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TITLE: Modulation of chaotic nanocontact vortex oscillators

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ABSTRACT BODY:

Digest Body: Spin-torque nano-oscillators (STNO) have strong potential for applications such as rf communications, microwave generation, field sensing, and neuro-inspired computing. An important aspect involves phase-locking [1] and modulation [2] due to external signals, which have been studied extensively in vortex-based systems. However, the role of vortex core reversal [3] in this context has remained largely ignored. Indeed, in nanocontact-based systems, core reversal can give rise to more complex states such as chaos [4]. Because of the sensitivity to initial conditions, chaos is potentially useful for information processing as a large number of patterns can be generated rapidly [5].

We have conducted experiments to probe how nanocontact vortex oscillators can be modulated in the chaotic state by an external signal. Such states are obtained by sweeping the applied dc electrical current or magnetic field, where transitions between different oscillation regimes can be seen as jumps in the central frequency and changes in the number of modulation sidebands, as shown in Figure 1. These different regimes correspond to how the periodicity of the vortex core reversal relates to the frequency of core gyration around the nanocontact [4]; a commensurate phase appears when the reversal rate is an integer fraction of the gyration frequency, while a chaotic state appears when this ratio is irrational.

An example of the effect of external modulation is shown in Figure 2, where the power spectral density exhibits rich features due to the modulation between the external source frequency, gyration frequency, and core reversal frequency. We can explain these features with first- or second-order modulation between the three frequencies. Phase-locking is also visible between the external source frequency and internal vortex modes. We explored the phase-locking properties in both the commensurate and chaotic regimes, where chaos appears to impede phase-locking while a more standard behavior is seen in the commensurate phase.

We have also conducted micromagnetics simulations with the MuMax code [5], where most of the salient features are reproduced. We also explored larger coupling strengths between the external signal and the NCVO, where different fractional regimes can be identified in Arnold tongue diagrams [6]. This allows us to quantify the role of the coupling strength on synchronization and transitions to chaos.

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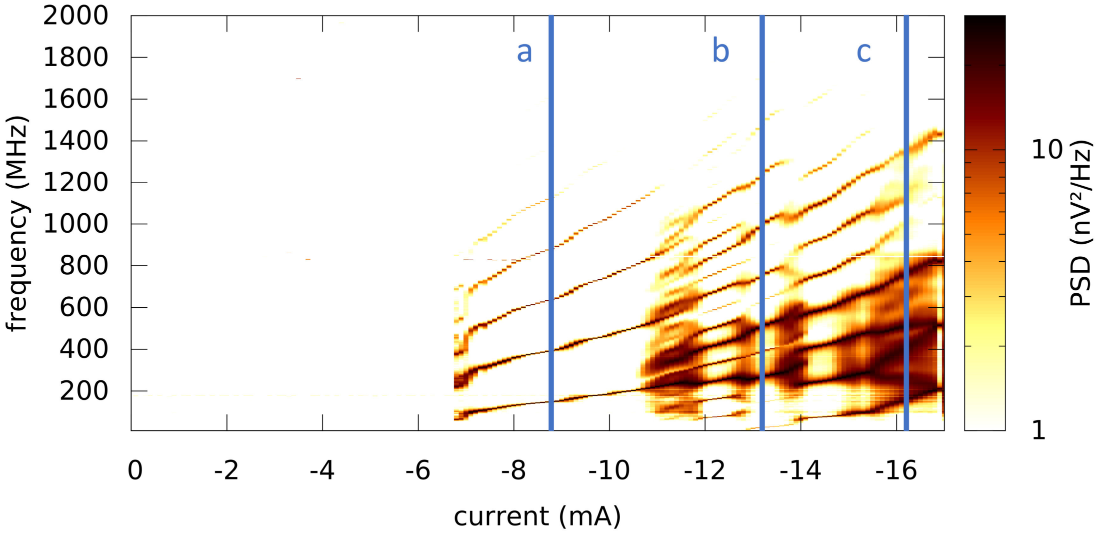
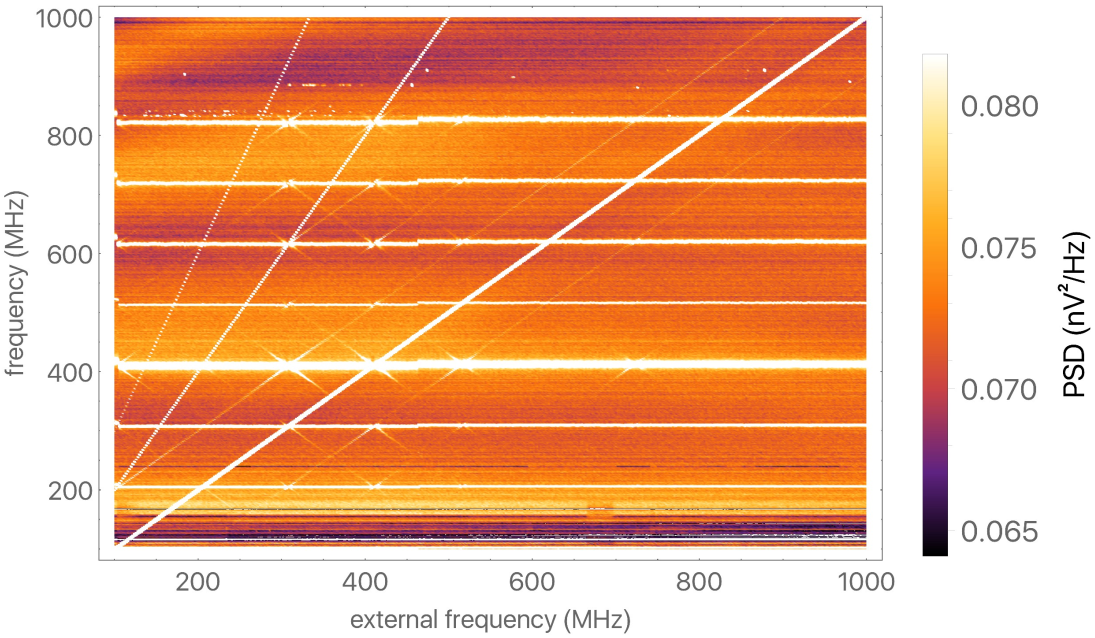
KEYWORDS: Chaos, Vortex, Modulation, Phase-locking.



[Figure 1] Frequency vs current map of the power spectral density. On this figure is given the natural output power of the vortex according to the sent DC current. Different dynamical regimes are observed. No oscillations are observed below 6.8 mA . (a) Steady state gyration, where harmonics indicate elliptical trajectories. (b) Commensurate state, where periodic core reversal modulates the vortex gyration. (c) Chaotic state, where gyration and core reversal frequencies are incommensurate.



[Figure 2] Power spectral density map as a function of external frequency for an NCVO in the commensurate state. Phase-locking occurs when the external frequency is equal to gyration frequency, 3:4 and 4:3 synchronization orders. Phase-locking between core reversal and external frequencies are also visible. Crossing frequencies near synchronization regions are due to modulation between external, gyration, and core reversal frequencies. Amplitudes are qualitatively higher if signals involve gyration or external frequencies, close to a synchronization region, and for increasing external frequency sweeps.

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Attendance at Conference: I acknowledge that I have read the above statement regarding the requirement that an author of this presentation must attend the conference to present the paper.