Metamodel-Assisted Fast and Accurate Optimization of an OP-AMP for Biomedical Applications

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Agenda

Motivation

Metamodel-assisted optimization flow

Op-Amp optimization

Verilog-AMS Op-Amp meta-macromodel

Conclusions
Traditional Top-down Approach

System Specifications

System-Level Optimization

Op-Amp Specifications

Op-Amp Design

High-Level Op-Amp model
Traditional Top-down Approach

- The high-level model is not a high-fidelity model

- System Specifications

- System-Level Optimization

- Op-Amp Specifications

- Op-Amp Design

High-Level Op-Amp model

- Low-order white-box models
- Some details are ignored
- Limited accuracy
- Lead to design iteration
Three-Step Bottom-Up Flow

- Metamodel-assisted optimization flow are proposed

Baseline Op-Amp Design →
Metamodel-Assisted Ultra-Fast Op-Amp Optimization →
Op-Amp Meta-Macromodel Construction →
Fast AMS System Optimization →
Verilog-AMS Op-Amp Meta-Macromodel →
New Op-Amp Baseline Design
- 30 transistors, 90 nm CMOS, 1-V VDD
The op-amp characteristics are estimated using POlynomial Metamodell (POM)

\[ f(x) = \sum_{i=0}^{N_B-1} \beta_i x_1^{p_1} x_2^{p_2} x_3^{p_3} \ldots x_N^{p_N} \]

Transistor widths, lengths, bias current, ...

Gain
Bandwidth
Phase Margin
Slew Rate
Power
Op-Amp POM Generation

- The goal is to find the coefficients for the polynomials

- Design Variable Range Determination
- Op-Amp Design Space Sampling
  - This work: 200 samples
  - Latin Hypercube Sampling with SPICE Simulations
- Design Variable Samples
- Op-Amp Response Samples
- Polynomial Regression
- Op-Amp Characteristic POMs
Op-Amp Optimization

- The power is to be minimized with other performance metrics as constraints

Op-Amp Design Space

Power minimize

Objective

Constraints

Gain
Bandwidth
Phase Margin
Slew Rate
The Cuckoo Search algorithm provides high converge rate
POM-assisted optimization is much faster

<table>
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<tr>
<th>Performance</th>
<th>Constraint</th>
<th>Optimal\textsubscript{POM}</th>
<th>Optimal\textsubscript{SCH}</th>
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</thead>
<tbody>
<tr>
<td>$A_0$ (dB)</td>
<td>$&gt; 43$</td>
<td>56.4</td>
<td>52.8</td>
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<tr>
<td>$BW$ (kHz)</td>
<td>$&gt; 50$</td>
<td>58.9</td>
<td>85.5</td>
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<tr>
<td>$PM$ (degree)</td>
<td>$&gt; 70$</td>
<td>84.4</td>
<td>87.7</td>
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<tr>
<td>$SR$ (mV/ns)</td>
<td>$&gt; 5$</td>
<td>7.1</td>
<td>8</td>
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<table>
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<tr>
<th>Objective</th>
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<th>Optimal\textsubscript{POM}</th>
<th>Optimal\textsubscript{SCH}</th>
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<tr>
<td>$P_D$ ($\mu$W)</td>
<td>$\sim 65$</td>
<td>65.5</td>
<td>68.1</td>
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<table>
<thead>
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<th>Performance</th>
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<th>Optimal\textsubscript{POM}</th>
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<tr>
<td>Power Reduction</td>
<td>$\times 3.71$</td>
<td>$\times 3.86$</td>
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<td>Number of iterations</td>
<td>1200</td>
<td>1200</td>
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<tr>
<td>Computation Time</td>
<td>12.5 h</td>
<td>2.6 s</td>
</tr>
<tr>
<td>Normalized Speed</td>
<td>1</td>
<td>$\times 17120$</td>
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Parametrized op-amp macromodel with the parameters estimated using POMs is constructed in Verilog-AMS (Verilog-AMS-POM)

- The parameters are computed in Verilog-AMS `initial` block
- The transfer function is implemented using `laplace_nd()` function
- The op-amp Verilog-AMS-POM can be used in system-level simulations
SPICE vs Verilog-AMS-POM

- AC analyses

**Magnitude**

**Phase**

![Graph showing AC analyses](image-url)
SPICE vs Verilog-AMS-POM

- Transient analysis

![Graph showing transient analysis](image)

- **Voltage (V)**
- **Time (ns)**

- Inp
- Outp (Schematic)
- Outp (1st order POM)
- Outp (2nd order POM)
Conclusions

- The proposed bottom-up optimization flow mitigates the flaw of the top-down approach

- Ultra-fast block-level op-amp optimization is achieved by using POMs

- Op-amp Verilog-AMS-POM has been constructed for accurate and efficient system-level optimization
Questions?

Thank You!!!