Lap Project, Master 1: Maximization of Self-Stimulated Spin-Echo Trains from Inhomogeneously Broadened Spin Ensembles

Quentin ANSEL, quentin.ansel@univ-fcomte.fr

29 septembre 2020

Keywords : Cavity QED, spin ensembles, quantum optimal control, quantum technologies, Jaynes Cummings model.

In magnetic resonance, the magnetization of a spin ensemble does not remain constant over time, due to the different Larmor frequencies of the spins in a material. This inhomogeneity of the spin ensemble produces a decay of the magnetization amplitude. However, it is possible to reverse (at least partially) the process with a specific control field. The refocusing of the spin magnetization is called a spin echo. This effect is one of the main building block of quantum computing experiments, Nuclear Magnetic Resonance (NMR) spectroscopy, and Magnetic Resonance Imaging (MRI).

Recently, echo trains have been discovered (see [1,2]). An echo train is a periodic series of echoes. This is made possible if the light-matter coupling becomes stronger than the dissipative losses. This condition can be found with a spin ensemble coupled to a cavity. In [1], a model has been proposed and several properties of the effects have been investigated. The authors were limited in their analytical predictions, due to an approximation that removes most of the relevant non linear dynamical effects. Additionally, they used standard square pulses in their numerical simulations. Square pulses are simple control fields that allow us to control spin systems, but they suffer from several disadvantages in cavity QED (in particular they introduce cavity artefacts and they provide a poor signal to noise ratio (SNR) of the spin echo).

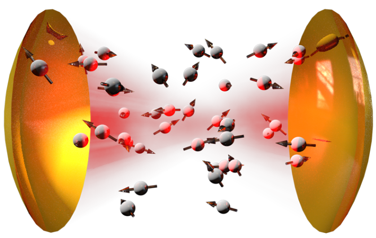

Figure 1 – Spin ensemble coupled to a cavity.

As a preliminary work, the selected candidate will study bibliography references about open quantum systems, cavity QED, and controlled spins systems coupled to a cavity. The next step is to study analytically and numerically the echo train, out of the regime of the Holstein-Primakoff approximation. Then, it will be possible to have a better understanding of the echo shape, and to emphasize a control mechanism that allows us to maximize the SNR. Further additional steps are possible : to verify if bump pulses can enhance the SNR of the entire sequence, or to determine numerically a control field (with optimal control algorithms) that allows us to reach the physical limit of the SNR.

[1] Kamanasish Debnath and al., Self-Stimulated Pulse Echo Trains from Inhomogeneously Broadened Spin Ensembles, PRL, 125,137702 (2020).
[2] Stefan Weichselbaumer and al. , Echo Trains in Pulsed Electron Spin Resonance of a Strongly Coupled Spin Ensemble,PRL, 125,137701 (2020).