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Efficient Spin-Wave Interference Modeling Using the Huygens-Fresnel Principle-Based Method

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Spin-wave-based information processing offers a promising alternative to conventional electronics, providing low-energy and highly parallel computing capabilities. However, numerical modeling of spin-wave propagation in large magnetic systems remains computationally expensive, limiting the ability to explore complex interference effects. To address this, we present a Huygens-Fresnel Principle-Based Calculation (HFPBC) method, a time-efficient approach to generating spin-wave interference patterns without the need for multiple micromagnetic simulations.

The HFPBC method leverages the convolution theorem to reconstruct complex spin-wave fields by combining the response of individual wave sources. Instead of running separate simulations for each configuration, we utilize a precomputed wavefront from a single-source micromagnetic simulation and apply a convolution operation to generate arbitrary interference patterns (Fig. 1). This significantly reduces computational overhead while maintaining accuracy, making it possible to explore multi-layered architectures and programmable spin-wave circuits.

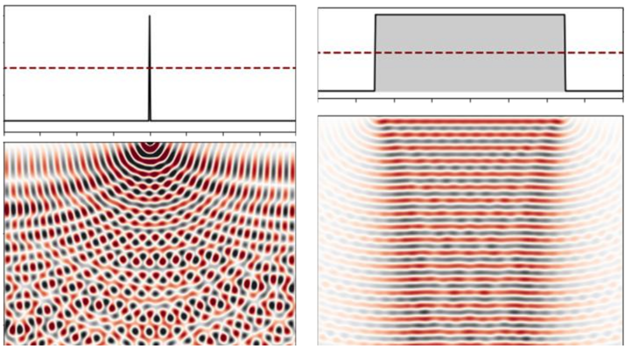

Fig. 1. Schematic representation of a single-point spin-wave source (left) and its transformation using convolution with a step function, resulting in an aperture-like spin-wave input (right). This approach enables controlled wavefront shaping.

We demonstrate the effectiveness of the HFPBC method through numerical simulations of YIG thin films with an out-of-plane external field. By strategically placing phase-shifting resonators in an array of spin-wave sources, we control the interference pattern and create self-imaging effects that can serve as a foundation for magnonic lookup tables (LUTs) [1].

Recent optimizations, including multithreading, vectorization, and efficient memory management, have reduced the computation time for a 10-source interference pattern to just over 1 ms. This acceleration enables large-scale parameter sweeps and real-time simulations of spin-wave interference in programmable devices.

The HFPBC framework provides a versatile and computationally efficient tool for modeling spin-wave-based information processing systems. By allowing precise control over amplitude and phase distributions at each stage, it opens new possibilities for reconfigurable magnonic circuits, neuromorphic computing, and machine learning applications.

The source code for the HFPBC method is openly available at **GitHub Repository** [2]. The research that led to these results has received funding from the National Science Centre of Poland, project No. UMO-2020/39/I/ST3/02413 and the European Union's Horizon Europe research and innovation program under Grant Agreement No. 101070347-MANNGA.

[1] M. Gołębiewski, P. Gruszecki, M. Krawczyk, *Self-Imaging Based Programmable Spin-Wave Lookup Tables*, Adv. Electron. Mater. **8**, 2200373 (2022).

[2] https://github.com/mateusz-golebiewski/hfpbc-code.git