Anisotropic spin-wave patterns generated by spin-torque nano-oscillators

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Spin-wave excitations due to spin-momentum transfer in ferromagnetic thin films will enable new types of information processing and memory storage. Here, we show how arrays of spin-torque nano-oscillators (STNOs) can be used to create anisotropic spin-wave interference patterns, which can be used for information processing. We consider STNO arrays contacting a thin ferromagnetic film. Contacts to the film (including the STNOs themselves) can be used to detect the spin-waves and then, when coupled to a simple circuit, can create new excitation patterns. The propagating spin-wave patterns can be generated by pulsing transponders. Arrangements of transponders create resonant (reverberating) spin-wave activity—that may be the basis of polychronous wave computation of the arithmetic and Boolean functions as well as information storage. © 2011 American Institute of Physics. [doi:10.1063/1.3566000]
interferes throughout the two-dimensional thin film. Spatial-dependent amplitudes, $|m|$, are plotted at times $t_1, t_2 > t_0$.

The ability to create propagation spin-wave interference patterns enables a new type of information processing known as polychronous wavefront computation (PWC). The PWC idea is to encode information into time delays of propagating waves and accomplishes Boolean operations using constructive interference of wave packets. The key ingredients for PWC are a medium that can support interference patterns of propagating activity packets and transponders that can sense the size of incident activity and respond to super-threshold inputs by generating a propagating wave. The propagation times of peak-wave interference correspond to conduction-time delays. The analogy to excitation of a neuron is excitation of a transponder that may fire when a certain threshold
of inputs, from other transponders, is exceeded. In this case, the transponder may generate a new current induced spin-wave excitation, perhaps after some time delay.

STNOs are used to create microwave-frequency excitations in thin films and the same (or other) contacts can also serve as detectors. STNOs may be used to read the state of the system (e.g., the amount of spin-wave activity, arriving spin-wave packets, etc.). The respective alignment of the fixed and free layers of an STNO determines its electrical resistance. Thus, small currents (that do not excite magnetization dynamics) through the point-contacts would serve to read the state of the free layer. In order to enhance the readout signal, a magnetic tunnel junction (MTJ) can be used as a detector (see Ref. 12).

In Ref. 12, we described a possible scheme for transponders that would detect spin-wave activity in the propagating medium and respond by initiating new spin-waves. They are basically integrate-and-fire circuits, where a storage device (e.g., a capacitor or an inductor) accumulates charge that is discharged rapidly when a certain threshold level is achieved.

To add complexity to the system and hence create information-processing capacity, configurations that can maintain stable reverberating activity are needed. Detectors may be set to a threshold only reachable through more-than-one arriving energy packets. In Fig. 5 reverberating memory using three transponders is shown. Transponders spike at the same time the wave-front packets propagate from one to the others and intersect at each transponder reaching the detector threshold and creating new waves. Reverberation loops are closed and the activity is periodic with a period depending on the distance between transponders.

The state of the unit is time-dependent. We can encode information in the phase (i.e., timing) of excitation relative to some external timing signal. Any real number could be encoded into the phase of reverberating activity (bounded by the noise in the physical implementation of the system).

Another application would be programming transponder arrangements having graded reverberating frequencies to create a look-up table, similar to the ones in the brain. Consider the analogy of a piano keyboard; an array of several devices as in Figs. 3(a) or 3(b) having a gradient of natural frequencies (i.e., different separations between nodes in reverberators result in different resonant frequencies) are simultaneously exposed to a double-spike signal with period \( \tau \). The device with resonant interspike interval \( \tau \) will respond coherently, while the others will not. Namely, the double spike will not match with the resonant frequency of others and will create complex reverberating activity from which the coherent one can be distinguished.

Summarizing, we have proposed a design for magnetic nanoscale elements in ferromagnetic thin films that can create controllable spin-wave patterns. The propagating spin-wave packets may be used to accomplish some brainlike behaviors through PWC, but on much shorter time scales and on smaller spatial scales. Micromagnetic simulations offer a useful way to design optimal STNO arrangements for specific interference, both steady and propagating patterns.

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19F. C. Hoppensteadt and E. M. Izhikevich, Weakly Connected Neural Networks (Springer-Verlag, New York, 1997).