An Open Source Collaborative Matlab Toolbox for the Design and Simulation of Continuous-Time ΣΔ modulators

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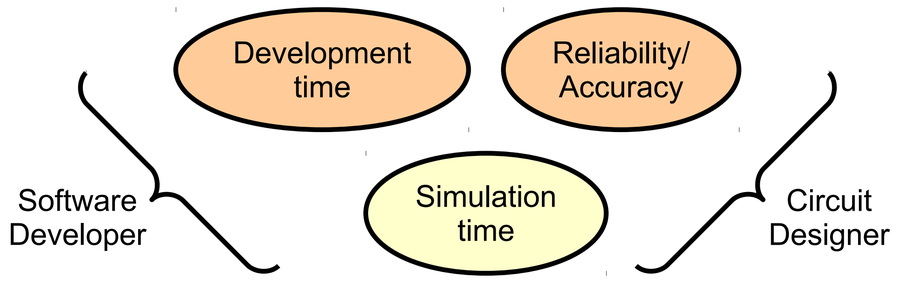
Introduction

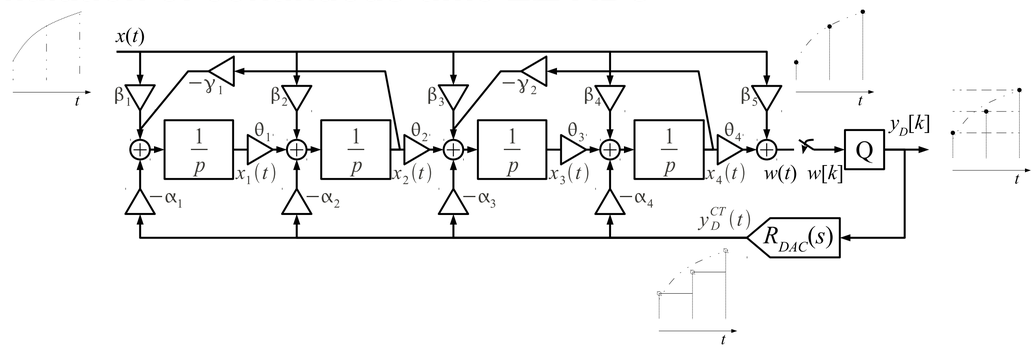
General context

- Simulation of electronic circuits

⇒ Critical step for circuit design



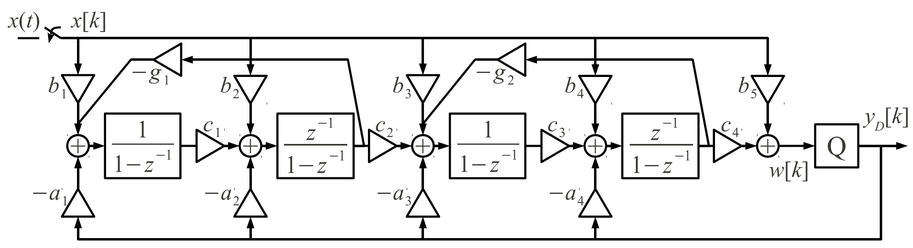
Simulation of continuous-time ΣΔ ADC



- Mixed CT/DT system
  - CT differential equation
- Nonlinear system
  - Time domain simulation

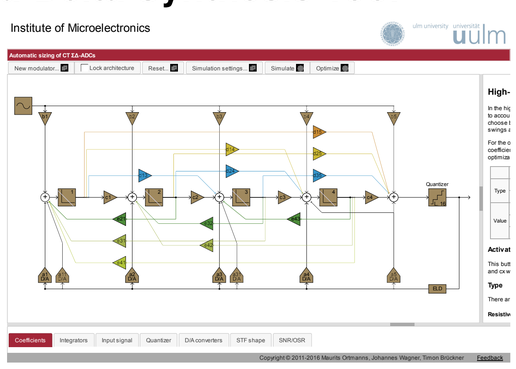
Famous available tools

Schreier's Delta Sigma Toolbox



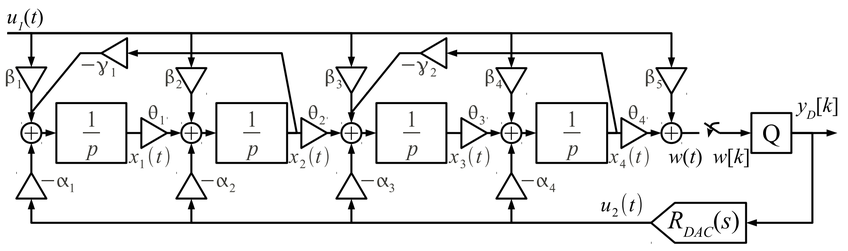
- Advantages
  - State space description
  - Wide range of architectures
  - Open source
- Limitations
  - Discrete time only
  - Non-idealities

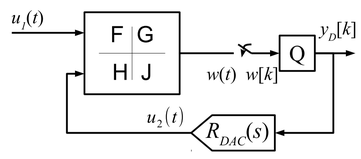
Uni Ulm Sigma-Delta Synthesis Tool



- Advantages
  - Optimization algorithms
  - Nonidealities
- Limitations
  - Custom features
  - Cascaded architectures
  - Test signals

Continuous time state space description – Modeling and simulation principle





$$\begin{pmatrix}\dot{x}_1(t)\\ \dot{x}_2(t)\\ \dot{x}_3(t)\\ \dot{x}_4(t)\end{pmatrix} = \begin{pmatrix}0 & -\gamma_1 & 0 & 0\\ \theta_1 & 0 & 0 & 0\\ 0 & \theta_2 & 0 & -\gamma_2\\ 0 & 0 & \theta_3 & 0\end{pmatrix}\begin{pmatrix}x_1(t)\\ x_2(t)\\ x_3(t)\\ x_4(t)\end{pmatrix} + \begin{pmatrix}\beta_1 & -\alpha_1\\ \beta_2 & -\alpha_2\\ \beta_3 & -\alpha_3\\ \beta_4 & -\alpha_4\end{pmatrix}\begin{pmatrix}u_1(t)\\ u_2(t)\end{pmatrix}$$

$$y(t) = \begin{pmatrix}0 & 0 & 0 & \theta_4\end{pmatrix}\begin{pmatrix}x_1(t)\\ x_2(t)\\ x_3(t)\\ x_4(t)\end{pmatrix} + \begin{pmatrix}\beta_5 & -\alpha_5\end{pmatrix}\begin{pmatrix}u_1(t)\\ u_2(t)\end{pmatrix}$$

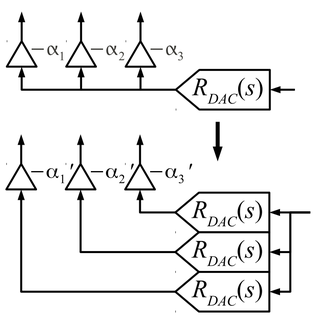
$$\begin{cases}\vec{\mathbf{X}}(t) &= \mathbf{F}\cdot\vec{\mathbf{X}}(t) + \mathbf{G}\cdot\begin{pmatrix}u_1(t)\\ u_2(t)\end{pmatrix}\\ w(t) &= \mathbf{H}\cdot\vec{\mathbf{X}}(t) + \mathbf{J}\cdot\begin{pmatrix}u_1(t)\\ u_2(t)\end{pmatrix}\end{cases}$$

- Time discretization : $T_{OvS} = \dfrac{Ts}{kOvS} \ll Ts$

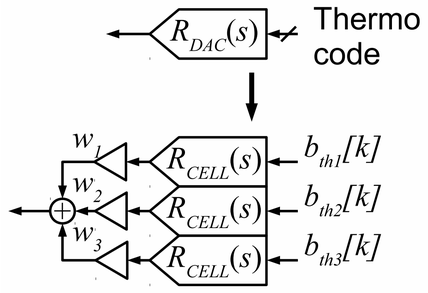
$$\begin{cases}\vec{\mathbf{X}}_D((k+1)T_{ovs}) &= \mathbf{A}\cdot\vec{\mathbf{X}}_D(k\,T_{ovs}) + \mathbf{B}\cdot\begin{pmatrix}u_1(k\,T_{ovs})\\ u_2(k\,T_{ovs})\end{pmatrix}\\ w_D(k\,T_{ovs}) &= \mathbf{C}\cdot\vec{\mathbf{X}}_D(k\,T_{ovs}) + \mathbf{D}\cdot\begin{pmatrix}u_1(k\,T_{ovs})\\ u_2(k\,T_{ovs})\end{pmatrix}\end{cases} \text{ with } \begin{cases}\mathbf{A} &= \exp(\mathbf{F}T_{ovs})\\ \mathbf{B} &= \mathbf{F}^{-1}(\mathbf{F}-\mathbf{I})\mathbf{G}\\ \mathbf{C} &= \mathbf{H}\\ \mathbf{D} &= \mathbf{J}\end{cases}$$

Nonidealities modeling

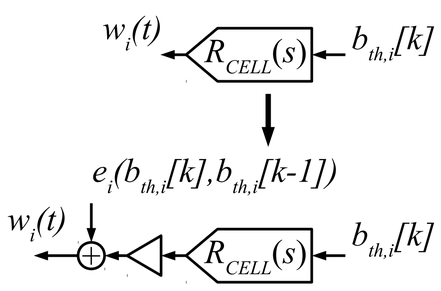
Inter-DAC mismatches



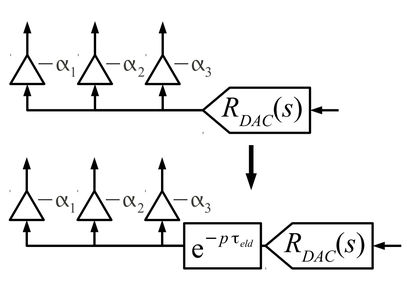
DAC inter-cell mismatches



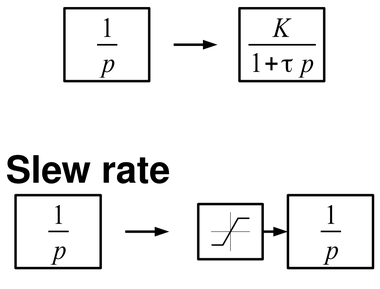
DAC intersymbol interferences



Excess Loop Delay



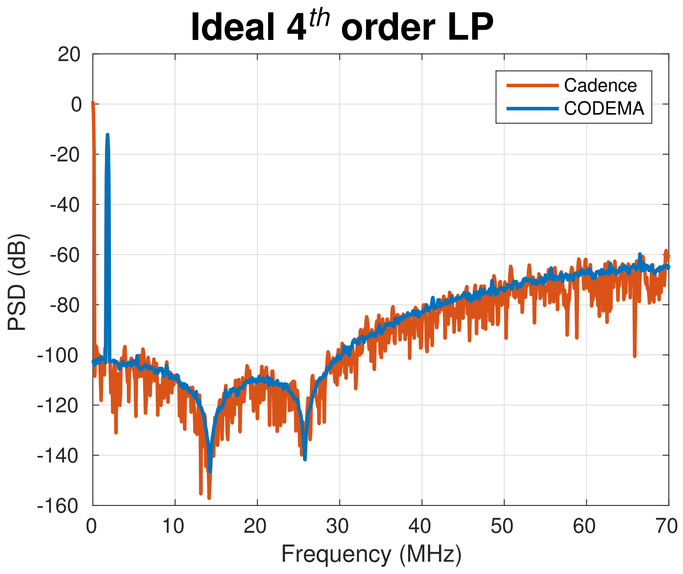
DC Gain



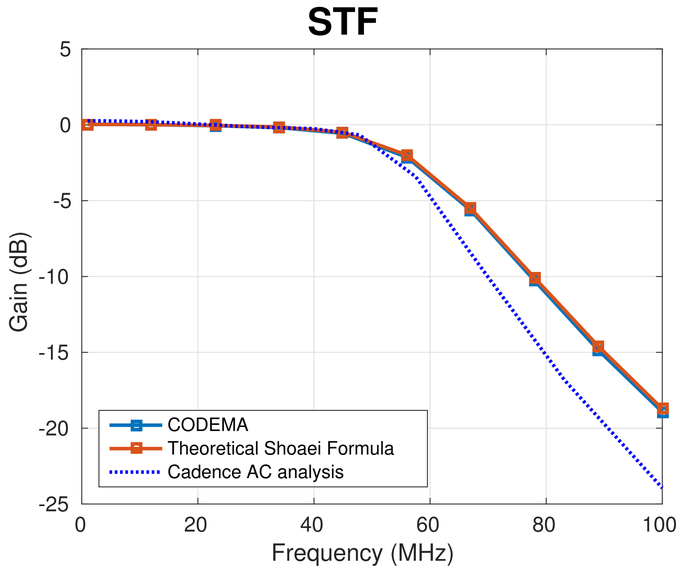
Slew rate

Simulation results

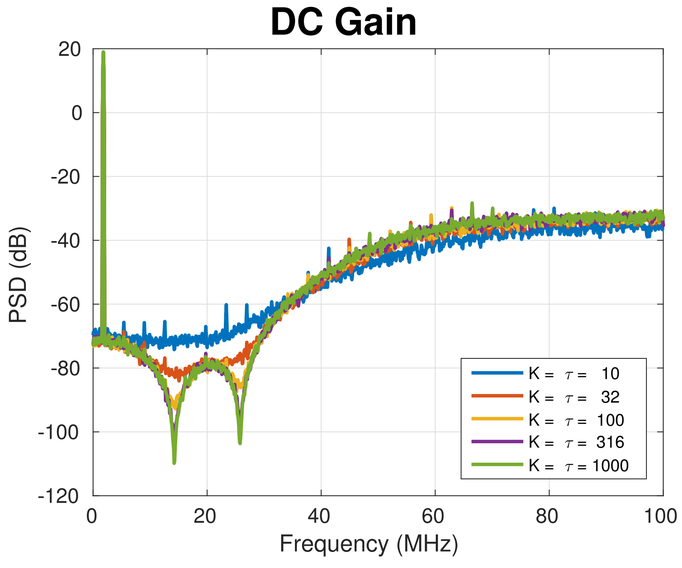
Ideal 4th order LP



STF



DC Gain



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