilities, and plasma-material interactions. We envision that a productive mode of inter-SciDAC operation in the future will involve the various groups producing "integratable ready" physics component codes, and interact with each other through the platform provided by a dedicated integrated modeling SciDAC.

The RF SciDAC has a suite of codes routinely employed as source modules in integrated simulation. In addition to the many custom integrations, these are used as components within more focused integration efforts including the TRANSP time dependent analyses, and many workflows under the Integrated Plasma Simulator (IPS) framework [2, 3]: see, for instance, Refs. 4-16. Example couplings by the RF SciDAC Center that have resulted in validated reduced models are : A quasi-linear coupling of a linear kinetic full-wave code with a Fokker-Planck update to the velocity space ion distribution function under RF power (AORSA + CQL3D) validated with Compact Neutral Particle Analyzer (CNPA) on C-Mod. And a coupling of a first principles evaluation of the velocity space diffusion due to RF (GENRAY + CQL3D), validated with Fast Ion D-Alpha (FIDA) data for high harmonic ICRF heating in NSTX.

These comparisons with experiment have made it possible to understand the regimes where zero ion-orbit width Fokker-Planck treatments of the fast ion distributions may be adequate, such as in ICRF minority heating experiments in Alcator C-Mod and where finite ion orbit width corrections are needed [17, 18], such as in HHFW experiments in NSTX and DIII-D where ICRF power is damping on fast neutral beam ions.

While much of the physics within such codes has been validated, at least for the core kinetic plasma response (e.g., the physics kernels for ICRF mode conversion have been validated with Phase-Contrast-Imager measurements on C-Mod [19]), there is perhaps work to be done to add the level of robustness to the codes that we envision will be required for a whole device model; in addition to a more rigorous statistical approach to validation and uncertainty quantification (i.e., more than the code developers comparing a few runs with a few shots). An example of future validation effort might be setting up a Dakota [20] + IPS driven simulation to extend our previous validations of the GENRAY + CQL3D coupling with HXR data to compare with a statistical sampling of experimental data for which HXR data is available. Then, using the modular replacement of GENRAY for TORLH, repeat the simulation and compare the validation of the reduced and medium-fidelity models.

Depending on the required physics, a hierarchy of fidelity exists to choose from within the RF suite. Within SciDAC effort we have, and continue to foresee the need for couplings of both reduced models, and of large-compute / first-principles model. For example, the impact of the RF driven sheath potentials at the plasma-material interface requires a 3-D simulation that resolves the entire launching structure and at least some part of the plasma at appropriate resolutions (meaning multiple TeraByte level simulations). These types of problems, although not ready (or appropriate) for a whole device model, are being coupled with high fidelity simulations of core plasma as the core and SOL responses are coupled.

While any future whole device model is not likely to directly couple to high fidelity codes, we think that an important aspect of any larger approach to integrated simulation is a focus on modularity whereby the validation of reduced models using first-principles / large-compute models is facilitated via swapping of modular components that interface a common source of data for their initial conditions. This obviously also translates to benchmarking of codes. Examples where the RF-SciDAC has validated reduced physics models with higher fidelity models are: The coupled AORSA + CQL3D solver has been checked against more complete models employing finite ion orbit width effects such as DC, FOW-CQL3D, and ORBIT-RF. And the coupled TORLH + CQL3D first principles calculation have been compared with the reduced model GENRAY + CQL3D.

While the RF source modules are intrinsically crucial to advance the whole device predictive capability, several integrations at different levels of accuracy with other specific topical areas, are still necessary to seriously move towards a whole device modeling. A few examples are the following: Integration with turbulence codes to understand RF driven flows / currents and their impact on transport barriers and pedestal modification, plasma rotation, and impurity transport (in the core and edge). Interaction with fast-particles (via f_0) to understand possible (de)stabilizations of fast-particle modes with RF power; As current sources in extended MHD simulation such EC stabilization of NTMs (a first step in the development of integrated, predictive models for ECCD/MHD interactions was done by Jenkins et al [21]), or RF modification of sawteeth; As providing sheath profiles for sputtering sources to SOL fluid models to develop strategies for mitigating RF generated impurities.
Experience in the code couplings within integrated modeling frameworks has made clear that for any real progress on a true predictive, integrated fusion capability, a strong model for community wide engagement is required. We envision that a productive mode of inter-SciDAC operation in the future will involve the various groups producing "integratable ready" physics component codes, and interacting with each other through the platform provided by a dedicated integrated modeling SciDAC.

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