

EXTRACTION OF PARAMETERS OF PLANAR TRANSFORMERS USING GENETIC ALGORITHMS

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An approach for extraction the model parameters of planar transformers 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 transformers

1. INTRODUCTION

The planar inductors and transformers are widely used passive components in RF circuits. The precise RF model development of inductor and transformer elements is an important step in the design of microelectronic circuits for RF applications. The models can be extracted and optimized using Genetic Algorithms (*GA*).

A general approach for parameter extraction of the model parameters for planar transformers is proposed and compared with the results, obtained via similar methods [1,2,3,4,5]. The presented extraction approach is applicable and with a good accuracy. It is based on computer models, developed using the possibilities of *MATLAB* and *GA* toolbox [6]. *GA* programs are designed using the *MATLAB GA* toolbox for parameter extraction of the model parameters of planar transformers. A verification of the obtained results for the extracted model parameters is done by comparison of the simulation results obtained using *PSpice* of the corresponding model and measurement data in [4].

2. EXTRACTION OF THE MODEL PARAMETERS OF PLANAR TRANSFORMERS

A *PSpice* model of the planar transformer is presented in Fig.1. The model parameters of the planar transformers can be extracted using the *S*-parameters, measured in advance for the microelectronic implementation of the planar transformer [4] and compared to the *S*-parameters of the corresponding *PSpice* model [2,3]. The *S*-parameters (S_{11} , S_{12} , S_{21} , S_{22}) 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 model parameters are R_{s1} , C_{s1} , C_{ox1} , L_{s1} , R_{s2} , C_{s2} , C_{ox2} , L_{s2} , C_{ov} and a variation range is given for each of the parameters.

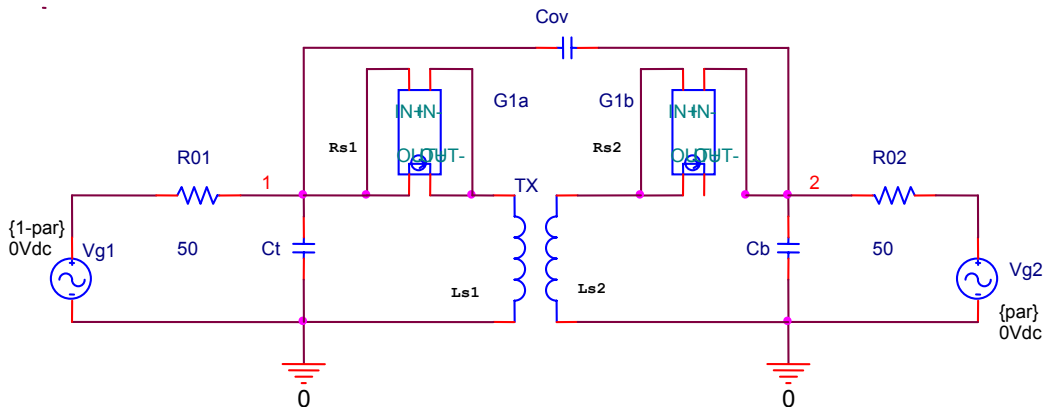


Fig.1 PSpice model of the planar transformer

The parameters R_{s1} and R_{s2} , depending on the geometric parameters of the planar transformer, are calculated for each of the frequencies. For R_{s1} and R_{s2} a variation range can not be defined, because this parameters represent the skin effect at high frequencies and are frequency dependent. The initial values of the model parameters for the model shown in Fig.1 are:

$$\begin{aligned} C_t &= C_{s1} + C_{ox1} = 49.86 \times 10^{-15} \text{ F} \\ L_{s1} &= 8.924 \times 10^{-9} \text{ H} \\ C_b &= C_{s2} + C_{ox2} = 254.0 \times 10^{-15} \text{ F} \\ L_{s2} &= 24.79 \times 10^{-9} \text{ H} \\ C_{ov} &= C_{12} = 351.0 \times 10^{-15} \text{ F} \end{aligned}$$

The corresponding variation ranges for the parameters are:

$$\begin{aligned} C_t &= C_{s1} + C_{ox1} = 45.0 \times 10^{-15} \div 55.0 \times 10^{-15} \text{ F} \\ L_{s1} &= 8.5 \times 10^{-9} \div 9.5 \times 10^{-9} \text{ H} \\ C_b &= C_{s2} + C_{ox2} = 200.0 \times 10^{-15} \div 300.0 \times 10^{-15} \text{ F} \\ L_{s2} &= 24.0 \times 10^{-9} \div 26.0 \times 10^{-9} \text{ H} \\ C_{ov} &= C_{12} = 300.0 \times 10^{-15} \div 400.0 \times 10^{-15} \text{ F} \end{aligned}$$

The S -parameters are expressed using $ABCD$ matrix analysis for cascaded planar transformer model [5]. This $ABCD$ matrix analysis gives the equations which connect the S -parameters with the model parameters. The following cycle gives the connection between the S -parameters and the model parameters of the planar transformer model in *MATLAB M-File* format:

```
for ix = 1:Nind
    M = k*sqrt(Ls1(ix)*Ls2(ix));
    Alfa = [1.0 0.0; s*(Cs1(ix)+Cox1(ix)) 1.0];
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Beta = [1.0 Rs1; 0.0 1.0];
Hi = (-1.0).*[Ls1(ix)/M s*((Ls1(ix)*Ls2(ix))/M - M); 1.0/(s*M) Ls2(ix)/M];
Delta = [1.0 Rs2; 0.0 1.0];
Epsilon = [1.0 0.0; s*(Cs2(ix)+Cox2(ix)) 1.0];
Fi = [1.0 1.0/(s*C12(ix)); 0.0 1.0];
I = Alfa*Beta*Hi*Delta*Epsilon;
F = (1.0/(I(1,2)+Fi(1,2))).*[((I(1,1)*Fi(1,2))+Fi(1,1)*I(1,2)) I(1,2)*Fi(1,2);
(((I(2,1)+Fi(2,1))*(Fi(1,2)+I(1,2)))+(I(2,2)-Fi(2,2))*(Fi(1,1)-I(1,1)))
((Fi(2,2)*I(1,2))+I(2,2)*Fi(1,2))];
S11(ix,1) = (F(1,1)+(F(1,2)/Z0)-(F(2,1)*Z0)-
F(2,2))/(F(1,1)+(F(1,2)/Z0)+(F(2,1)*Z0)+F(2,2));
S12(ix,1) = 2.0/(F(1,1)+(F(1,2)/Z0)+(F(2,1)*Z0)+F(2,2));
S22(ix,1) = (((-1.0)*F(1,1))+(F(1,2)/Z0)-
(F(2,1)*Z0)+F(2,2))/(F(1,1)+(F(1,2)/Z0)+(F(2,1)*Z0)+F(2,2));
End

```

Nind is the number of individuals, generated for each model parameter, i.e. each model parameter is represented by a column vector with *Nind* members. For each member the model parameters are calculated. *F* is the *ABCD* matrix of the entire model, *Alfa*, *Beta*, *Hi*, *Delta*, *Epsilon* and *Fi* are the corresponding *ABCD* matrices of the building two-port blocks of the planar transformer model [5]. $S_{12} = S_{21}$, therefore only S_{11} , S_{12} and S_{22} vectors are calculated. S_{11_req} , S_{12_req} and S_{22_req} are obtained from the measurement data [4] and 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_t , L_{s1} , C_b , L_{s2} , C_{ov} . S_{11} , S_{12} and S_{22} are the values for the *S*-parameters for every step of the *GA*. On each step new values for the model parameters C_t , L_{s1} , C_b , L_{s2} , C_{ov} are generated. The following expression describes the object function for the extraction of the model parameters of the planar transformer:

$$g_fun = g_fun + \text{abs}(\text{real}(S_{11}) - \text{real}(S_{11_req})) + \text{abs}(\text{real}(S_{12}) - \text{real}(S_{12_req})) + \text{abs}(\text{real}(S_{22}) - \text{real}(S_{22_req})) + \text{abs}(\text{imag}(S_{11}) - \text{imag}(S_{11_req})) + \text{abs}(\text{imag}(S_{12}) - \text{imag}(S_{12_req})) + \text{abs}(\text{imag}(S_{22}) - \text{imag}(S_{22_req})); \quad (6)$$

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. The *GA* iterations and the achievement of the best value for the purpose function 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:

$$\begin{aligned}
C_t &= 54.9999687001084 \times 10^{-15} \text{ F} \\
L_{s1} &= 9.49999970111932 \times 10^{-9} \text{ H} \\
C_b &= 299.99994988064 \times 10^{-15} \text{ F} \\
L_{s2} &= 25.9999916355117 \times 10^{-9} \text{ H} \\
C_{ov} &= 300.000000484767 \times 10^{-15} \text{ F}
\end{aligned}$$

The *PSpice* model is resimulated with these values. Fig.7, Fig.8 and Fig.9 present the *S*-parameters corresponding to the measured data [4] (graphic 1) and the *S*-parameters of the equivalent circuit with the 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 measurement data:

$$\begin{aligned} S_{11err} &= 5.54\% \\ S_{12err} &= 10.61\% \\ S_{22err} &= 4.63\% \end{aligned}$$

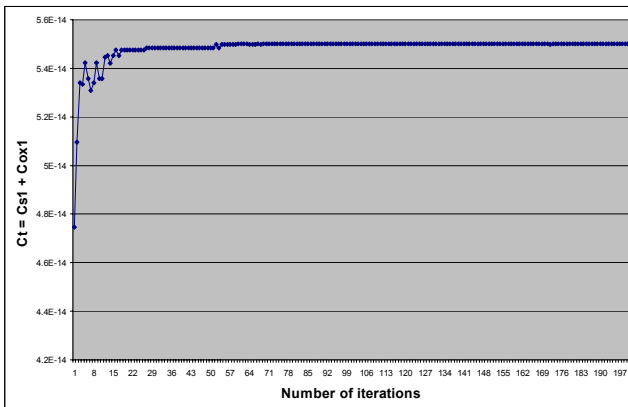


Fig.2 Extraction of the model parameter C_t of the planar transformer

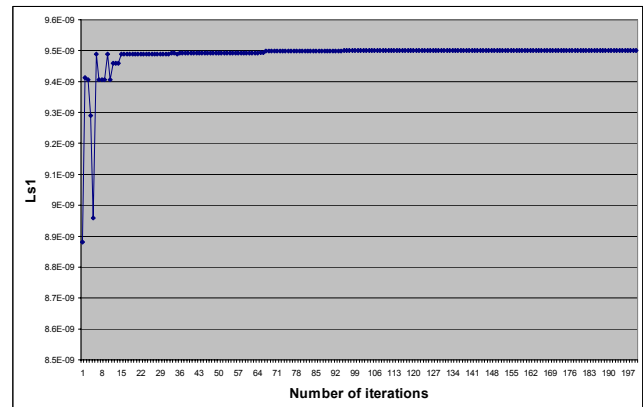


Fig.3 Extraction of the model parameter L_{s1} of the planar transformer

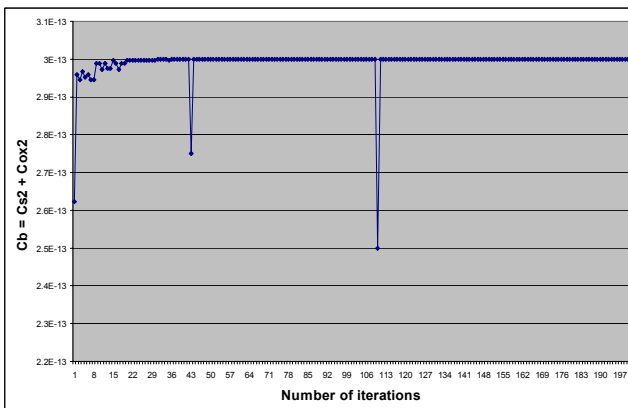


Fig.4 Extraction of the model parameter C_b of the planar transformer

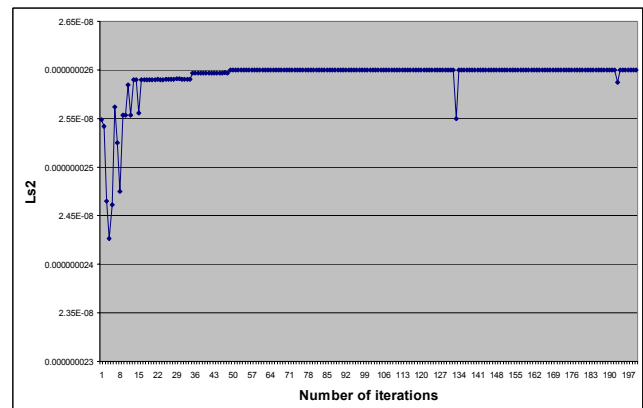


Fig.5 Extraction of the model parameter L_{s2} of the planar transformer

3. CONCLUSIONS

The realization of the *GA* optimization approach for parameter extraction the model parameters of planar transformer is presented. The extraction is realized using the *GA* toolbox in *MATLAB*. The obtained results are in agreement with previous parameter extraction methods and have acceptable accuracy.

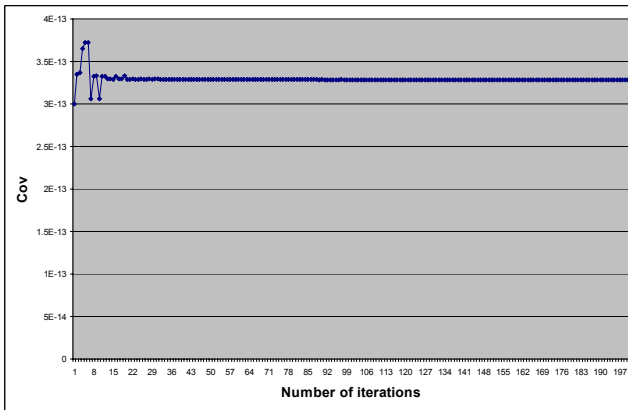


Fig.6 Extraction of the model parameter C_{ov} of the planar transformer

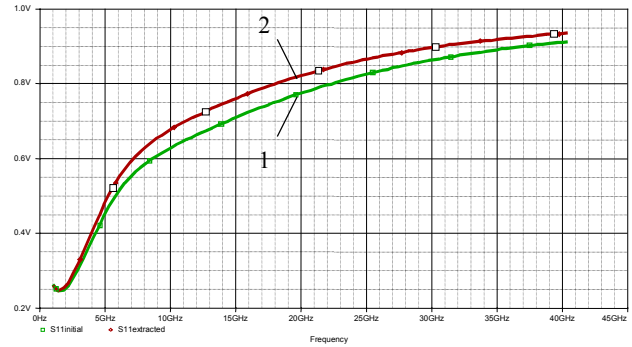


Fig.7 Planar transformer - accuracy estimation for S_{11}

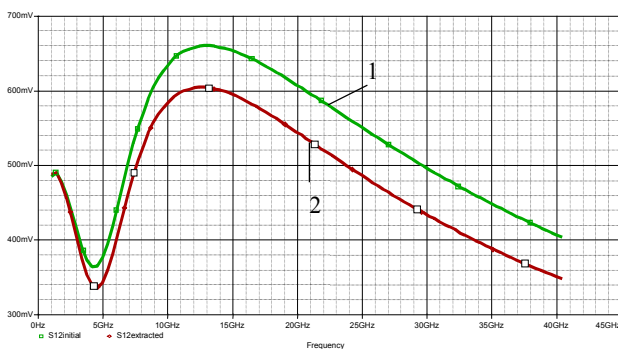


Fig.8 Planar transformer - accuracy estimation for S_{12}

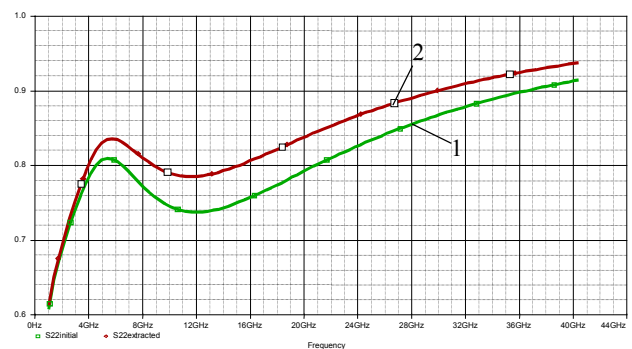


Fig.9 Planar transformer - accuracy estimation for S_{22}

4. ACKNOWLEDGEMENT

This research is in the framework of the BY-TH-115/2005 project.

5. REFERENCES

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