EXTRACTION OF PARAMETERS OF PLANAR SPIRAL INDUCTORS USING GENETIC ALGORITHMS

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An approach for extraction the model parameters of spiral inductors is proposed in the paper. The extraction is realized via the S-parameters of the corresponding models using optimization, based on Genetic Algorithm. The approach is useful in RF model design, as the S-parameters can be easily measured for a given microelectronic technology.

Keywords: Genetic Algorithms (GA), parameter extraction, S-parameters, planar spiral inductors

1. INTRODUCTION

The fast growth in the microelectronic industry and especially in RF applications needs reliable and predictable hardware. The precise RF model design is an important step in the way of constructing such hardware. The models can be well optimized using Genetic Algorithms (*GA*) in various applications – parameter optimization, parameter extraction, circuit synthesis. A general approach for parameter extraction of the model parameters of spiral inductors is presented and compared with the results, obtained via similar methods [1,2,3,4]. The presented extraction approach is applicable and with good accuracy. It is based on computer models, developed using the possibilities of *MATLAB* and *GA* toolbox [5]. *GA* programs are designed using the *MATLAB GA* toolbox for parameter extraction of the model parameters of spiral inductors. A verification of the obtained results for the extracted model parameters is performed by comparison of the simulation results obtained using *PSpice* of the corresponding model and measurement data given in [4].

2. GENERAL CONCEPT OF THE GENETIC ALGORITHMS

The *GA* is a stochastic global search method, which is based on a mechanism resemble the natural biological evolution. GA operates on a population of solutions and the fitness of the solutions is determined from the objective function of some specific problem. Only the best fitted solution remains in the population after a number of predefined cycles.

In microelectronic technologies and in the microelectronic design the problems are often presented as a mathematical functions of multiple variables. The optimization of the values of these variables is in some cases a complex problem, especially when the amount of the variables is huge. The big advantage of the genetic algorithms is that these algorithms do not require derivative information or other knowledge. Only the objective function and the corresponding fitness levels influence the direction of search. This makes the *GA* a useful tool for parameter optimization in microelectronics and especially for geometric optimization of microelectronic components, when the parameters of the technology are known. The opposite task can also be solved – once the parameters of some model are known, the microelectronic technology can be easily determined with *GA* using the corresponding equations, which give the connection between the electrical parameters and the geometric parameters, to form the variables in the object function.

The basic genetic algorithm has the following stages [5]:

1. *Create population* – at this stage the random population is generated first. In the process of optimization this population is processed in order to obtain the maximum fitness of its components.

2. *Assign fitness values* – at this stage a fitness value is assigned to every member of the population. The fitness value determines the fitness of the component according to the range predefined for the variable.

3. *Selection* – this is the process of determining the number of times, a particular individual is chosen for reproduction and, thus, the number of offspring that an individual will produce. In the implemented models for optimization the spiral inductors model parameters a Stochastic Universal Sampling (SUS) function was applied for selection of the individuals.

4. *Recombination* – this stage is the actual process of creation the new offspring (Crossover). The individual in the new offspring has the individual features inherited from both the parents. The percentage of inheritance depends on the crossover point [5].

5. *Mutation* – this is a process of change the new generated individuals in probability way. For example, if a binary representation of an individual is used, mutation process will change one bit in the binary string.

6. *Evaluation* – at this stage the objective function is applied to every individual and its fitness is calculated.

7. *Reinsertion* – at this stage the new individuals are reinserted into the old population.

3. Extraction of the Model Parameters of Spiral Inductors

A *PSpice* model of the spiral inductor is presented in Fig.1. The model parameters of the spiral inductors can be extracted using the *S*-parameters, measured for the microelectronic implementation of the spiral inductor [4] and compared to the *S*-parameters of the corresponding *PSpice* model [2,3]. The *S*-parameters (S_{11} and S_{12}) are used for the parameter extraction using *GA*. The *GA* makes the difference between the model *S*-parameters and the optimized *S*-parameters minimal.

The *PSpice* model is presented in Fig.1 [4]. The model parameters are C_s, L_s, C_{ox}, R_{si}, C_{si}, R_s, and for C_s, L_s, C_{ox}, R_{si}, C_{si} a variation range is given. R_s is calculated for each of the frequencies, depending on the geometric parameters of the spiral inductor. For R_s a variation range can not be fixed, because this parameter represents the skin effect for high frequencies and is frequency dependent.

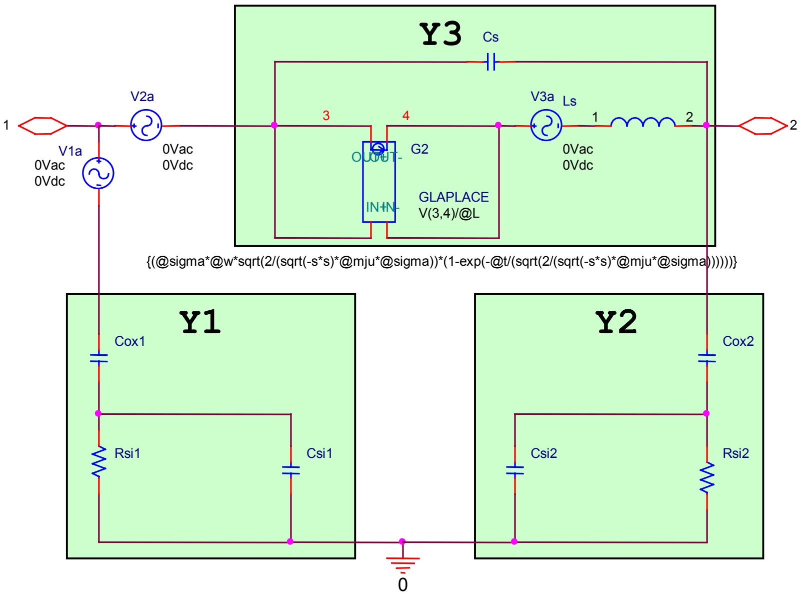

Fig.1 PSpice model of the spiral inductor

The initial values of the model parameters for the model from Fig. 1 are:

C_s = 28.580599×10^{-15} F
L_s = 3.0003193×10^{-9} H
C_{ox} = 228.758391×10^{-15} F
R_{si} = 335.142548 Ω
C_{si} = 149.190244×10^{-15} F

The corresponding variation ranges for the components are:

C_s = $28.0\times10^{-15} \div 29.0\times10^{-15}$ F
L_s = $2.5\times10^{-9} \div 3.5\times10^{-9}$ H
C_{ox} = $200.0\times10^{-15} \div 300.0\times10^{-15}$ F
R_{si} = $300.0 \div 340.0$ Ω
C_{si} = $145.0\times10^{-15} \div 155.0\times10^{-15}$ F

The *S*-parameters are expressed via the *Y*-admittances Y_1, Y_2 and Y_3 in Fig. 1. The *Y*-admittances give the equations which connect the *S*-parameters with the model parameters. The expressions (1), (2), (3) and (4) give the connection between the *S*-parameters and the *Y*- admittances in *MATLAB* M-File format ($Y_1 = Y_2$):

Y3req = 2*S12req(i)*Y0/((1+S11req(i))^2 - S12req(i)^2); (1)
Y1req = Y0*(1-S11req(i)^2+S12req(i)^2)/((1+S11req(i))^2-S12req(i)^2)-Y3req; (2)
Y1 = (s.*Cox.*(1.0 + s.*Rsi.*Csi))./(1.0 + s.*Rsi.*Csi + Rsi); (3)
Y3 = (1.0./(Rs + s.*Ls)) + s.*Cs; (4)

Y1req, *Y3req*, *S11req*, *S12req* are the requested values. *S11req* and *S12req*, corresponding to the measured data [4], are stored in a file. The *MATLAB M*-File *GA* script processes this file and creates another file with the best fitted values for the model parameters C_s, L_s, C_{ox}, R_{si}, C_{si}. Y_1 and Y_3 are the values for the *Y*-admittances for every step of the *GA*. On each step new values for the model parameters C_s, L_s, C_{ox}, R_{si}, C_{si} are generated.

The following expression describes the object function for the extraction of the model parameters of the spiral inductor:

g_fun = g_fun + abs(real(Y1) - real(Y1req)) + abs(real(Y3) - real(Y3req)) +
abs(imag(Y1) - imag(Y1req)) + abs(imag(Y3) - imag(Y3req)); (5)

The goal of the optimization is to minimize the difference between the functions *Y1req*(*f*) and *Y1*(*f*) from one side, and *Y3req*(*f*) and *Y3*(*f*) from another, where *f* is the frequency in the *AC* analysis. This means that the purpose function of the *GA* minimizes the difference between the measured *S*-parameters and the obtained *S*-parameters for the corresponding variation ranges of the model parameters (Fig. 1).

The *GA* iterations and the achievement of the best value for the purpose function for each of the model parameters are presented in Fig.2, Fig.3, Fig.4, Fig.5 and Fig.6. The values of the model parameters after the *GA* extraction procedure are:

$$C_s = 28.5799363154162\times10^{-15}\ \text{F}$$
$$L_s = 3.00032304733394\times10^{-9}\ \text{H}$$
$$C_{ox} = 224.548102995091\times10^{-15}\ \text{F}$$
$$R_{si} = 327.010801211336\ \Omega$$
$$C_{si} = 150.805582781445\times10^{-15}\ \text{F}$$

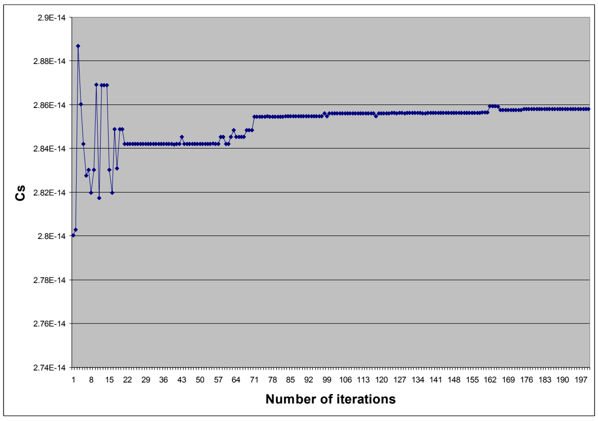

Fig.2 Extraction of the model parameter C_s of the spiral inductor

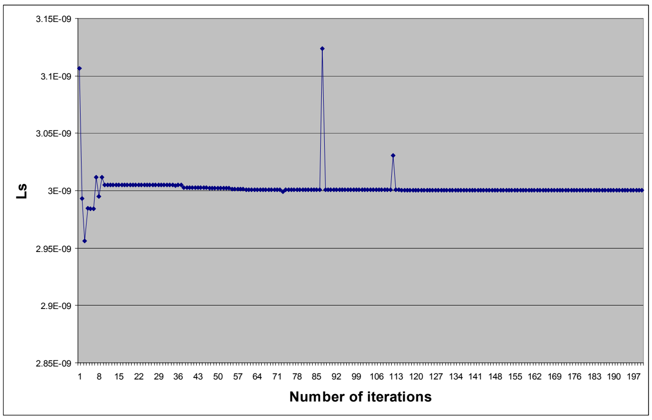

Fig.3 Extraction of the model parameter L_s of the spiral inductor

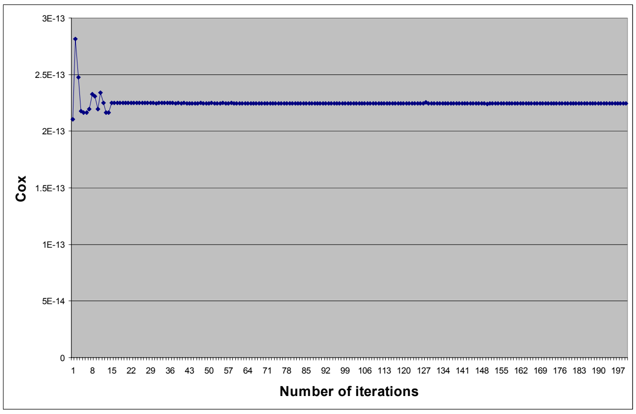

Fig.4 Extraction of the model parameter C_{ox} of the spiral inductor

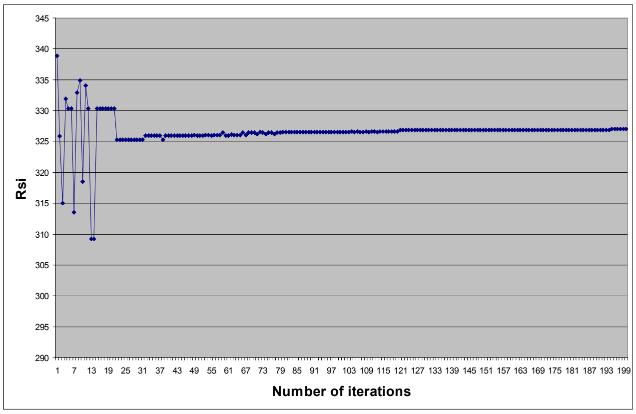

Fig.5 Extraction of the model parameter R_{si} of the spiral inductor

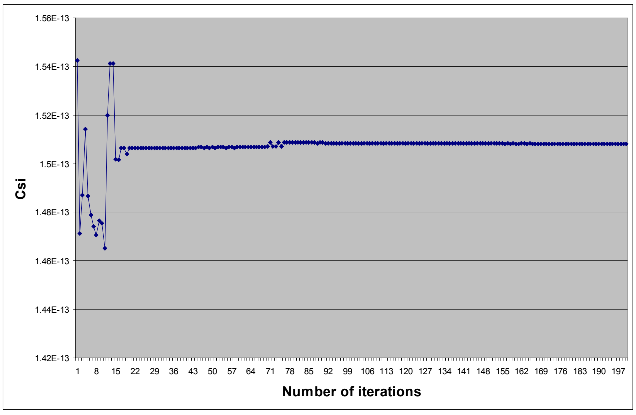

Fig.6 Extraction of the model parameter C_{si} of the spiral inductor

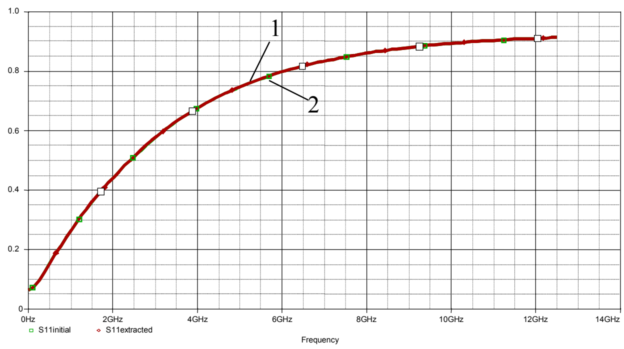

Fig. 7 Spiral inductor - accuracy estimation for S_{11}

The *PSpice* model is resimulated with these values. Fig. 7 and Fig. 8 present the *S*-parameters corresponding to the measurement data [4] (graphic 1) and the *S*-parameters of the circuit with the optimized values of the model parameters after the extraction procedure (graphic 2).

The accuracy of the method can be estimated with the full range average relative error of the S-parameters compared to the measured data [4]:

S11err = 0.08%
S12err = 0.03%

4. CONCLUSIONS

The realization of the GA optimization approach for parameter extraction the model parameters of spiral inductors has been presented in the paper. The extraction is realized using the GA toolbox in MATLAB. The obtained results are in agreement with previous parameter extraction methods and have a better accuracy.

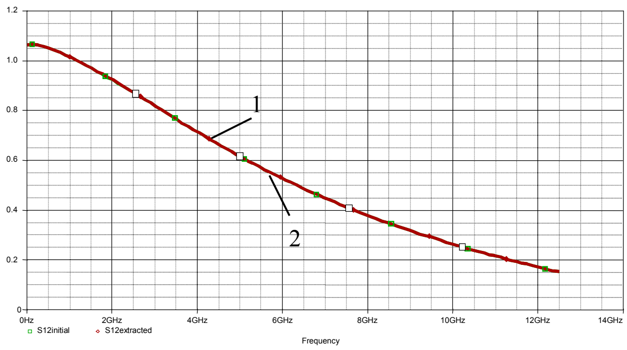

Fig. 8 Spiral inductor - accuracy estimation for S12

5. ACKNOWLEDGEMENT

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