Fundamental energy limits in the physics of small-scale computing systems

abstract:

Is it possible to operate a computing device with zero energy expenditure?
This question has been addressed during the second half of last century by a number of scientists and has led to a version of the second principle of thermodynamics that, assuming the Shannon information as a special form of the Gibbs-Boltzmann entropy, establishes that necessary condition to operate a computing device with zero energy dissipated is that the computing process does not decrease information[1,2]. This result, often invoked as "Landauer principle", has been recently put under experimental test[3] with the aim of exploring the limits in low power computation.
It is a well-known fact that in the last forty years the semiconductor industry has been driven by its ability to scale down the size of the CMOSFET devices, and to increase computing capability density up to a point where the power dissipated in heat during computation has become a serious limitation[4]. Thus the fundamental limits in computing are rapidly becoming a strategic issue for the development of future ICT.

In modern computers information is processed through binary switches, usually realized with transistors, i.e. microelectronic devices. Thus binary switches represent a paradigmatic example of "small scale physical systems" employed in the process of information.

In order to take into account a realistic representation of the switch dynamics we assume a single-*dof* dynamical model for the switch that is coupled to a thermal bath at temperature T. Although the switch is isolated, exchanges of heat Q between the switch and the thermal bath are possible. Moreover, due to the coupling with the thermal bath a fluctuating force *x(t)* appears. At thermal equilibrium the Fluctuation-Dissipation theorem links *x(t)* and the dissipative force. According to this description the switch dynamics can be described in terms of a Langevin equation, where the fluctuating force appears together with a dissipative term.

In this talk we discuss the role of switching procedure with reference to the fundamental limits in minimum energy dissipation. We show that the minimum energy depends on the switching procedure and test this result with micromagnetic simulations of a nanoscale switch realized with single cylindrical element of permalloy (NiFe). Finally we establish a relation between minimum energy and switching error probability[5].

References

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