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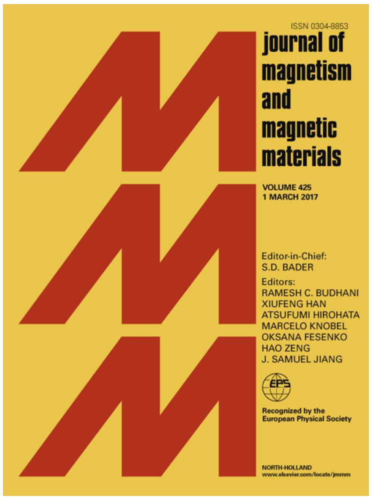

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A Proposed Method for Electronic Feedback Compensation of Damping in Ferromagnetic Resonance

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We propose an experimental technique for extending feedback compensation of dissipative radiation used in nuclear magnetic resonance (NMR) to encompass ferromagnetic resonance (FMR). This method uses a balanced microwave power detector whose output is phase shifted $\pi/2$, amplified, and fed back to drive precession. Using classical control theory, we predict an electronically controllable narrowing of field swept FMR line-widths. This technique is predicted to compensate other sources of spin dissipation in addition to radiative loss.

The reintroduction of dissipated energy back into a dynamic system plays a unique role in many aspects of physics. This radiative 'back-action', originally discovered by Drexhage [1, 2], has profoundly influenced our understanding of energy dissipation in a diverse array of subjects spanning from optics [1–3] and photonics [4], to plasmonics[5] and acoustics[6]. As recently demonstrated in an elegant didactic study, the Drexhage effect manifests as a systematic shift of a system's resonance frequency and linewidth as the distance between the system and a reflective surface is altered, allowing for extraction of the intrinsic radiation efficiency [6]. In contrast to the Drexhage effect found in optics and acoustics, nuclear spin systems are also subject to radiative back-action that originates from counter currents excited in the probing inductive coil [7]. This radiative back-action is considered a nuisance that distorts the nuclear magnetic resonance (NMR) spectral line-shape by broadening and shifting the resonance, and several methods for mitigating its effects such as Q-switching [8], pulse sequencing [9, 10], and counter action from electronic feedback [11–13], have been developed.

In recent years, Drexhage like radiative back-action was also observed in solid-state spintronic systems using ferromagnetic resonance (FMR) [14]. There, radiative back-action was identified as a source of FMR spectral broadening that further obfuscates separation of spin relaxation rates into constituent spin dissipation and dephasing [15–19] contributions. To date, no methods for mitigating its effects have been developed. From among the various techniques for countering the effects of radiative dissipation in nuclear spin systems, electronic feedback [11–13] is a unique case. Unlike optic [1–3] and acoustic [6] Drexhage experiments which control the system dynamic resonance and damping by moving the radiating source away from a reflective surface, electronic feedback in NMR controls the system dynamic resonance by engineering a circuit that mimics the back-action from a reflective surface[11–13]. Since NMR experiments measure the time resolved inductive nuclear spin impulse response on time scales of several micro-seconds, such feedback electronics are not directly applicable to FMR experiments where spin lifetimes are on the order of nanoseconds.

In spintronic and ferromagnetic systems, energy dissipation away from precessing spins and into the lattice [15–19] manifests as an intrinsic broadening of the FMR linewidth. Quantifying the energy dissipation from FMR spectra is complicated by dephasing from spatial distributions of local resonances [19] and degenerate spin wave modes [15–18] that introduce additional extrinsic broadening. Over the past century, a number of remarkable techniques for separating out broadening mechanisms have been developed[15–24]. Despite this tremendous progress, non-linear linewidth vs frequency due to nanostructure size effects [20, 21] and intentional patterning [22] are resistant to analysis from slope-intercept [24] and in-to-out-of-plane[15, 16] methods for determining spin dissipation rates. Preventing over-fitting by constraining the extra degrees of freedom introduced by more sophisticated models that account for non-linear linewidth frequency dependence [21, 22] will be critical for quantifying dissipation in nanoscale spintronic devices.

In this Article, we propose adapting the electronic feedback control circuit used for compensating radiative power loss in NMR systems [11–13] for application in FMR experiments. Using classical control theory, we predict that changing the feedback gain and phase can decrease the FMR linewidth. The method we describe is summarized by the circuit diagram in figure 1 and equations 9 and 10, which predict how the FMR linewidth and resonant field are affected by the feedback gain. The results presented here will facilitate the separation of FMR broadening contributions by providing an electronic feedback model together with a set of fit parameters that can either be used on their own to separate out broadening contributions or to constrain more sophisticated models [21–23] that are used in regions of non-linear linewidth frequency dependence.

In Figure 1, the control diagram for compensating dissipative radiation using electronic feedback is shown. Microwaves with voltage V_{in} and frequency ω are applied