ToPoliNano: NanoMagnet Logic Circuits Design and Simulation

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***Abstract*—Among the emerging technologies Field-Coupled devices like Quantum dot Cellular Automata are particularly interesting. Of all the practical implementations of this principle NanoMagnet Logic shows many important features, such as a very low power consumption and the feasibility with up-to-date technology. However, its working principle, based on the interaction among neighbor cells, is quite different with respect to CMOS devices behavior. Dedicated design and simulation tools for this technology are necessary to further study this technology, but at the moment there are no such tools available in the scientific scenario.**

We present here ToPoliNano, a software developed as a design and simulation tool for NanoMagnet Logic, that can be easily adapted to many others emerging technologies, particularly to any kind of Field-Coupled devices. ToPoliNano allows to design circuits following a top-down approach similar to the one used in CMOS and to simulate them using a switch model specifically targeted for high complexity circuits. This tool greatly enhances the ability to analyze, explore and improve the design of Field-Coupled circuits.

I. Introduction

Among the emerging technologies NanoMagnet Logic is one of the most interesting. In this technology single domain nanomagnets with only two stable states are used to represent the logic values ’0’ and ’1’ [1]. They represent a particular application of the Quantum dot Cellular Automata [2] idea, and more generally of the Field-Coupled principle, where the computation is performed by the interaction of neighbor cells. The specific advantages of NanoMagnet Logic are represented by an extreme low power consumption [3], the possibility of combining memory and logic in the same devices and, not less important, the possibility to fabricate circuits with up-to-date technology [4]. Circuits can be studied using a VHDL model [5][6], however, to deeply study this technology, appropriate tools are required. While for general QCA a specific software, QCADesigner [7], is available, nothing exists for NanoMagnet Logic, if not time consuming and unpractical micromagnetic simulators, that cannot serve as design tools.

We present here our ongoing efforts on the development of ToPoliNano, Torino Politecnico Nanotechnology tool, a tool targeted to design and simulate circuits based on different types of emerging technologies, and specifically here Nano-Magnet Logic circuits. ToPoliNano emulates the top-down approach used in CMOS design, where circuits are described using the VHDL language, the synthesis is executed, the layout is automatically generated, and a switch level simulation can be performed. Circuits can be simulated and important information on the circuit behavior and the power consumption can be extracted, knowing exactly the circuit area and the precise placement of every element [8]. Mostly important, the open and modular structure of the software allows to easily integrate other emerging technologies, like we have done with Silicon Nanowires NanoPLA [9], making it the ideal platform for the study of emerging technologies.

II. Structure

The structure of ToPoliNano is shown in Figure 1.

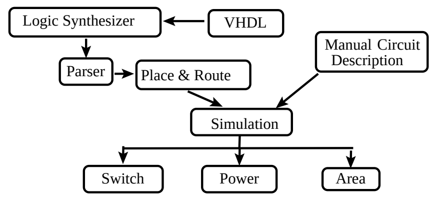

Fig. 1. ToPoliNano structure.

Following CMOS design flow the input circuit is given through a set of VHDL files. Up to now the circuit must be represented using a structural description. This means that the circuit must be represented by a collection of logic gates, based on the logic gate library available with NanoMagnet Logic (Majority voter, And/Or gates, Inverter). One of the planned features of the software is the possibility to represent the circuit with a generic description and then to automatically map it on the target technology library using a Logic Synthesizer. The VHDL files are translated by the Parser block into a graph used for in-memory circuit representation. After this phase it is possible to use the Place&Route block to automatically generate the circuit layout. This is the most complex part of ToPoliNano and, for now, it supports only pure combinational circuits. Circuits layout can be also manually described (in a full custom style) using a vector graphics program. A in-program editor to build circuits is also planned as future ToPoliNano feature. ToPoliNano is written in C++ with the help of some Perl scripts.

The circuit can at this point be simulated using a switch model of the magnets. It is a simplified tri-states model, where every magnet is assigned to a numerical value which represents its state. The magnetization of each element is therefore calculated as the weighted sum of the magnetization of its neighbor. It is a simplified model designed to fast simulate very

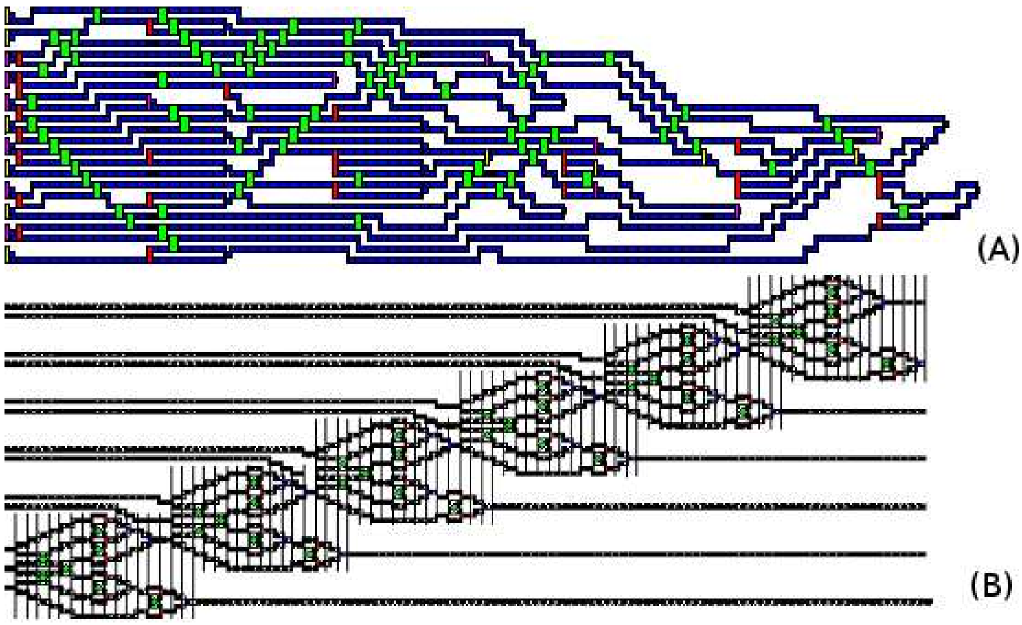

Fig. 2. Example of circuit layouts of a 6-bit adder. A) Automatically generated B) Manually generated.

complex circuits (for example a simple microprocessor based on NML might be based on more than 700k nanomagnets [6]). We are now expanding this simulation engine including circuit area calculation, power estimation and fault analysis. We are also including different types of interesting new NanoMagnet Logic technologies, like Multilayered NanoMagnet Logic [3] and out-of-plane NanoMagnet Logic [10].

III. Results

Figure 2 shows an example of a circuit layout obtained using ToPoliNano. Figure 2.A shows a 6-bit adder automatically generated by the Place&Route, while Figure 2.B shows the same circuit manually designed. This circuit layout is relies on a clock zone layout organization based on parallel lines, which is the only one currently experimentally demonstrated [11]. The results obtained by the automatic Place&Route is clearly better, since the layout is more compact and less wasted area is present. Currently we are testing the Place&Route engine over several benchmarks of increasing complexity and exploring different algorithms to optimize the length of interconnects and to reduce the number of crosswires used.

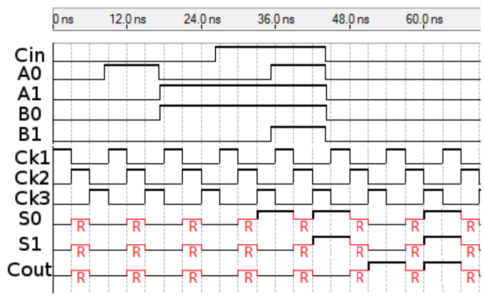

Fig. 3. Simulation of 2 bit adder.

Figure 3 shows instead a simulation of a 2 bit adder obtained used the automatic Place&Route. Results are obtained at magnet level and here only the main input/output signals are reported in the output waveforms for sake of brevity. All signals show the expected behavior and the simulation is obtained in extremely short time. We are currently testing the simulator performance over the benchmarks adopted for the Place&Route in order to prove its efficiency.

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