# iVAMS: Intelligent Metamodel-Integrated Verilog-AMS for Circuit-Accurate System-Level Mixed-Signal Design

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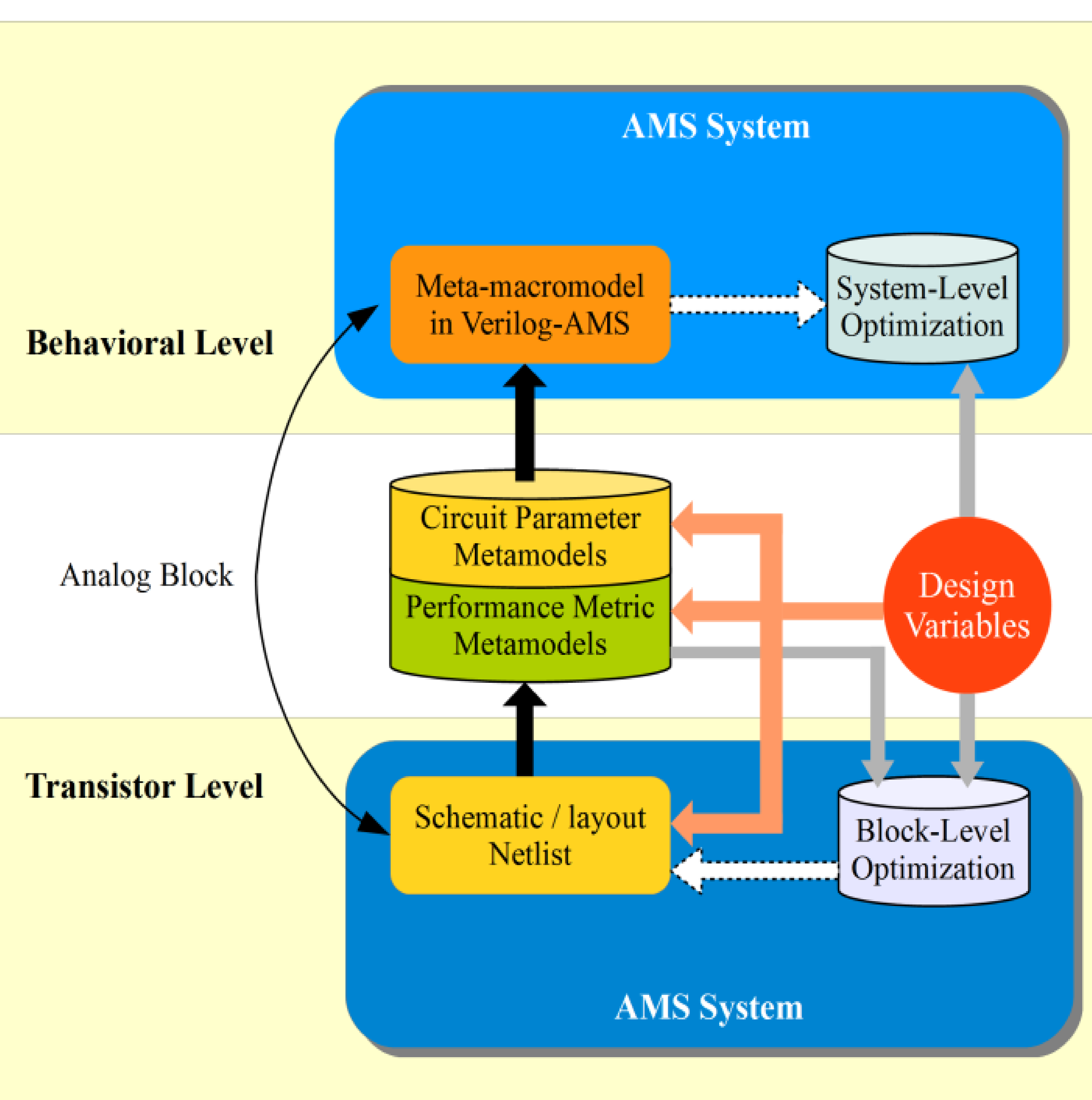
## Abstract

The gap between abstraction levels in analog design is a major obstacle for advancing analog and mixed-signal design automation. Intelligent surrogate models for low-level analog building blocks are needed to bridge behavioral and transistor-level simulations. Parameterized behavioral models in Verilog-AMS based on the neural network metamodels are constructed for efficient system-level design exploration. To the best of the authors' knowledge this is the first paper to integrate artificial neural network models in Verilog-AMS. To demonstrate the application of iVAMS, a biologically-inspired "firefly optimization algorithm" is applied to an OP-AMP design. The optimization process is sped up by 5580× due to the use of iVAMS with negligible loss in accuracy.

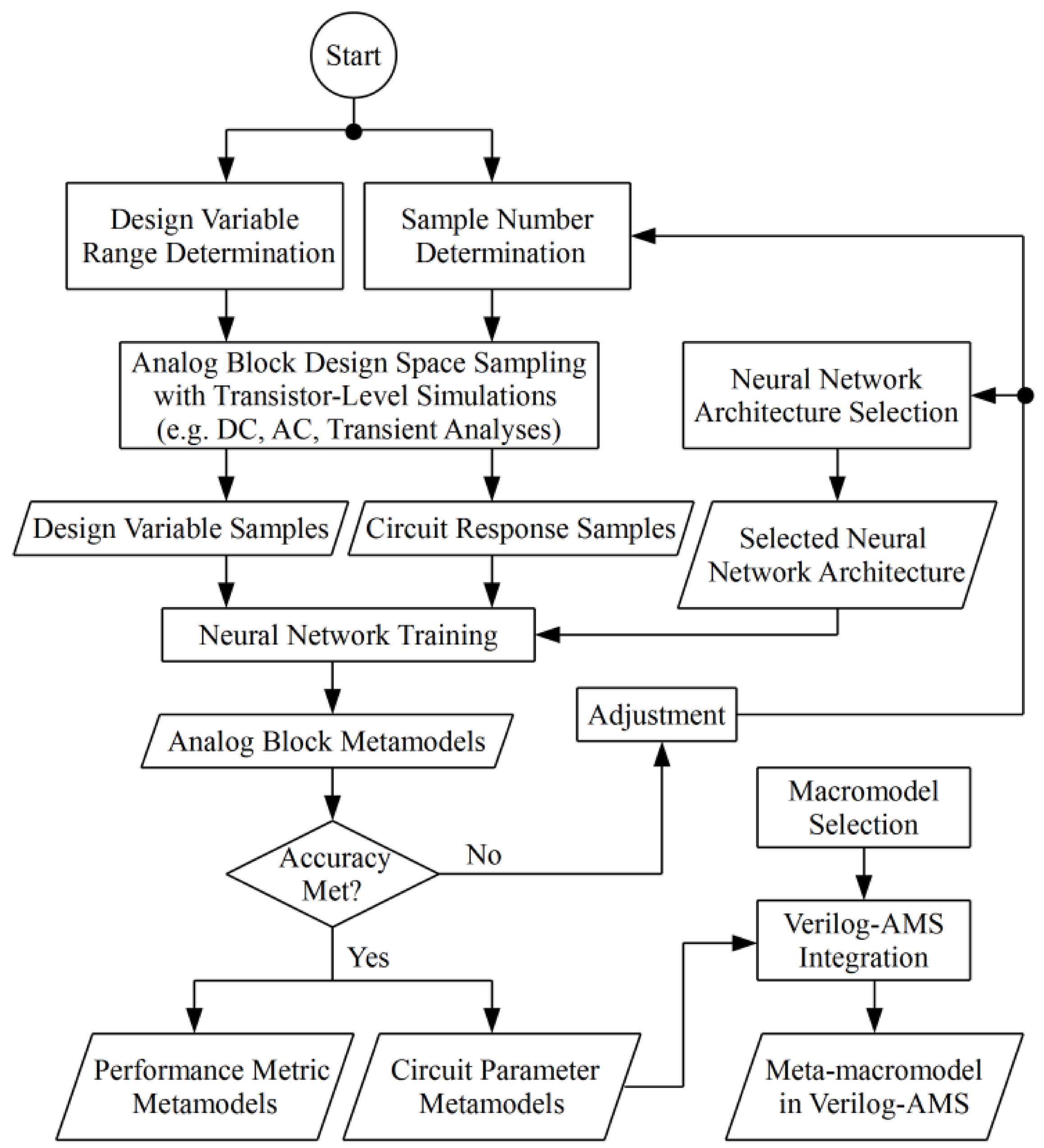
## iVAMS Concept

iVAMS aims at closing the gap between behavioral- and transistor-level Analog/Mixed-Signal (AMS) design exploration. Parameterized Verilog-AMS modules incorporating transistor-level non-idealities are provided for high-level design exploration. Efficient metamodels are generated for low-level block optimization. The concept is illustrated below:




## iVAMS Generation

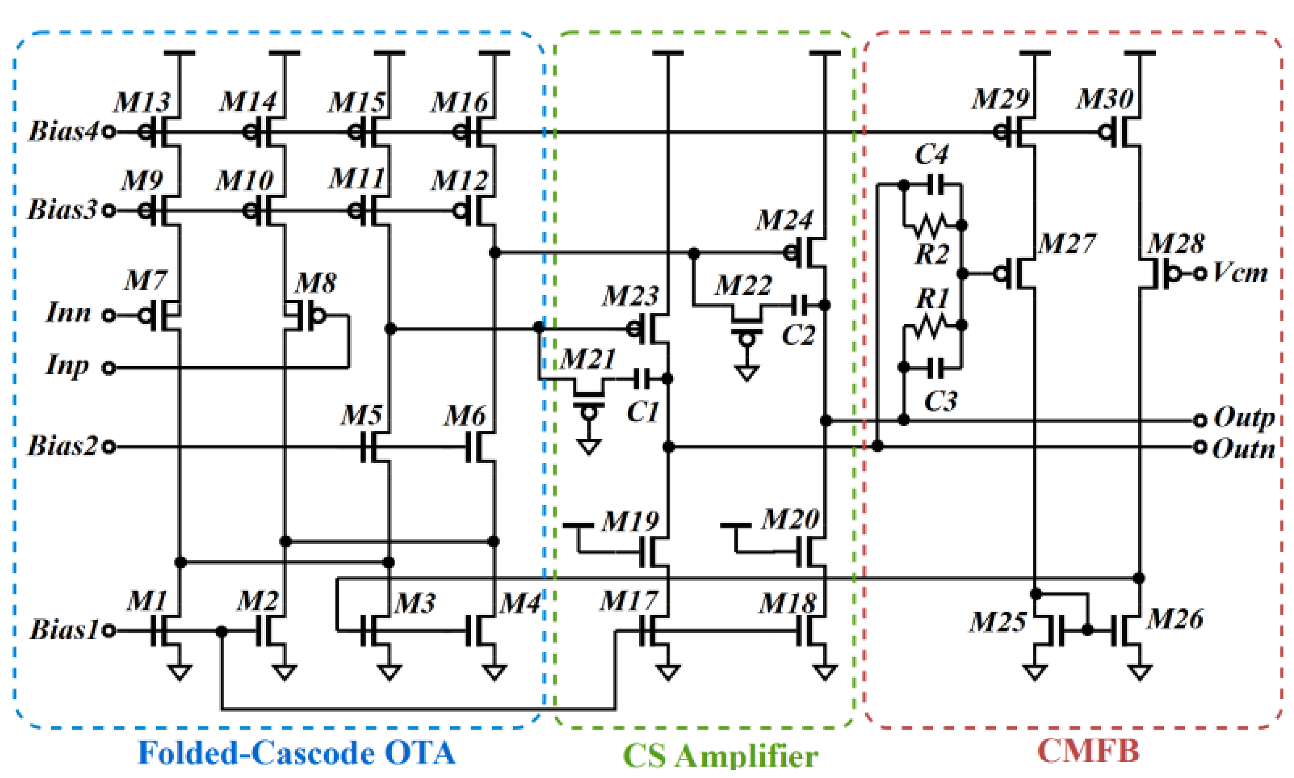
Given an analog block, the goal of iVAMS generation is to obtain the neural network metamodels and the meta-macromodel integrated Verilog-AMS module.




## Case Study Circuit: Op Amp

iVAMS is applied to a fully-differential Op Amp:
- 90 nm CMOS process, 1-V supply.
- 16 design variables (Ls and Ws, bias current...).

Metamodels:
- neural networks with a single hidden layer.
- 4-neuron hidden layer is used.




## Metamodel Accuracy

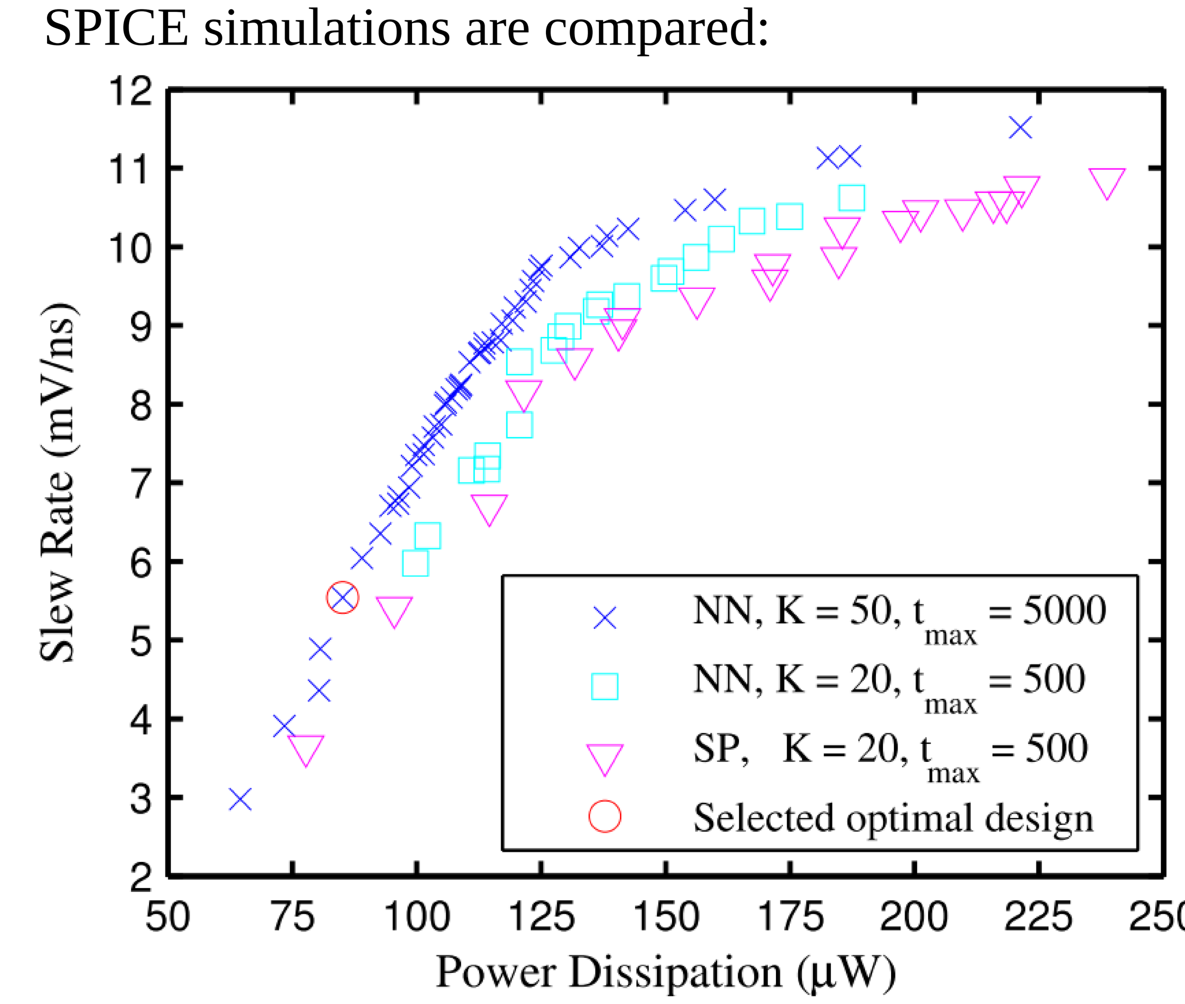
- The neural networks were trained using 500 samples.
- A verification set consists 2000 samples were used.

| Metamodel Output | Type | $R^2$ | RMAE | RRSE | RMSE |
|---|---|---|---|---|---|
| $A_0$ | NN | 0.959 | 1.324 | 0.202 | 41.93 V/V |
| | PO | 0.973 | 1.044 | 0.163 | 33.78 V/V |
| $BW$ | NN | 0.987 | 0.894 | 0.116 | 2.12 kHz |
| | PO | 0.986 | 0.965 | 0.117 | 2.14 kHz |
| $PM$ | NN | 0.901 | 2.161 | 0.317 | $4.99^o$ |
| | PO | 0.348 | 4.466 | 0.807 | $12.70^o$ |
| $SR$ | NN | 0.989 | 0.483 | 0.105 | 0.292 mV/ns |
| | PO | 0.985 | 0.662 | 0.119 | 0.332 mV/ns |
| $P_D$ | NN | 0.996 | 0.523 | 0.062 | 8.306 $\mu$W |
| | PO | 0.980 | 1.314 | 0.141 | 18.817 $\mu$W |

(Accuracy Metric: $R^2$, RMAE, RRSE, RMSE)

## Block-Level Multi-objective Optimization

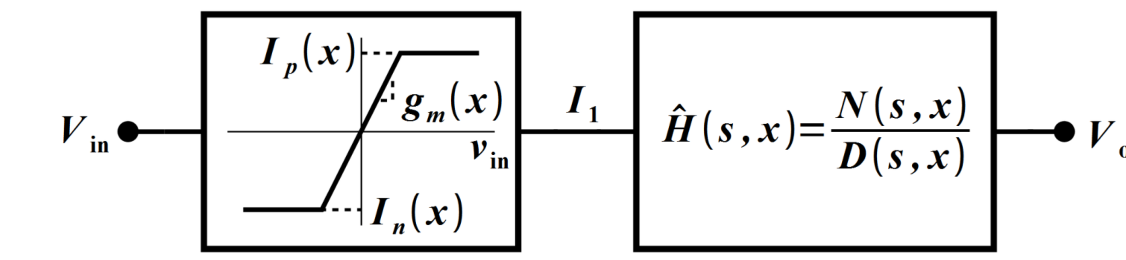
- Objective: minimize power and maximize slew rate.
- A metaheuristic multi-objective firefly algorithm is employed to generate the Pareto front.
- The results from neural network metamodel and SPICE simulations are compared:




| Optimization # | 1 | 2 | 3 |
|---|---|---|---|
| Model Type | NN | NN | SP |
| Number of Pareto Points, $K$ | 50 | 20 | 20 |
| Number of Iterations, $t_{max}$ | 5000 | 500 | 500 |
| Runtime | 0.57 h | 84.63 s | 131.18 h |
| Normalized Speed | – | ×5580 | 1 |

## Meta-Macromodel Construction

The following macromodel is selected to be implemented in Verilog-AMS:

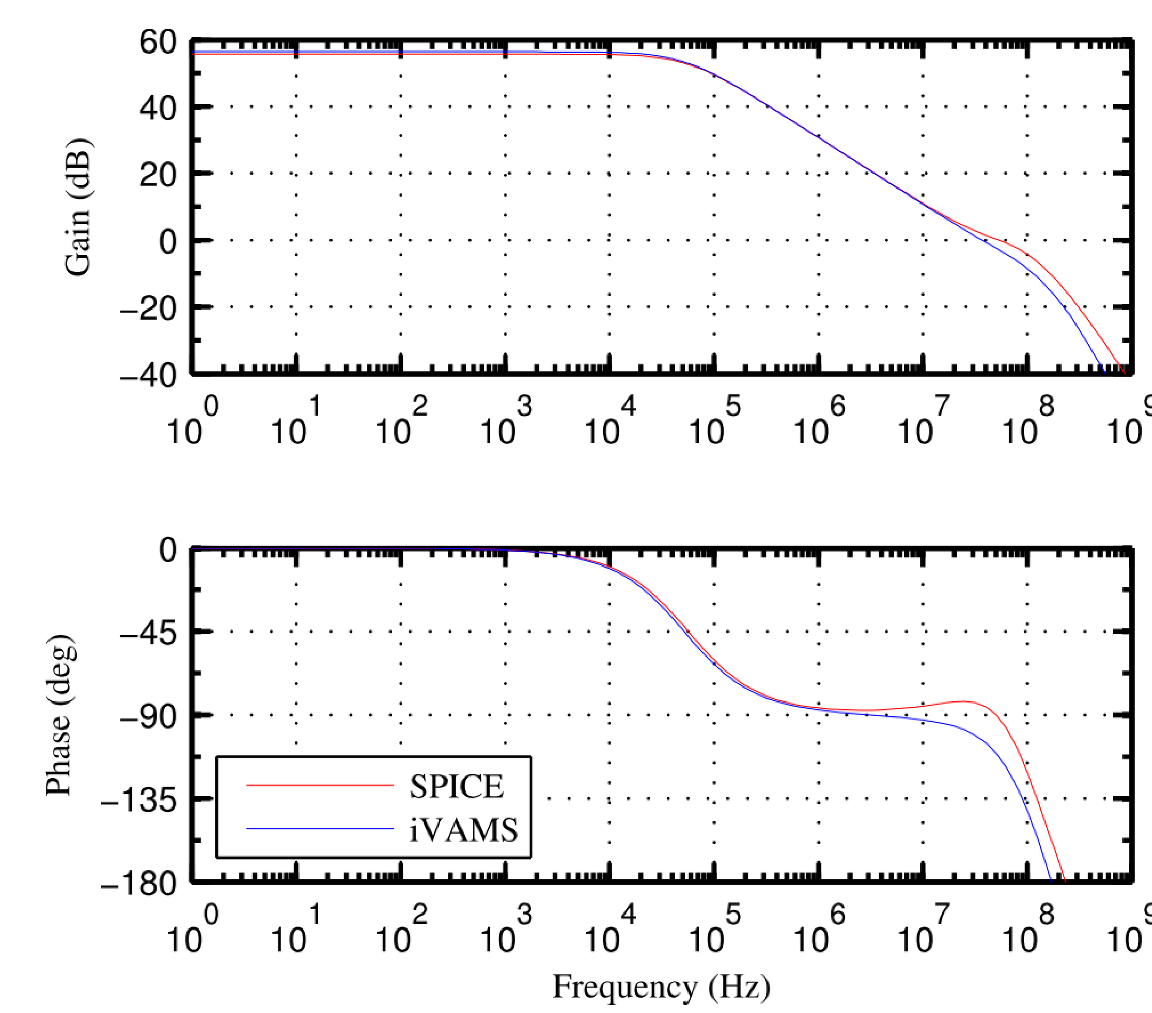



$$\hat{H}(s,x)=\frac{N(s,x)}{D(s,x)}$$

The circuit parameters, Ip, In, gm, the poles and zeros in the transfer function are parameterized and estimated using neural network metamodels:

$$\hat{y} = b_{21} + \sum_{j=1}^{M} w_{2,j} \cdot \tanh\left(b_{1j} + \sum_{i=1}^{N} w_{1,ij} \cdot x_i\right)$$

The above mathematical function is implemented in Verilog-AMS. The SPICE and iVAMS simulations are compared:




## Conclusion

iVAMS:
- is a circuit-level modeling framework.
- creates efficient models that bridge different abstraction levels of AMS designs.
- is compatible with optimization algorithm.

Future research includes adding yield-estimation capability.

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