Micromagnetic analysis of nonlinear dynamics in spintronic analog modulators

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I. Introduction

Some recent experiments showed that the simultaneous action of a *dc* and an *ac* spin-polarized current on a magnetic multilayered nano-contact structure [1] may generate a particular typology of persistent magnetization dynamics in the thinner layer of the structure which was classified as a frequency-modulated (FM) output signal [2]. In particular, differently from a classical FM linear modulation scheme, where the output instantaneous frequency linearly shifts with the input current, we investigate the case in which the dependence frequency *vs.* current is strongly nonlinear, as it happens in a lot of real systems and, in particular, in spintronic oscillators [1,2]. In such devices, two main characteristic features have been experimentally reported: (i) the central frequency undergoes a shift with the increase of the amplitude of the modulating signal; (ii) the sidebands, while symmetrically located with respect to the central peak, are characterized by different amplitudes [2].

Earlier analytical and numerical macrospin models tried to physically justify the observed nonlinear dynamics but failed in the attempt to reproduce the whole phenomenon, especially the second mentioned feature. It was mainly due to the fact that non-negligible additive nonlinear amplitude modulation (AM) effects were disregarded [2].

With this in mind, we recently developed a generalized model which accounts for the whole nonlinear dynamics observed in combined AM-FM nonlinear modulators [3]. Such a model includes the nonlinear dependences of both instantaneous frequency and amplitude on the input stimulus (the applied current). Nonetheless, since the model has been derived independently of the physical mechanism originating the nonlinearity, it can encompass the description of nonlinear analog modulators of any physical nature. To validate the proposed theoretical model, a micromagnetic analysis of the nonlinear dynamics occurring in spintronic modulators has been carried out with success [3]. In that work, in particular, we performed numerical calculations where the frequency of the modulating signal f_m was kept fixed and its amplitude A_m was varied. Owing to the excited magnetization dynamics takes place at microwave frequency, such a micromagnetic analysis has been useful to gain time-domain information not acquirable in a laboratory experiment [2,3].

In this work, we want to gain a different understanding on the nonlinear modulation process by performing an analysis in which the frequency of the modulating signal f_m is varied whereas its amplitude A_m is kept fixed. The goal is achieved by analyzing the output modulated signals in time, spatial and spectral domains. A 2D map of the excited modes is also built through the usage of the Micromagnetic Spectral Mapping Technique (MSMT) [4].

II. Results

The micromagnetic study, carried out by using the same setup as in [3], results in following considerations.

First, independently of the values of amplitude and frequency of the modulating signal, the spatial configuration of the spin-wave mode excited in the modulation process exhibits a radial symmetry and the inequality between the sidebands amplitude corresponds to different mode-intensities associated to the peaks in the Fourier spectra.

Second, according to our parameter set [3], we deal with a narrowband modulation. If the hypothesis of a pure “FM” process were valid in the present case [2], it would be possible, in principle, to apply modulating signals having frequency f_m close to the carrier frequency, as the total transmission bandwidth approximates the value $2f_m$. On the other hand, since a non-negligible AM modulation process takes place simultaneously, such possibility is actually prevented as the time-envelope of the modulated signal cannot be visualized (and therefore detected) satisfactorily.

Third, a full-scale investigation involving variable modulating frequencies opens the possibility to estimate the effective damping rate (one of the most important oscillator parameters), as described in a recent tutorial work [5].

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