A Multi Output Formulation for Analog Circuits Using MOM-SVM

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Abstract

This paper proposes performance based macro modeling of analog circuit using Multi Output Modeling (MOM) with the help of Support Vector Machine (SVM). SVM models the analog circuits and provides a relation between multi-input and multi-output parameters. In this work, Voltage Controlled Oscillator (VCO) is modeled as a test circuit which is designed in Cadence Virtuoso GPDK 45nm technology. From the Spice simulation results, the feasible dataset has been extracted from the complete dataset. Then, the VCO output frequency and phase noise is modeled by the width of the transistors which are the input parameters of the transistors. After tuning the model properly by k-cross validation method, the accuracy was found to be 96.1% which is good enough to make it use for the circuit synthesis purpose.

Keywords: Kernel methods, Machine Learning, Macro modeling, Mean Square Error, Regression Analysis

1. Introduction

Circuit designing is one of the important fields which play a very vital role in almost all of the applications where electronics is dealt with. While designing the appropriate circuit to work on a specified range, it requires a very in-depth analysis of the circuits. But the growing complexity of the reduced area of the integrated circuits has provided the circuit designers a keen concern to formulate the circuits to take them to market under a stipulated period. While synthesizing the circuit and to obtain the best suitable input parameters for optimized results, a lot of simulation work has to be performed. But performing simulations, especially for complex circuits will led the designers to take a lot of time to obtain the proper results. Circuit modeling has been one of the most important concerns for the researchers to formulate better modeling techniques to behave as like the original circuit. Once the model is ready, then the synthesis or circuit optimization will take very less time to obtain the results.

In recent years, many modeling techniques have been proposed which have a wide range of area of implementation without compromising the accuracy and time for modeling. Equation-based modeling, symbolic modeling are some of the best modeling methods [1-3]. But the increase in complexity has increased the time to model using these methods. Also, the growing demand for creating the simulated result models to be more accurate to the real time models has asked the designers to think new techniques which can provide better accurate models compromising minimal time. Neural network models [4-6] were such an out of the box implementation in the field of circuit design. But still it is affected by problems like dimensionality problem and convergence towards local minima. Support Vector Machine (SVM) [7-9] can be a preferable modeling technique which is least affected by such type of problems. This modeling technique in the field of machine learning which provides a good accuracy of the output parameters for the design parameters can be good perspective for modeling the circuits to a larger extent. Its regression modeling, analysis has provided robust as well better accurate models in very less time. Although, in recent years, Extreme Learning Machine (ELM) [10-12] has shown better perspective in the regression modeling field which has the big advantage of handling big data in very less time. Still, while modeling less data numbers, the accuracy of the model is not that good enough whereas SVM outperforms in that aspect.

In this paper, the regression model of SVM has been used to perform Multi-Output Modeling (MOM) which can be able to model multiple parameters at a time. A differential two-

stage voltage controlled oscillator (VCO), which is shown in Figure 1 has been used for the purpose of modeling the parameters like frequency and phase noise.

        The rest of the paper assigned as follows. Section-II describes about the proposed methodology and section-III discusses about the formulation of MOM-SVM and its algorithm. In section-IV, the simulation results have been analyzed followed by conclusion in section-V.
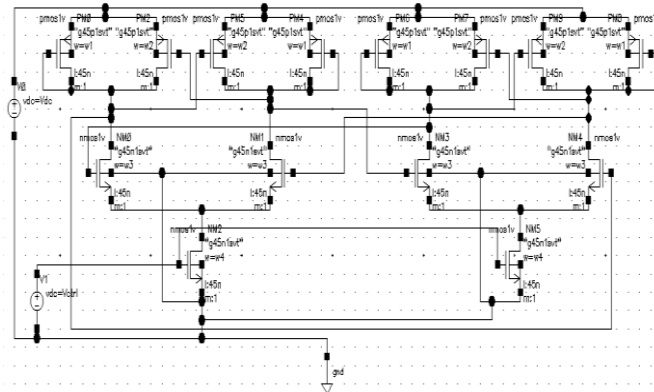

Figure 1. A two-stage differential ring VCO [13]

2. Proposed Methodology

        SVM was earlier proposed by Vapnik et.al., [7, 14] which has shown better modeling behavior in many applications. It is a type of machine learning and can be categorized under supervised learning. It is used especially for classification or regression type of problems. Classification types of problems are those problems which can be used to classify the features according to some common features. But in regression type of problems, the model is expected to find out the expected output for a given set of input parameters.

        SVM [21] deals with the input feature data points which are mapped into another space called as feature space. These parameters in this new feature space can be easily separable by forming the hyperplane. This paper focuses on estimating the results, so the model has been implemented as regressors. While taking regression as the objective of modeling, then Kernel functions play a vital role in increasing the performance of the model. So, choosing the appropriate Kernel can help for the designers to obtain better results.
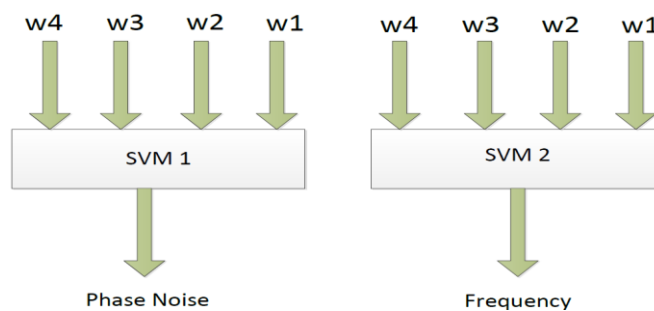

Figure 2. Traditional way of modeling multi-output based SVM

        Many researchers have proposed various multi-regression problems and obviously some of them have been implemented successfully using SVM also. Figure 2 shows one of such modeling the multi-output parameter of VCO using SVM. Here, w1, w2, w3 and w4 which represent the width of the transistors of VCO as shown in Figure 1 are the input parameters and phase noise and frequency are the output parameters. In this type of modeling, it has got

demerits. Firstly, the main problem is that it will not be able to model properly in the case if the output parameters are correlated to each other. Secondly, individual modeling will take a lot more time in comparison to multi-modeling simultaneously, which has been verified clearly in simulation results.

So, this paper shows one of such implementation methods to model the voltage controlled oscillator the output parameters frequency of operation as well as phase noise simultaneously.
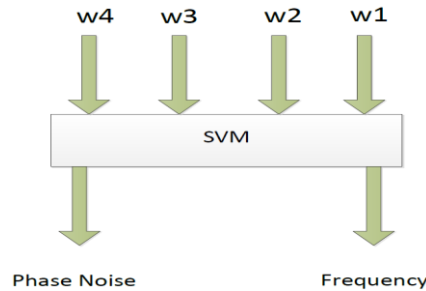

Figure 3. Multi-output parameter modeling using SVM

3. MOM-SVM

Multi-parameter Modeling Analysis [15-17] using Support Vector Machine carries out the modeling of the input parameters which are the ratio of width and length of the MOSFETs used in this circuit against the multi-output parameters frequency and phase noise. In this proposed technique, the output parameters are considered to be somewhat interdependent to each other. This makes a general way modeling the circuit using SVM is not that way similar to the single output based modeling. The proposed MOM-SVM modeling technique for the multi-output based VCO is shown in Figure 3.

3.1. MOM-SVM Algorithm

The flow chart for MOM-SVM which has been implemented in this paper has been shown in Figure 4. Let the inputs $\{x_i\}$ which are the width of the transistors are represented by 'w'. The outputs $\{y_i\}$, frequency represented by 'f' and phase noise by 'p'. So, the input and output set $\{x_i, y_i\}$ can be represented in together by $\{\{w\}, \{f, p\}\}$ where $x_i \in \Re^n$, $y_i \in \Re^q$. Here 'n' is four as four number of transistor width have been taken as input parameters and 'q' is two as frequency and phase noise are the two output parameters. This input vector set $\{x_i\}$ is transferred to another non-linear function of higher dimension than the dimension of input $\{x_i\}$ of 'm'.

So, the estimating function $f(x)$ is calculated as $f(x) = (W.\Phi(x)) + B$ where $\Phi(x)$ is the higher dimensional non-linear function of dimension let 'm'. 'W' is the weighted matrix of $m \times m$ and 'B' is the bias matrix. This leads to the formulation of the objective function which is to minimize represented as:

$$R_{reg}(f) = C\sum_{i=1}^{n} L_\varepsilon(y_i, f(x_i)) + \frac{1}{2}\|W\|^2 \tag{1}$$

where C is user specified constant, $L_\in$ is the extension of the $\in$-sensitive loss function. Here the objective function is calculated for the single objective or output type of problems. With the introduction of slack variables and the constraints, it will lead to the solution for the 1-Dimensional problem. With the help of the constraints, the 'W' and 'B' variables are calculated. But while formulating the multi-dimensional problem (as in this paper), the above optimization

problem has to be modified to the below mentioned objective function which is to be minimized is represented as:

$$R'_{reg}(W',B) = C \sum_{i=1}^{n} L_{\varepsilon}(u_i) + \frac{1}{2} \sum_{j=1}^{q} \left\| W^j \right\|^2$$

(2)

Here $L_{\varepsilon}(u_i)$ is the loss function which can be defined as:

$$L(u) = \begin{cases} 0 & u < \varepsilon \\ u^2 - 2u\varepsilon + t^2 & u \geq \varepsilon \end{cases}$$

(3)

Where,

$$u_i = \left\| e_i \right\| = \sqrt{e_i^T e_i}$$

(4)

$$e_i^T = y^T - \Phi^T(x_i).W' - B^T$$

(5)

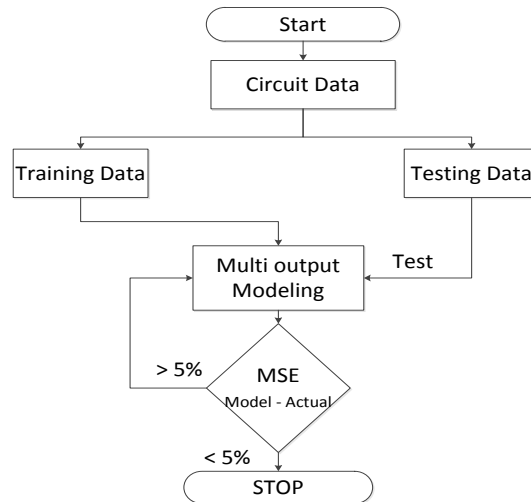$$W' = [W^1 ... W^q]$$

(6)

$$B = (B^1 ... B^q)$$

(7)

Figure 4. Proposed flow-chart to implement MOM-SVM for analog circuit

Since it is a multi-dimensional problem, the above equation (2) is solved by the help of IRWLS method (Iterative Re-Weighted Least Square) [18] to minimize the function. So, to obtain the next level of solution iteratively (W^{t+1}, B^{t+1}) from (W^t, B^t) , the first order Taylor expansion approach has been implemented. So, the equation (2) is modified after implementing the above methods is mentioned in equation (4) below as:

$$L(W',B) \approx \ddot{L}(W',B) = \frac{1}{2} \sum_{j=1}^{n} \alpha_i y_i^2 + C.\lambda + \frac{1}{2} \sum_{j=1}^{q} \left\| W'^j \right\|^2$$

(8)

Where, $C.\lambda$ is the constants generated while approaching to equation (8) and is independent of W' and B.

$$\alpha = \begin{cases} 0, & u_i^k < \varepsilon \\ 2C\dfrac{u_i^k - \varepsilon}{u_i^k}, & u_i^k \geq \varepsilon \end{cases} \tag{9}$$

With the help of the stationary point condition, the solutions for the W' and B can be solved from the matrix equation.

$$\begin{pmatrix} K + D_\alpha^{-1} & 1 \\ \alpha^T & 1^T \alpha \end{pmatrix} \begin{pmatrix} \beta^j \\ B^j \end{pmatrix} = \begin{pmatrix} y^j \\ \alpha^T y^j \end{pmatrix}, \quad j = 1, 2, \dots, q \tag{10}$$

Where, K is the kernel matrix which is to be used for modeling SVM and can be defined as:

$$K_{ij} = K(x_i, x_j) = \Phi^T(x_i).\Phi(x_j) \tag{11}$$

$$D_\alpha = \begin{pmatrix} \alpha_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \alpha_n \end{pmatrix} \tag{12}$$

$$\alpha = \begin{pmatrix} \alpha_1 \\ \vdots \\ \alpha_n \end{pmatrix} \tag{13}$$

$$\beta^j = \begin{pmatrix} \beta^j_1 \\ \vdots \\ \beta^j_n \end{pmatrix} \tag{14}$$

$'B'$ is a scalar quantity
y_j is the estimated output.

For input x,

$$y(j) = \sum_{i=1}^{n} K(x, x_i)\beta_i^j + b^j \text{ for j=1,2,..q.} \tag{15}$$

So, to obtain the value of output y; K, β, B is required where β, B values can be obtained from equation (10). α can be obtained from u and $L(u)$ which are obtained from B and W'. By initializing at the starting of the algorithm and then with the help of recursive iteration method, β, B values are updated subsequently using the help of line search method optimization process [15].

4. Simulation Results and Analysis
        VCO which has been designed in CADENCE VIRTUOSO tool in 45nm technology and its circuit parameters and output data have been extracted using SPICE simulation. The input parameters, i.e. width of the transistors have been varied in between the range of 120nm to 1um. From these data sets, 750 feasible data has been extracted to implement in MATLAB

using LSSVM for modeling purposes. Using hold out method [19], 80% of data has been taken as training data set and rest 20% for the testing data set has been used for testing the model accuracy. The comparative analysis of the training time, testing time and accuracy between single output based modeling and MOM-SVM has been shown in Table 1.

From the results, it can be clearly analyzed that although the training time and testing time in case of MOM-SVM to that of SVM generating individual model is more (when considered individually), but less when complete result (individual models are added) is generated. Also, there is a significant improvement in accuracy when compared with the phase noise output parameter modeling when considered in together in case of single output modeling.

function estimation using MOM-SVM$_{\gamma=16.31,\sigma^2=0.68}^{RBF}$ datapoints (green plus - phase noise), (black dots - frequency) and estimation (red line - frequency), (blue line - phase noise)
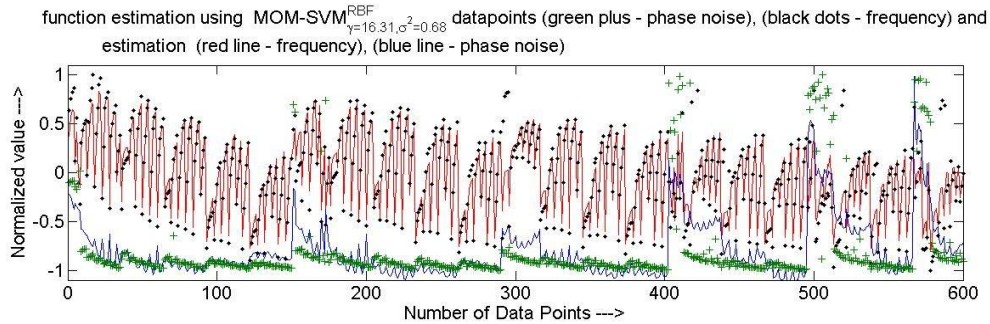

Figure 5. Estimation of the output frequency and phase noise of the VCO

Table 1. Simulated Results for comparative analysis of mom-svm with individual modelling by svm on the basis of kernel type

Sl.No.	Kernel Type	SVM1 (Frequency Modeling)			SVM2 (Phase Noise Modeling)			MOM-SVM		
		Training Time	Testing Time	Accuracy	Training Time	Testing Time	Accuracy	Training Time	Testing Time	Accuracy
1	RBF	0.14s	0.11s	97.25%	0.19s	0.09s	93.92%	0.25s	0.16s	95.59%
2	Linear	0.11s	0.06s	92.61%	0.11s	0.08s	89.02%	0.23s	0.09s	90.82%
3	Polynomial	0.16s	0.06s	96.51%	0.11s	0.08s	93.00%	0.26s	0.11s	94.76%
4	Sinc	0.17s	0.14s	82.54%	0.17s	0.12s	83.76%	0.26s	0.20s	83.15%
5	Wavelet	0.21s	0.16s	97.16%	0.17s	0.20s	93.44%	0.26s	0.30s	95.30%

Table 2. Tuning of MOM-SVM Parameters using Cross-Validation Method

Runs	γ	σ^2	MSE
1	15.22	0.63	0.0390
2	16.53	0.76	0.0391
3	19.21	0.83	0.0392
4	17.55	0.58	0.0389
5	13.05	0.61	0.0389
Mean	16.31	0.68	0.0390

Table 2 shows the tuning of RBF Kernel based modeling of MOM-SVM parameters i.e. γ (regularization parameter) and σ (RBF-Kernel parameter). The tuning has been done with the help of k-cross validation method [20] having 10 folds. From the results, it is inferred that the γ values lies in between 13.05 to 19.21 and σ^2 lies in 0.58 and 0.83. The MOM-SVM has been trained and tested to the mean value obtained for γ and σ^2 as shown in Figure 5. Figure 5 shows the correlation between the modeled output values and the actual data-points using MOM-SVM for both the output parameters frequency and phase noise simultaneously. Also, the mean square error was found to be 0.0390.

5. Conclusion

This paper shows a novel modeling technique to develop macro-model for analog circuits using MOM-SVM. This method models accurately the multi-output parameters of VCO in terms of its transistor width as input parameter. Modeling accuracy has been improved tuning of regularization parameter and RBF-Kernel parameter. Also, RBF kernel helps MOM-SVM to generate model with better accuracy of 96.1% using k-cross validation method.

References

[1]   Gielen GGE, Rutenbar RA. *Computer-aided design of analog and mixed-signal integrated circuits.* Proc IEEE. 2000; 88(12): 1825-1854.
[2]   Gielen G, Wambacq P, Sansen WM. *Symbolic analysis methods and applications for analog circuits: A tutorial overview.* Proc IEEE. 1994; 82(2): 287-304.
[3]   Borchers C. *Symbolic behavioral model generation of nonlinear analog circuits.* IEEE Trans Circuits Syst II Analog Digit Signal Process. 1998; 45(10): 1362-1371.
[4]   Haykin S, Network N. A comprehensive foundation. *Neural Networks.* 2004; 2(2004).
[5]   Wolfe G, Vemuri R. *Extraction and use of neural network models in automated synthesis of operational amplifiers.* IEEE Trans Comput Des Integr Circuits Syst. 2003; 22(2): 198-212.
[6]   Mandal SK, Sural S, Patra A. *ANN-and PSO-based synthesis of on-chip spiral inductors for RF ICs.* IEEE Trans Comput Des Integr circuits Syst. 2008; 27(1): 188-192.
[7]   Vapnik V, Golowich SE, Smola A, others. Support vector method for function approximation, regression estimation, and signal processing. *Adv Neural Inf Process Syst.* 1997: 281-287.
[8]   Smola AJ, Schölkopf B. A tutorial on support vector regression. *Stat Comput.* 2004; 14(3): 199-222.
[9]   Ceperic V, Baric A. *Modeling of analog circuits by using support vector regression machines. In: Electronics, Circuits and Systems,* 2004 ICECS 2004 Proceedings of the 2004 11th IEEE International Conference on. 2004: 391-394.
[10]   Huang GB, Zhu QY, Siew CK. *Extreme learning machine: a new learning scheme of feedforward neural networks.* In Neural Networks, 2004 Proceedings 2004 IEEE International Joint Conference on. 2004: 985-990.
[11]   Das SP, Padhy S. Unsupervised extreme learning machine and support vector regression hybrid model for predicting energy commodity futures index. *Memetic Comput.* 2016; 1-14.
[12]   Patro BS, Mandal SK. A Novel Modeling Technique for Operational Amplifier Using RBF-ELM. *J Eng Sci Technol Rev.* 2016; 9(4): 74-76.
[13]   Patro BS, Panigrahi JK, Mandal SK. *A 6--17 GHz linear wide tuning range and low power ring oscillator in 45nm CMOS process for electronic warfare.* In Communication, Information & Computing Technology (ICCICT), 2012 International Conference on. 2012: 1-4.
[14]   Vapnik V. The nature of statistical learning theory. Springer Science & Business Media. 2013.
[15]   Vazquez E, Walter E. *Multi-output support vector regression.* In 13th IFAC Symposium on System Identification. 2003: 1820-1825.
[16]   He D, Kuhn D, Parida L. Novel applications of multitask learning and multiple output regression to multiple genetic trait prediction. *Bioinformatics.* 2016; 32(12): 37-43.
[17]   Xu S, An X, Qiao X, Zhu L, Li L. Multi-output least-squares support vector regression machines. *Pattern Recognit Lett.* 2013; 34(9): 1078-1084.
[18]   Pérez-Cruz F, Navia-Vázquez A, Alarcón-Diana PL, Artes-Rodriguez A. *An IRWLS procedure for SVR.* In Signal Processing Conference, 2000 10th European. 2000: 1-4.
[19]   Pandit S, Bhattacharya SK, Mandal C, Patra A. *A fast exploration procedure for analog high-level specification translation.* IEEE Trans Comput Des Integr Circuits Syst. 2008; 27(8): 1493-1497.
[20]   Refaeilzadeh P, Tang L, Liu H. Cross-validation. In: Encyclopedia of database systems. Springer. 2009: 532-538.
[21]   Feng LV, Fengning K, Hao S. The Predictive Method of Power Load Based on SVM. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2014: 3068-3077.