Automated Optimal Design of Switched-Capacitor Filters

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We present a method for automated design of CMOS switched-capacitor filters (SCFs) from user-defined top-level specifications to component sizes and physical layout. In other words, we present a complete top-down design flow for SCFs.

The method is based on careful analysis and modeling of the SCF using analog circuit design and system engineering expertise, formulating design constraints in a special convex form, and numerical optimization (geometric programming).

This method has the following important features:

- *Specification-driven.* The method takes as input all of the well-known top-level specifations of a SCF. These include specifications on power, dynamic range, passband ripple, stopband attenuation, layout area, etc. Therefore, only an understanding of the top-level specifications is required for designing SCFs using this method.

- *Automatic.* The process of mapping design specifications to component sizes and physical layout for the SCF using this method is fully automatic. No human (expert) intervention is required in the process.

- *Fast and optimal.* The method reduces design time by orders of magnitude, reducing months of manual design time into hours on a typical Wintel machine. Also, the method produces globally optimal designs, i.e., designs that achieve the best performance among all designs satisfying the specifications. This is a result of the availability of efficient and globally optimal numerical algorithms for solving geometric programs.

- *Portable.* The method takes as input the process (CMOS technology) parameters, which means that it is easily portable as process dimensions shrink, making analog design re-use possible.

- *Physical layout constraints.* This methodology combines physical layout design with circuit design (transistor and component sizing) in one step. This allows the user to specify physical layout constraints on the SCF such as layout area, width, height, and aspect ratio along with electrical constraints such as dynamic range and power.

- *Hierarchical and modular.* The method incorporates hierarchy and modularity in its implementation. In other words, the top-level constraints for the SCF are written (in special convex form) in terms of the input/ouput specifications of different smaller circuit blocks in the SCF (i.e., op-amps and CMOS switches.) This hierarchy is critical in automated design of complicated analog circuit cells such as SCFs. It results in better maintainability of the implementation and enables re-use of code when implementing the method for different SCF topologies.

The design is performed in two steps. The first step is a system level design step, in which an LC ladder filter and its corresponding SCF circuit topology is designed for the desired frequency response (passband ripple, stopband attenuation, etc.). This step may follow a classical filter design method such as Chebychev, Elliptic, or Bessel filter design. In the second step, which is the circuit level design step, the circuit components are designed for optimum performance using geometric programming. This includes computing transistor dimensions and capacitances of the circuit components, and placement and routing of the circuit components.

Geometric programming has already been used for the automated design of CMOS operational amplifiers (Hershenson & Boyd 1997). This work takes automated analog circuit design one step further, and demonstrates that previous results can be extended to more complicated system-level analog circuits such as SCFs with potentially hundreds of transistors.