Towards a Simulation Framework for Coupled Microwave and Micromagnetic Structures

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In electromagnetic models, magnetic materials are almost always included by means of a permeability function, which is treated as a macroscopic material parameter. This approach is overly simplistic if complex, nonlinear magnetization dynamics take place in the magnetic material – the magnetization dynamics, in general, depend on the frequency and amplitude of the electromagnetic excitation, the external magnetic field, and on the geometry of the magnetic material.

This motivates the development of our simulation framework, schematically shown in Fig. 1, where an electromagnetic model is coupled to a full micromagnetic model of the magnetic material. We study a coplanar waveguide on top of a low-damping magnetic film (YIG). The joint electromagnetic and micromagnetic problem is split into an electromagnetic domain and a micromagnetic domain. The problem is initially solved in HFSS to find incident fields upon the magnetic film. A micromagnetic simulator (OOMMF) then is used to solve for the magnetic material's response (scattered fields), and the result is integrated with the electromagnetic solution to obtain the complete solution. In order to reduce the computational requirement of this co-simulation framework, the electromagnetic domain was reduced to solving a 2D cross-section. The micromagnetic domain solved for the scattered fields along the top surface of the film's cross-section (1D line). An angular spectrum expansion is used to extend that solution to the entire 2D cross-section. The total field is the sum of the incident and scattered fields and can be processed to solve for the overall electromagnetic/micromagnetic response of the structure.

The magnetic film acts as a tunable, nonlinear and frequency dependent inductance [1], coupled to the waveguide. There are a number of device proposals [2] that exploit magnetization dynamics for computing and signal processing. These typically use waveguides for generating magnetic excitations, and the waveguide may also sense the magnetization dynamics. Our study intends to lay the groundwork for the simulation and design of such devices, and we present an example shown in Fig. 2.

[1] Paul, Clayton R., Inductance: Loop and Partial, John Wiley & Sons, 2011.
[2] Papp, Ádám, Wolfgang Porod, Árpád I. Csurgay, and György Csaba. "Nanoscale spectrum analyzer based on spin-wave interference." Scientific Reports 7, no. 1 (2017): 9245.

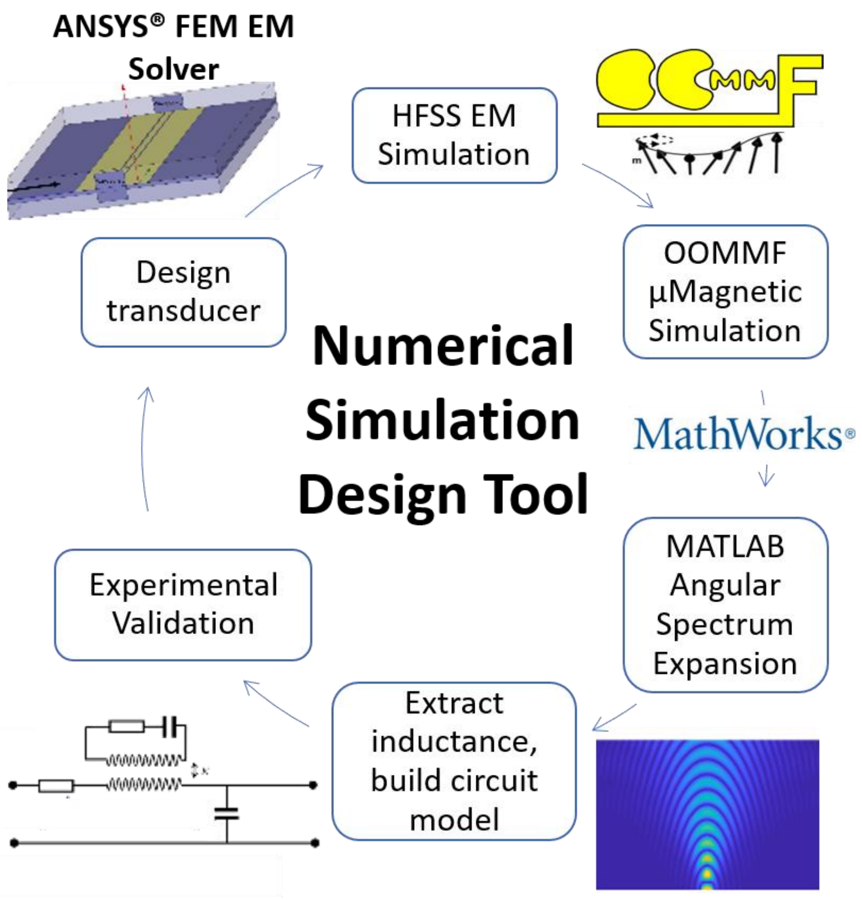

Fig. 1. The numerical simulation design tool flow chart.

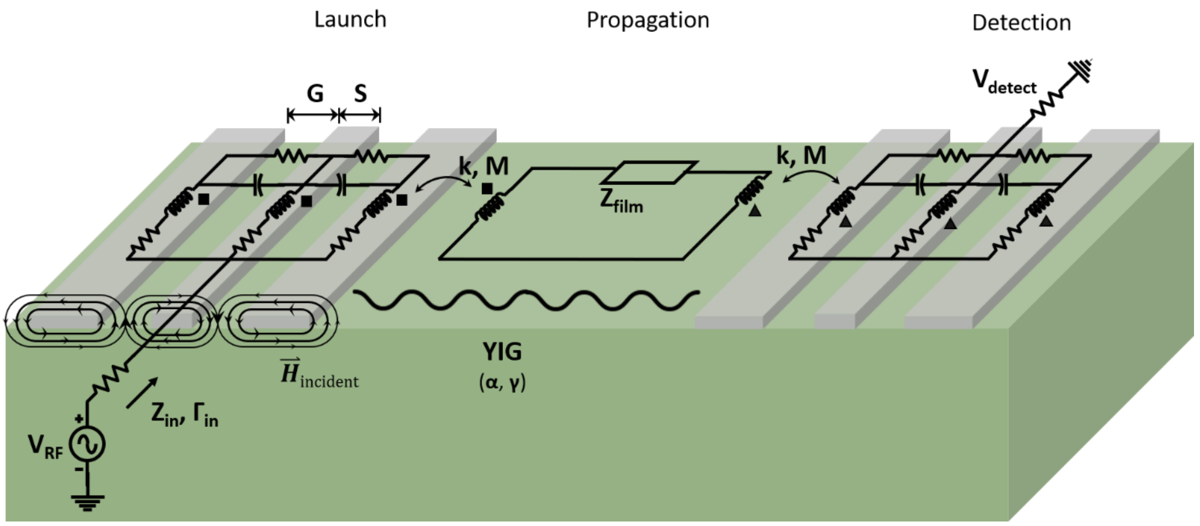

Fig. 2. As a concrete example of our simulation framework, we study structures consisting of coplanar waveguides on top of magnetic films (YIG in this case) to launch, propagate, and detect spin waves. The magnetic fields due to the microwave signal on the waveguide excite spin waves in the magnetic film, and this coupling can be modeled as an inductive coupling. The microscopic simulations provide the parameters for a circuit model for the transmission line and its effect on the magnetic film. This circuit model is schematically superimposed on the physical structure.