Demystify Nonlinear RF Magnetic Devices with Circuit Models Coupling Electromagnetic Waves to Spin Waves

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Abstract – **Nonlinear RF magnetic devices such as frequency selective limiters (FSL) can offer tremendous amount of benefit to the robustness of a RF front-end as it sets a power limit only to the frequencies where strong signal presents while allowing weak signals at different frequencies to pass. Its behavior involves coupling of electromagnetic waves to spin waves oscillations in ferrite material on which no traditional model is available to provide quantitive prediction of its performance. In this talk, we will present a nonlinear circuit model for FSL device design. The dominant magnetic-behaviors of FSL devices are translated into equivalent circuits with parameters rigorously determined from fundamental physics. The spin motions as well as the ferromagnetic resonance (FMR) are modeled by RLC parallel circuits with parameters derived from Polder's tensor and Kittel's equations. The exchange coupling between spins is modeled by an inductor added between adjacent RLC circuits based on quantum spin theory. The nonlinear cross-frequency coupling from signal at ω to spin waves at ω/2 is represented by a pendulum model that predicts the parametric oscillations of spins. The circuit units are cascaded to describe the spin wave propagation inside the magnetic material, and transmission line parameters are added finally to describe the RF signal propagation. The simulation results match the measurement results published, and the model successfully predicts the threshold power level, nonlinear insertion loss, time delay, and frequency selectivity of the device. The modeling approach opens a new paradigm in simulating strong, nonlinear wave-matter coupling in certain RF devices, in which the macroscopic behavior of the device is linked to quantum physics that is happening in nanometer dimensions.**