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# A numerical study of spin torque nano-oscillators based Ising machines

Spin torque nano-oscillators (STNO) are nanoscale devices based on a magnetic tunnel junctions. Such STNOs generate microwave voltage signals upon injection of a DC current. The phase dynamics of weakly coupled arrays of STNOs and/or coupling of STNOs to an external RF signal (injection locking), can be harnessed to develop novel hardware approaches for unconventional computing [1]. When injection locked to a signal with two times the natural frequency of the oscillator (2f injection locking), the phase difference between the STNO and the external signal can take two discrete stable values, i.e. its steady state becomes binary. In such a case, the STNO phase states can be exploited to represent the binary spins of an Ising Hamiltonian, given in Eq.1. Here $\sigma_i$ represent the binary spins, $J_{i,j}$ is the coupling between spins $i$ and $j$ and the Hamiltonian gives the energy of the coupled Ising spin system.
$\mathcal{H}(\sigma) = \sum_{i,j} J_{i,j}\sigma_i\sigma_j - \mu\sum_j h_j\sigma_j$ (Eq. 1)
Interestingly, many combinatorial optimization problems (COP) can be mapped to such an Ising Hamiltonian. The minimization of it or, in other words, the inherent convergence towards the global energy minimum of the Ising system can then used as an algorithm to determine the solution of a COP. Specific hardware implementations of such an Ising system are called Ising machine (IM). Here we address in a numerical study the implementation of an Oscillator based Ising Machine (OIM) [2] using STNOs.
For the extraction of the dynamic properties of STNOs, we resort to solving numerically the Landau-Lifshitz-Gilbert-Slonczewski equation including thermal fluctuations, in combination with the non-linear auto-oscillator model [3].
The possibility of implementing an STNO based IM has been demonstrated in [4] for a particular set of parameters. Nevertheless, since the dynamics of STNOs described by the Lifshitz-Gilbert-Slonczewski (LLGS) equation is quite complex, it is crucial to explore a wider set of conditions analyzing how the phase states and the coupling of the oscillators evolve. With this in mind we simulate systems of multiple STNOs that are electrically coupled. For every case, the stochastic (due to thermal fluctuations) phase dynamics, the correlation of the phase states under coupling and the corresponding phase state probabilities are investigated. This is done as a function of the operating point, the temperature, the strength and sign of the coupling between the STNOs as well as the frequency mismatch to the external locking signal. The results will provide a guide for the practical implementation of an OIM based on STNOs, considering the specific non-linear dynamic properties of STNOS.

[1] J. Grollier, et al., Nat Electron 3, 360–370 (2020)
[2] T. Wang, J. Roychowdhury, arXiv:1709.08102v2 (2017)
[3] A. Slavin et al., IEEE Trans Magn, 45, 1875 (2009)
[4] D. Albertsson et al., Appl Phys Lett, 118, 112404 (2021)

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