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Coherence of spin-torque microwave oscillators

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Recently discovered effect of microwave generation in current-driven magnetic nano-structures caused by the spin-transfer torque opens a possibility for the development of a new class of tunable microwave auto-oscillators. The spin-torque oscillators (STO) are strongly nonlinear as their frequency $\omega(P)$ and total (positive plus negative) damping $\Gamma(P)$ are dependent on the oscillation power P . We developed a theory of the generation linewidth of a *nonlinear* auto-oscillator, and showed that the nonlinear frequency shift (characterized by the coefficient$N = d\omega/dP$) leads to an effective increase of the phase noise. In a strongly supercritical regime, when the oscillation energy $E(P)$ is much larger than the thermal energy $k_B T$, the generation linewidth of a STO can be written as $\Delta\omega = \Delta\omega_0[1 + (N/\Gamma_{eff})^2]$, where $\Delta\omega_0 = \Gamma(0)[k_B T/E(P)]$ is the oscillator linewidth without account for the nonlinear frequency shift and $\Gamma_{eff} = d\Gamma/dP$ is the effective nonlinear damping of the oscillator. Our theory explains the following features of the STO linewidth observed in experiment: (i) general linewidth narrowing with the increases in the bias current I and the oscillation energy $E(P)$; (ii) presence of a minimum in the linewidth dependence on the orientation of the external bias magnetic field; (iii) linear dependence of the linewidth on the absolute temperature. Our theory also demonstrates that in the array of n phase-locked STO the generation linewidth decreases linearly with the increase on the number of oscillators n, while the generated power P increases as n^2.