Dynamical theory of spin noise and relaxation - Beyond extreme narrowing

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Recent developments in spin noise and relaxation and their interrelationship in terms of a modified spin density (MSD) have focussed on the case of extreme narrowing where the timescale of the field fluctuations that give rise to the spin process are negligibly small. It is customary in this case to model the random magnetic field as a(n) (isotropic) white noise process and thereby formulate a stochastic differential / Langevin type equation for the spin ensemble. It is notable in this case that the usual perturbation treatment becomes exact since the perturbation expansion truncates at second order, a characteristic familiar feature of the Wiener process, which has finite quadratic variation but whose higher order infinitesimal moments vanish. In terms of the field spectrum the Larmor frequency plays no essential role here, since such a flat spectrum is invariant to frequency shifts.

Of much greater experimental relevance is the non-extreme narrowed case where the field fluctuations have a finite auto-correlation time and a corresponding power spectrum with finite bandwidth. In such cases the Larmor frequency plays a special role in terms of its situation within this narrowed spectrum. Provided the strength of the fluctuations is small it is possible to formulate the spin dynamics (perturbatively) while retaining the full spectral character of the random field - more recently a non-perturbative treatment has also been possible. This is achieved through the description of the field in terms of an (3-dimensional) Ornstein-Uhlenbeck process, consistent (via Doob's theorem) with the requirements that the process be Gaussian, Markov and stationary. The result is significant in that it predicts a non-Lorentzian spectrum - it is interesting therefore both theoretically and experimentally.

In turn we derive a spin noise / relaxation process that inherits spectral features from both the amplitude and frequency characteristics of the driving random magnetic field. The intimate connections that exist between spin noise and relaxation in the extreme narrowed case persist in this more general context, whereby standard relaxation emerges as the ensemble average of spin noise, the latter being essential to describe non-ensemble averaged (real time) properties of spin systems.

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