Electrical Performance Optimization of MOSFETs Using Multiobjective Genetic Algorithms

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Abstract- This paper focuses on a novel method of optimization of the small signal parameters of a MOSFET using multi-objective genetic algorithm (MOGA) for various applications. The small signal parameters like transconductance and the off current in saturation and subthreshold regions respectively have been optimized using analytical expressions. These equations forming a prerequisite to the Multi Objective Genetic Algorithm assist the search for optimal small signal parameters and acquire the most suitable electrical performances of the devices as per the applications.

Keywords –MOSFETs, optimization, genetic algorithm, subthreshold, small signal parameters

I. INTRODUCTION

The fundamental benefits of MOSFET scaling are the speed enhancement and reduction of energy required to drive the MOSFET [1]. MOSFETs can be scaled as per requirement, but downscaling of the MOSFET below 100nm anticipates unwanted changes in the electrical performance. Due to faster circuit operation, larger scale of integration, and higher level of transistor leakage current (Ioff) rapid scaling of MOSFET technology has brought about an increase in the energy consumption by the MOSFET [2]. To improve device immunity against SCEs new design advances are needed to improve the reliability and electrical performance of the devices. Evolutionary algorithms like genetic algorithm can be used to optimize parameters in concern.

In this paper, we use multi-objective genetic algorithm in order to optimize the transconductance and off current in saturated and subthreshold regions respectively. Initially, we do an accurate modeling of the parameters that we require. These electrical parameters have to be optimized to get desired results. The physical dimensions and electrical specifications can act as constraints. These along with the accurate model of the transconductance and off current pose as the prerequisites to the algorithm. The approach of multi objective algorithms aids the designer to specify multiple objective functions at the same time and all optimal results can be obtained. Many researchers are studying the application and advancements in evolutionary algorithms. The main advantages of the approach of multi objective genetic algorithm are its simplicity of implementation and provision of several possible solutions to the designer to choose one that best suites his application [3].

II. COMPUTATION METHODOLOGY

1.1 Multi objective genetic algorithm –

A Multi-objective optimization technique includes a vector of decision variables that satisfies some constraints and gives results that are appreciable and in our case implementable [4, 5]. The nonlinear systems have recently found useful applications in engineering fields. A multi-objective optimization procedure follows a convention. Initially
we find optimal solution for the objectives in space. Secondly, we choose the solutions that can survive the narrowing constraints. These solutions are thus sent to the next generation iteratively to repeat the first two steps.

In this paper, we inspect the validity of the multi-objective genetic algorithm optimization (MOGA) approach to optimize the subthreshold and saturation behaviour of MOSFETs. The primary objective of optimization is to obtain the best dimensions and electric parameters of the MOSFET in order to facilitate circuit design. We thus find the minimum or maximum of the fitness function that comprises of the transconductance and the subthreshold functions. The optimization of the objectives is done simultaneously. To do the same we use the “Pareto approach” taking into account its simplicity in implementation and provision for the designer to get the best solution out of several possible solutions. The main advantage of this approach is that the user gets the solution by performing the least work to best suit his application.

A schematic of a symmetric n-channel MOSFET and the definition of the geometrical and electrical characteristics are shown in Fig. 1. As shown in the figure, is the silicon film thickness, is the channel length, is the oxide thickness, and represents the doping level of the drain/source region, respectively.

As per the methodology explained above, compact models are used for optimization of the MOSFET in subthreshold and saturation regions. These compact models pose as objective functions to the MOGA. In this paper the objective functions are transconductance and off-current in subthreshold region. The effective electron mobility in the MOSFET due to the electric fields is given by (1):

$$\mu_{\text{eff}} = \frac{32}{1}$$

Where is the effective vertical field of the MOSFET given by (2):

$$E_{\text{eff}} = \frac{V_{GN}-2}{\epsilon_{SOX}} + \frac{V_{GS}-1}{\epsilon_{SOX}}$$

The equation for current in the subthreshold region in a MOSFET is given by the following expression [7]:

$$I = \mu_{\text{eff}} \frac{L}{L_{\text{ox}}} (m-1) \left( \frac{kT}{q} \right)^{\frac{1}{2}} \epsilon_{SOX}^{\frac{1}{p}} \left( 1 - \frac{V_{GS}}{V_{TH}} \right)$$

Where is typical electron mobility at room temperature (300 K) and is 1400 cm²/(V·s), is permittivity of oxide layer, m is body effect coefficient. Its typical value is between 1.1 and 1.4. is the gate bias voltage, is the threshold voltage, is the drain bias with respect to source and is the electron charge.

In the subthreshold region, the off-current of a MOSFET is defined for $V = 0$V. Hence the equation for off current is obtained by substituting $V$ by 0 in (3):

$$I_{V_{GS}=0} = \mu_{n} \frac{L}{L_{\text{ox}}} (m-1) \left( \frac{kT}{q} \right)^{\frac{1}{2}} \epsilon_{SOX}^{\frac{1}{p}} \left( 1 - \frac{V_{TH}}{V_{TH}} \right)$$

The drain current in the saturation region is given by (5):

$$I_{V_{DS}} = \mu_{n} \frac{L}{L_{\text{ox}}} (m-1) \left( \frac{kT}{q} \right)^{\frac{1}{2}} \epsilon_{SOX}^{\frac{1}{p}} \left( 1 - \frac{V_{TH}}{V_{TH}} \right)$$

The transconductance of the MOSFET is calculated using the following expression (6):
The transconductance of the MOSFET in saturation is derived from (6). The equation (7) acts as an objective to be fed to the MOGA. This has to be maximized. The off current (4) derived from subthreshold region (3) acts as another objective of the MOGA. Here the off current has to be minimized. Thus (8) is formulated as per the requirement.

\[ F(X) = \frac{1}{g_m(x)} + w_2 I_{off} \]  

III. EXPERIMENT AND RESULT

For optimizations using MOGA approach programs and subroutines were developed using MATLAB 7.10(R2010a). MOGA is based on laws of nature of survival of the fittest. It uses the operations of mutation and crossover. Thus, this method uses selection, operation and replacement as its steps iteratively. Initially from a randomly generated population, mutation eliminates least fit population after which crossover builds the offspring of the surviving population. It this method, we compare the total population before promoting it too the next generation. It has to be taken into account that encouraging one chromosome of an objective function does not relegate the performance of the other objective function. Thus a common function is built with the same objective. The fitness values of these chromosomes are obtained by evaluating the objective function. This cycle is repeated until a desired criterion is reached. This chromosome is the most evolved one and it becomes the solution of the objective function in concern.

The following expressions are taken to be our objective functions wherein:

1) minimization of the OFF-current state \( I_{off}(X) \);
2) maximization of the transconductance function \( g_m(X) \);

We use the weighted sum approach to arrive to the final objective function:

\[ F(X) = \frac{1}{g_m(X)} + w_2 I_{off} \]  

Since \( g_m \) has to be maximised the reciprocal of it has been taken. Weights \( w_1 \) and \( w_2 \) can be varied as per application. If high derived current, low power dissipation and high commutation speed transistor are the required parameters by the device designer, the transconductance and off-state current are equally important[2].

Thus the weights given to each function is same i.e. 0.5. If the application demands certain limit or weight age to some particular parameter, the weight of that parameter can be varied. In this method, it should be assured that the sum of all the weights is 1. Here, \( w_1 + w_2 = 1 \).

![Figure 2 Flow chart of the approach](image-url)

We get an overview of the approach from figure 2 [7], this method is adapted to achieve optimization. Once the problem is thoroughly defined a vector of solutions is created, with a randomly generated population with \( n \) chromosomes:

1) Overall objective function of each of the chromosomes in the population is calculated.
2) “N” off springs are made from the parent population using selection, crossover and Mutation operators.
3) The current population is replaced with the fitness solutions in the search space.
These steps are repeated in order till the termination criteria is reached.

![Fitness function chart](chart.png)

Figure 3 shows the variations in the fitness function with each generation. The optimization was achieved for a population size of 15 and the mutation rate of 9% was used. Maximum 200 iterations were performed to get a stable minimized value of the fitness function.

Table 1 Experiment Result

<table>
<thead>
<tr>
<th>SYMBOL</th>
<th>QUANTITY</th>
<th>OPTIMIZED VALUES</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t_{22}$</td>
<td>Thickness of</td>
<td>1.03 nm</td>
</tr>
<tr>
<td>$V_{22}$</td>
<td>Gate voltage</td>
<td>5.97 V</td>
</tr>
<tr>
<td>$V_{DS}$</td>
<td>Drain source voltage</td>
<td>2.25 V</td>
</tr>
<tr>
<td>$L$</td>
<td>Channel Length</td>
<td>10.11 nm</td>
</tr>
<tr>
<td>$g_m$</td>
<td>Transconductance</td>
<td>23.18</td>
</tr>
<tr>
<td>$I_{off}$</td>
<td>Off-state current</td>
<td>6.377</td>
</tr>
</tbody>
</table>

Table 1 show the peak signal to noise ratio of performance of our proposed method of watermarked image and original image with various watermark image, where our watermarked images peak signal to noise ratio has a better performance than others.

IV. CONCLUSION

MOGA-based approach is put forth to enhance the performance of an n-MOSFET in the subthreshold and saturation behavior. This paper reflects the applicability of the MOGA method in minimizing/maximizing parameters in order to maximize the electrical performance of a MOSFET. The geometric and electric parameters can be optimized using MOGA to get best possible electric performance in a MOSFET. It can be concluded the approach successfully accomplishes the objective and gives potentially assuring results. The results of these MOGAs can be validated practically. This would also mean the sighting new problems and correlations between parameters. This approach can be extended to optimize more geometric and electric parameters with the motive of circuit design.

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REFERENCES


