Fast Analog Design Optimization using Regression based Modeling and Genetic Algorithm: A Nano-CMOS VCO Case Study

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Abstract

•*This work presents a novel design flow for constrained optimization of nano-CMOS analog circuits.*
•*Proposed analog design flow combines polynomial-regression based models and genetic algorithm for fast optimization..*
•*Power minimization in a 50nm CMOS based current starved voltage-controlled oscillator (VCO) is carried out, while treating oscillation frequency as a performance constraint..*
• *The goodness-of-fit of the models is evaluated using SSE, RMSE and R^2.*
• *The flow achieved 21.67% power savings, with a constraint of frequency ≥ 100 MHz.*

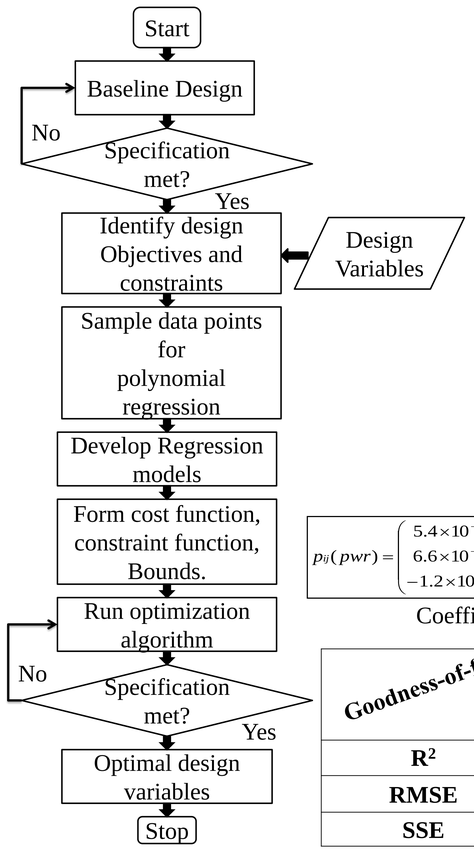
Introduction

• Modern analog integrated circuit (IC) optimization problems are highly complicated and involve minimizing a cost function subject to certain constraints.
•Multivariant technique is implemented to understand constrained optimization in this research.
•In most analog design situations, a designer must make trade-offs between conflicting behavioral requirements, dealing with functions that are often non-linear, such as power consumption and frequency of a VCO.
•Optimizing two or more design objectives while subjecting design variables or performance metrics to constraints has been aimed for multi-objective optimization
•Polynomial regression model is an x abstracted model of the netlist which enables a fast design space search. It can be used as an alternative to the exhaustive search of the actual circuits design space.

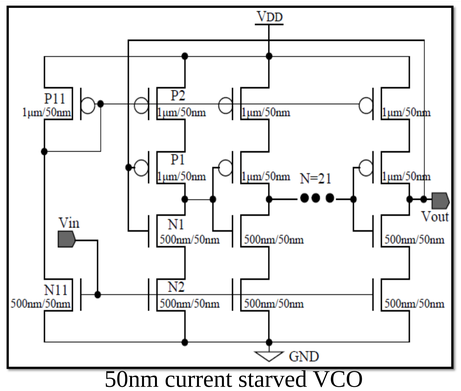
•The goodness-of-fit of the models is evaluated using *SSE, RMSE and R^2*. Using these models, we form a constrained optimization problem which is solved using genetic algorithm.
•The model can also be used in a variety of tools, such as MATLAB, and is language independent and can be used in a flexible fashion.

Proposed Optimization Flow for Nano-CMOS VCO

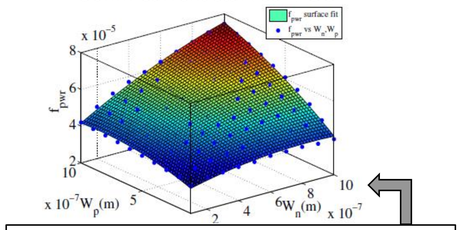
The input to the proposed design flow is a baseline design of circuit. This is one time manual design step. At this stage a netlist is sufficient for the design flow.



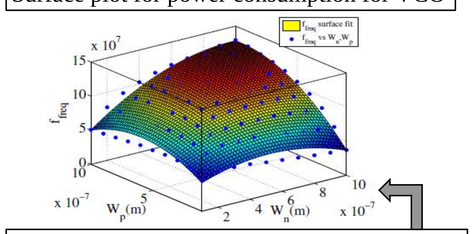
Design and Polynomial Modeling of VCO



50nm current starved VCO



Surface plot for power consumption for VCO



Surface plot for oscillating frequency for VCO

$$p_{ij}(pwr) = \begin{pmatrix} 5.4\times10^{-5} & 6.8\times10^{-6} & -1.3\times10^{-6} \\ 6.6\times10^{-6} & 2.7\times10^{-6} & 0 \\ -1.2\times10^{-6} & 0 & 0 \end{pmatrix} \quad p_{ij}(freq) = \begin{pmatrix} 1.10\times10^{8} & 1.61\times10^{7} & -1.02\times10^{7} \\ 1.17\times10^{7} & 8.57\times10^{6} & 0 \\ -8.41\times10^{6} & 0 & 0 \end{pmatrix}$$

Coefficient matrix for the power and frequency model.

Goodness-of-fit	Power model	Frequency model
R^2	0.9943	0.9953
RMSE	0.2378μW	2.184 MHz
SSE	56.55pW	4.76 × 10^{15} Hz

Constrained Optimization using GA

Problem to be solved:

$$\text{minimize } g(x) = Power_{VCO}$$
$$\text{such that} \rightarrow \begin{cases} 100\times10^{6} - Frequency_{VCO} \le 0, \\ 100\,nm \le x \le 1\mu m \end{cases}$$

Where cost function is $g(x)=Power_{VCO}$ *and constraint function* is $h(x) = 100\times10^{6}$-$Frequency_{VCO}$. *The lower and upper* bounds for the design variable set $x = [Wp,Wn]^T$ *are 100nm* and 1μm *respectively. The cost function is minimized through* a Genetic Algorithm.

•**Input:** Cost function g(x), constraint function h(x), 100nm ≤ x ≤ 1µm, design solution set *x*.
•**Output:** Optimal design solution $x_{opt.}$
•Generate initial population design variable *x*.
•Initialize the number of iterations, gen = 0.
•**while** gen < maxgen-1 **do**
  •Select mating pool from the initial population as *x'*
  •Initialize set of children *x"* = Ø.
  •**for** i=0 to populationsize-1 **do**
    •Select individuals x'_a at random from *x'*.
    •Apply crossover to x'_a to produce child x'_{child}.
    •Randomly mutate produce child x'_{child}.
    •$x" = x" \cup x'_{child}$.
  •***end for***
  •$x''' = x" \cup x'$.
  •Evaluate fitness using g (*x'''*), *h(x''')*.
  •Increment the counter as gen=gen+1.
•**end while**
•The optimal solution is obtained: $x_{opt} = x'''$.
•Assign x_{opt} to transistors in VCO and recreate the design using the new parameters.
•Re-simulate VCO to characterize for *freq* and *pwr.*

Comparison of objectives in baseline and optimized VCO

Design	W_p	W_n	PowerVCO	$Frequency_{VCO}$
Baseline	1µm	500nm	60µW	111.4MHz
Optimized	482nm	434nm	41µW	105.4MHz

Conclusions and Future Work

•A polynomial regression model assisted constrained multiobjective optimization has been carried out on a 50nm VCO for simultaneous frequency and power optimization.
•It was observed that a model based approach is beneficial as it is faster than optimizing the actual circuit.
•As part of future research, regression based models will be developed, taking into account supply sensitivity, temperature sensitivity, process variation and parasitics.
•VCO performance parameters other than power and frequency, such as phase noise, tuning linearity will also be considered.

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