Spintronic oscillator networks : taming a non-linear dynamical system of coupled non-isochronous and distributed oscillators

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PhD may follow: Yes

Summary :

Spintronic oscillators are based on magnetic tunnel junctions that provide a large oscillating output voltage signal in the GHz range when driven by a spin polarized DC current. The spin momentum transfer counter-acts natural damping and drives the magnetization into large angle steady state oscillations. These are converted into an electrical signal via the magneto-resistance. A defining feature of spintronic oscillators is their non-isochronicity, i.e. their non-linear dependence of the precession frequency on the amplitude. While in the past many studies have been realized on single oscillator devices, current efforts concentrate on the coupling of different oscillators to enhance output signal levels, to reduce noise or to produce coherent magnetic fields for short distance wireless communication (e.g. inter- and intrachip). Coupling and mutual synchronization of these oscillators can occur via electrical or dipolar interactions. The challenge is to understand how the locking process, in particular the coupling phase, is influenced by the different coupling mechanisms and the excitation mode and conditions. This will be of importance when more than two oscillators will be coupled that are not identical (distributed network) and that will compete with each other.
Identifying the parameters that lead to stable coupling or chaotic states are of special interest. This is a general problem of non-linear dynamical systems applied to nanoscale spin torque oscillators. So far coupling has been demonstrated experimentally for two oscillators in the vortex configuration emitting at low frequency (

Full description :

Spin torque oscillators find potential applications as nanoscale signal sources used for stable carrier signals in transceivers. Important progress has been made by our group and collaborators for demonstration of such oscillators in phase locked loops. However, the output signal is too low and the phase noise still too high. The major route of improving the signal is to couple several oscillators. While coupling of two oscillators has been demonstrated for the low frequency range (1GHZ) and of more than two oscillators remains an open question and a severe experimental challenge. This is due in part to the fact that it is difficult to realize oscillators with exactly identical performances as well as to the strong non-isochronicity.

The objective of the Master project, followed by a PhD, is to undertake a combined experimental and theoretical study to understand the conditions for stable coupling of a network of non-isochronous and distributed spin torque oscillators. A main question concerns the role and efficiency of different coupling mechanisms (electrical and dipolar interaction), that act together and that can compete with each other. This competition in the coupling is of particular importance when considering the coupling of more than two oscillators that are not identical (in frequency, in volume, in their non-linear response etc). It is not clear whether the coupling will be mutual or whether one oscillator will drive the other and what is the role of the noise on the coupling. Coupling of several oscillators can lead to a fully coherent oscillation but can also result in a chaotic state. This is a general problem of non-linear dynamical systems applied to nanoscale spin torque oscillators.

The studies will be realized for oscillators with different orientation of magnetization that can be in-plane or out of plane magnetization. This will lead to different oscillation amplitudes and dynamic dipolar interactions strengths.

To guide the experimental studies, a numerical analysis will be made on the synchronisation of the spintorque oscillator to an external rf signal, which can be an rf current signal or an rf field signal. First synchronisation to one or the other source will be considered and then for both signal sources, to mimic the different coupling mechanisms and to understand how they cooperate or compete with each other. Here the strength of the coupling can be varied. In addition the effect of thermal noise on the robustness of the coupling will be considered. The numerical results will be compared to analytical models developed in a previous thesis. These theoretical studies will then be compared to experiments, for the different oscillator configurations (in-plane vs out-of-plane) leading to different excitation modes.

In a second step the mutual synchronization of two and more spin torque oscillators will be addressed. For the theoretical description an adequate model of the dipolar coupling or coupling via rf current will be established. This will be then implemented in the numerical simulation to investigate the conditions of the coupling as a function of several parameters: coupling strength and symmetry of the coupling (i.e. identical and non-identical oscillators). The role of thermal noise will be investigated on the robustness of the coupling. This theoretical description will guide the experimental realization of a two and if successful a network of coupled spintronic oscillator devices. These will be developed at our nanofabrication facilities (PTA cleanroom). The student will be trained to use the clean room facilities to realize the devices. The student will then characterize the devices using our microwave laboratory and compare the experimental results to the theoretical descriptions.

The project provides multidisciplinary training on spintronics concepts (spin polarized transport, spin momentum transfer), linear and non-linear magnetization dynamics, on non-linear dynamical systems, nanofabrication and microwave measurement techniques.

Requested skills :

Master in Physics and/or Nanosciences; Skills in programming for developing data analysis protocols;