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P:07 Power dissipation and noise in spin-wave-based computing systems

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Minimizing power dissipation is one of the main drivers behind the quest for emerging electronic devices. Spin-wave-based computing and processing devices are promising candidates in this field. It is claimed that they are both fast and low-power [1][2], which are usually conflicting requirements and are difficult to achieve simultaneously in electronic (CMOS-based) computing systems.

The fact that spin-waves themselves are low-energy excitations, does not necessarily mean that computing systems built from spin-waves will be similarly low-power. There are inefficiencies in the interconversions between the electric and magnetic domains and thermal noise puts an inherent lowest limit on the energy of the spin-wave system [3]. To our knowledge, the present work is the first assessment of fundamental energy limitations in a spin-wave based computing system.

MODEL SYSTEM

The system we study is sketched in Fig 1 [2]. Electrical inputs at the left-hand side generate a spin-wave distribution in the magnetic thin film. The result of the computation is represented in the interference pattern, which should be picked up and converted back to electrical signals [3].

There are a number of physical structures that may serve as input. Most straightforwardly, the Oersted field of a waveguide may generate the spin-wavefront. More localized (short-wave) excitation can be achieved with spin-torque (for magnetic metals) or spin-orbit torque (in case of magnetic insulators) [4]. Signals can be picked up inductively, by a magnetoresistive effect or by inverse spin Hall effect (iSHE).

DISSIPATION MECHANISMS

Spin wave signals are attenuated by Gilbert damping. In metallic ferromagnets the mean free path of magnons typically up to a few ten times the wavelength of the spin wave, while in magnetic insulators it can be several hundred times their wavelength [5]. Magnetoelectric interfaces both at the input and output side yield to large insertion losses. We estimate that in the case of spin-orbit torque, 5% of the electrical input signal is converted into magnetic energy, the rest is dissipated as Joule heating on the input structure. Similarly, a mere few percent of the spin-wave energy at the output wavefront can be picked up by the output structures.

ROLE OF NOISE

Low-energy, linear spin-waves give rise to few-ten microvolts of induced AC voltage in micron- scale inductive pick up antennas, iSHE yields DC voltages with similar magnitudes. If such signals have to be picked up with significant bandwidth, thermal noise in the antenna / pick-up structure and the amplifier will become the limiting factor in the device (see Fig 2).

A spin wavefront can be created by a few milliwatts of continuous power consumption, while picking up and amplifying the spin wavefront (i.e. the result of the computation) requires several milliwatts to several ten milliwatts of power per output point, depending on the amplifier construction and bandwidth. The data throughput of the device can be several gigabits per second. Based on these estimate, spin-wave-based devices does not seem to be an energyefficient substitute for logic gates, but they may be very efficient as high-frequency, analog signal processors, for example at RF front-ends.

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P:08 Quantization and analysis of acoustic modes in a rectangular microsound nanowaveguide fixed on a rigid substrate

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Microsound waveguides have been used as delay lines for more than a decade in microwave circuit. With shrinking device sizes there is a need to realize waveguides operating well into the terahertz regime. This article focuses on a waveguide with an isotropic overlay structure deposited on a substrate which has a larger area and much higher rigidity compared to the overlay. Given the known solutions [1] of the completely bound displacement fields inside the overlay; see fig. 1. For the first time the quantization of the displacement fields is performed with respect to normal-mode phonon displacement using following condition [2].

$$\frac{1}{ab}\left[\int_0^a dx \int_0^b dy \left(u_x u_x^* + u_y u_y^* + u_z u_z^*\right)\right] = \frac{\hbar}{2m\omega} \quad (1)$$

where m= mass of the single atom, ω = angular frequency of wave and u_x , u_y , u_z is given by-