Inductance Calculation and Layout Optimization for Planar Spiral Inductors

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Abstract-The inductance calculation and the layout optimization for spiral inductors still are research topics of actuality and very interesting especially in radio frequency integrated circuits. Our research work is fixed on the vast topics of this research area. In this effect we create a software program dedicate to dc inductance calculation and to layout optimization for spiral inductors. We use a wide range of inductors in the application made with our program; we compare our applications results with measurements results existing in the literature and with three-dimensional commercial field solver results in order to validate it. Our program is accurate enough, has a very friendly interface, is very easy to use and its running time is very sort compared with other similar programs. Since spiral inductors tolerance is generally on the order of several percent, a more accurate program is not needed in practice. The program is very useful for the spiral inductor design because it calculates the inductance of spiral inductors with a very good accuracy and also for the spiral inductor optimization, because it optimize the spiral inductor layouts in terms of technological restrictions and/or in terms of the designers' needs.

I. INTRODUCTION

The passive components parameters extraction from radio frequency integrated circuits, to wit inductance, capacitance and resistance extraction are research topics of great interest and very provocative. This fact is motivated by the continual technological progress thanks to; it is now possible to implement integrated circuit at microns dimensions. The decrease of the integrated circuit dimensions at this extreme level lead in an implicit way to the significant rise extraction importance with accuracy of the inductance, capacitance and resistance parameters form micrometric devices, opening multitudinous now research topics in this domain. Our research work focus on the study, analysis, simulation, modeling, design and optimization of spiral inductors. We are focus now to inductance calculation. The inductance value extraction was and is intense studied in the literature. At this moment exists many expressions and methods used for integrated circuits inductance extraction [1]-[6]. However, as is mentioned in the literature, there are limits in their application. For example, in some expressions not all the geometrical parameters that describe completely the spiral inductor are taken into account and so the typical errors are larger or smaller, tolerate or not in applications.

To design and to optimize the spiral inductors from integrated circuits is first necessary to find the exact inductance value. So the fast and accurate inductance extractions become more and more important for design, optimization and design verification of the spiral inductors and their performances improvement.

However things are the inductance calculation for spiral inductors, the spiral inductors optimization by finding the optimal layout for maximal inductance or for a given inductance value, keeping a constant area for the inductor spiral implementation in the integrated circuit are still needed to improve the spiral inductors performances. To this aim we devise a software program that allow fast and accurate inductance calculation and spiral inductor layout optimization. The program name is CIBSOC (Spiral Inductors Inductance Calculation and Layout Optimization) and it is composed of four modules. The first and the second one are devising to calculation the spiral inductor inductance, and the third and the fourth to optimize the spiral inductor layout. The first module of the program, CIPGC (Inductance Calculation for Constant Geometrical Parameters) is designed for calculate the total inductance of the spiral inductors with square, hexagonal, octagonal and circular shape (Fig.1), for constant number of turns and constant projecting geometrical parameters. The second module, CIPGV (Inductance Calculation for Variable Geometrical Parameters) is designed for the inductance variation calculation for the same spiral inductor shapes in terms of the number of turn's variation or with the one of the geometrical parameters variation. The
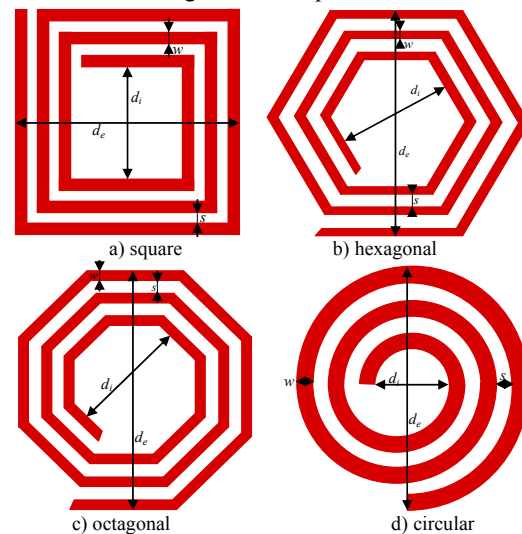

Fig. 1. Spiral inductors geometrical shapes used in CIBSOC program

third module OCBS (Spiral Inductor Layout Optimization), allow to optimize the layouts of the spiral inductors that have one of the shapes shown in Fig. 1, have a given inductance value and that will be implemented in a fixed area in the integrated circuit. The fourth module OCBSIM (Spiral Inductor Layout Optimization for Maximal Inductance) allow the layout optimization for square, hexagonal, octagonal and circular spiral inductors, for the maximal inductance of the inductor and for a fixed area in which the inductor will be incorporated in the integrated circuits.

II. THEORETICAL CONSIDERATIONS

The program is based for the calculation part on the current sheet method. Simple and accurate expressions for dc inductance of square, hexagonal, octagonal and circular spiral inductors can be obtained by approximating the spiral sides with equivalent symmetric current sheets with the same current densities [9]. For example, in the case of a spiral inductor, as is show in Fig. 2, are obtain four identical current sheets: the current sheets from opposite sides are parallel one each other, and the adjacent one are orthogonal one each other. Using the symmetry and the fact that the orthogonal current sheets have the mutual inductance zero, the inductance calculation is reduce to the self inductance evaluation of one current sheet and to mutual inductance evaluation of opposite current sheets. These self and mutual inductances are determinate using the geometric mean distance, the arithmetic mean distance and the arithmetic mean square distance concepts [9], [10]. The expressions for square, hexagonal, octagonal and circular spiral inductors inductances calculation are [11]:

$$L_{square\ inductor} = \frac{\mu N^2 d_m 1.27}{2}\left[\ln\left(\frac{2.07}{\rho}\right)+0.18\rho+0.13\rho^2\right], \quad (1)$$

$$L_{hexagonal\ inductor} = \frac{\mu N^2 d_m 1.09}{2}\left[\ln\left(\frac{2.23}{\rho}\right)+0.17\rho^2\right], \quad (2)$$

$$L_{octagonal\ inductor} = \frac{\mu N^2 d_m 1.07}{2}\left[\ln\left(\frac{2.29}{\rho}\right)+0.19\rho^2\right], \quad (3)$$

$$L_{circular\ inductor} = \frac{\mu N^2 d_m}{2}\left[\ln\left(\frac{2.46}{\rho}\right)+0.2\rho^2\right]. \quad (4)$$
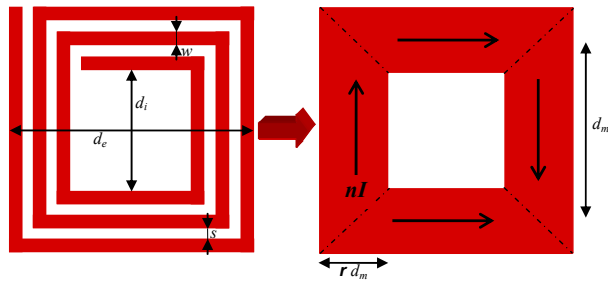

Fig. 2. The square spiral inductor and its equivalent current sheets.

where μ is the magnetic permeability, N is the number of turns, w is the width of the turn, s is the distance between the turns, the average diameter is $d_m = 0.5(d_e + d_i)$, d_e is the exterior diameter, d_i is the interior diameter, $d_e = d_i + 2Nw + 2(N-1)s$, $d_e = d_m + N(w+s) - s$, the fill ratio is $\rho = [N(w+s)-s]/d_m$, $\rho = (d_e - d_i)/(d_e + d_i)$, and $d_i \geq s$.

Studying the literature we found that these expressions are more simple and accurate, and we decide to use them in our program to calculate the inductance and to optimize the layout for the square, hexagonal, octagonal and circular spiral inductors.

The geometrical parameters that appear in these expressions, the shape of the spiral inductor and number of turns are defining completely the spiral inductors. Many expressions that exist in literature take into account only some of these parameters, so that is not a surprise that the errors are 20% or even bigger in some cases 80%, which are unacceptable in the inductors design and optimization [7]-[8].

III. APPLICATIONS IN *CIBSOC* PROGRAM

We design a set of spiral inductors which we use in the applications that we done with our program. We present in this paper only the application in which we use the square shape for spiral inductors, even if the program allows also the calculation for any of the four types of geometrical shapes generally used for spiral inductors. We use CIBSOC program effectively to calculate the total inductance for each of the square spiral inductors that we design and for theirs layouts optimization.

A. Applications in CIPGC Module of the Program

The *CIPGC* module of the *CIBSOC* program allows the inductance calculation for the geometrical shapes of the spiral inductors that are show in Fig.1. The module has a drawing algorithm that draw automatic the implemented spiral inductor and an inductance calculation algorithm that compute the inductance of the implemented spiral inductors.

In module are used as input quantities to completely define the spiral inductors the following: the geometrical shape of the spiral inductor, the number of turns, N; the turn width, w; the distance between the turns, s; the exterior diameter, d_e; the interior diameter, d_i and the turn thickness, t as we can see in the Fig. 3. The input quantities used in our applications have the following numerical values: $N \in [1,16]$ (turns) d_e=500(μm); s=5(μm) w=10(μm); and t=2(μm). All the dimensions used in the paper are in (μm) and the inductance values in (nH). Also as input quantities is necessary to select the type of material that is used for inductors' spiral. The program allows us to select the type of material from its library and also to add new materials. The material used for the square spiral inductor that we design is the cooper, Cu, because we note studying the literature that it is the most usually used material for practical realization of the inductor spiral. We detail for exemplification the square spiral inductor with sixteen turns from the set of the eight square spiral inductors elaborate.
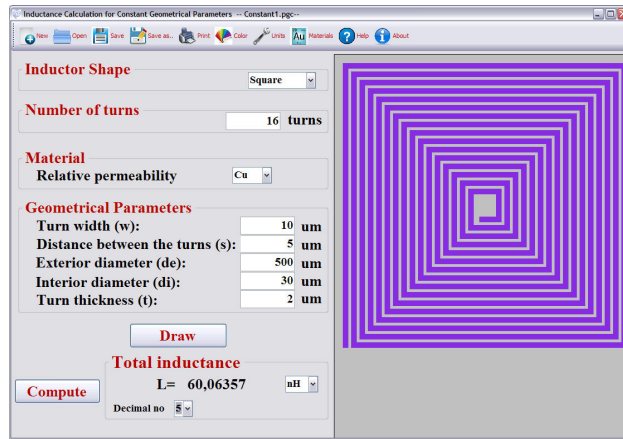
Fig. 3. The square spiral inductor with sixteen turns implemented for inductance calculation in the CIPGC module of the CIBSOC program.

We have implemented these inductors in our program as is show in Fig. 3. In Table I we present the results for all the eight square spiral inductors obtained with CIBSOC program.

TABLE I
INDUCTANCE CALCULATION RESULTS FOR THE EIGHT SQUARE SPIRAL INDUCTORS DONE IN CIPGC MODULE OF CIBSOC PROGRAM

Number of turns, N (turns)	Inductance, L_{CIBSOC} (nH)
1	1,80763
2	5,58207
3	10,52683
4	16,14966
6	28,08099
8	39,34739
12	55,3146
16	60,06357

Is obvious the utility of this module of the program, his simplicity referring to the implementation, calculation and drawing facilities and to the short running times that the program offers.

B. Applications in CIPGV Module of the Program

We study the inductance variation for the eight square spiral inductors in terms of the number of turns variation or of the one of the following geometrical parameters variation: turn width, w, distance between the turns, s; exterior diameter, d_e or turn thickness, t. In the module we can set the variation of the parameter in terms of which we want the inductance variation to be calculate and we can also to plot the results. The module has an inductance variation calculation algorithm and a graphical representation algorithm that can be used to directly plot the obtained results. We detail now the obtained results for the inductance variation in terms of the number of turn variation, then in terms of the turn width variation and then in terms of the distance between the turns variation. The inductance variation in terms of the turn thickness has no significant variation, so it will be not presented in the paper.

1. Inductance Variation in terms of the Number of Turns

The application is implemented in the *CIPGV* module to obtain directly the inductance variation in terms of the

number of turns, without the necessity of the independent implementation of each inductor and without the need of collecting the results in another program that allow also to plot the results.

In Fig. 4 can be observed the details regarding the implementation of the application in the module and also the obtain results for the inductance variation versus the number of turns. We consider the number of turn's variation between one and sixteen turns with the pass one. The other dimensions of the analyzed inductors are those mentioned above.

In essence we calculate the inductance of sixteen square spiral inductors in the same time directly, without being necessary to analyze independent each one inductor to obtain its inductance value and then to plot the inductance variation in terms of the number of turns. The results appear in the right side of the window as shown in Fig. 4a). This module permits also the directly plot of the obtained values, plot that is presented in Fig. 4b). The inductance varies direct proportional with the number of turns, i.e. if the number of turns increase also the inductance increase, normally knowing that the number of turn predominate in almost all the inductance calculation expressions.

2. Inductance Variation versus the Turn Width

We analyze now the influence of turn width on the inductance value. For this analysis we implement the spiral inductors in CIPGV module, varying for each one the turn
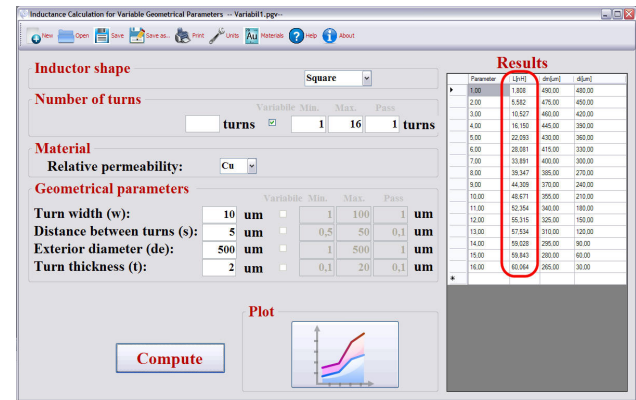
a) The results of inductance variation vs. number of turns, N;
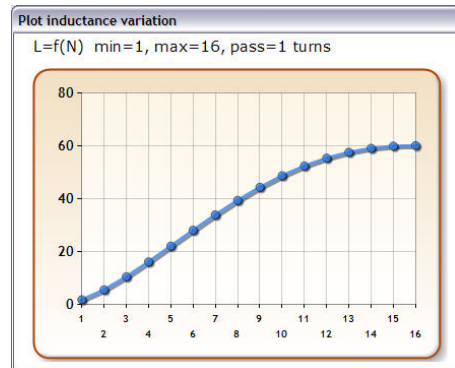
b) The plot of inductance variation vs. the number of turns
Fig. 4. Inductance vs. number of turns obtained in *CIPGV* module.

width between 1(μm) and 10(μm) with pass one, in only one applications all the variations.

The inductors have the other dimensions identical with those presented above. We calculate the inductance variations in terms of the turn width for the square spiral inductor with one, two, three, four, five, six, eight, ten, twelve, fourteen and respectively sixteen turns. We synthesized in Fig. 5a) and b) the inductance variation in terms of the turn width results and in Fig. 5 c) and d) we present the plots of these results only for the square spiral inductor with two respectively ten turns for exemplification.

Analyzing these plots we observe that the square spiral inductor inductance varies inverse proportional with the turn width, *w*. So if the turn width decreases the inductance increases.
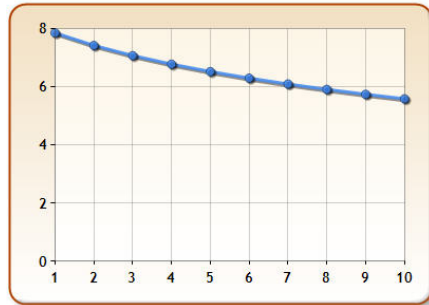
3. Inductance Variation in terms of the Distance between the Turns

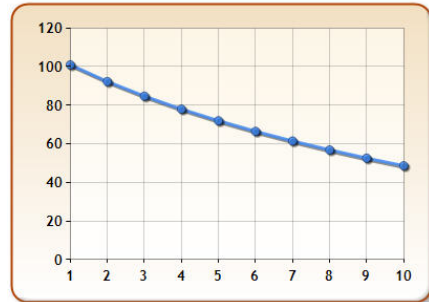We study now the influence of the distance between the turn on the inductance value. For this study we implement only seven from the eight types of create spiral inductors in CIPGV module, because the inductance of the square spiral inductor with one turn does not vary with the distance between the turn. So we vary for each inductor the distance between the turn from 1(μm) to 5(μm) with the pass one. The other inductors dimensions for the analyzed square spiral inductors remain the same.

We present only some of the applications for this variation study with the afferent results and graphical representations, i.e. the results for the four and respectively sixteen turns square spiral inductors in Fig. 6a), b) and respectively in Fig. 6c) and d).
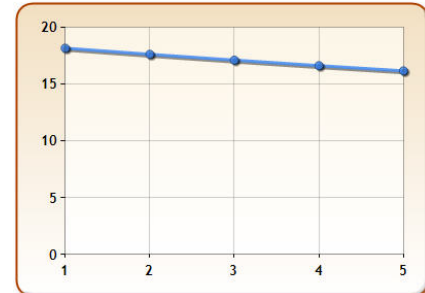
In the train of this analysis we can conclude that the inductance varies also inverse proportional with the distance between the turns, not only with the turn width. So the inductance is maximal when the distance between the turns in minimal.

We can conclude at the end of these variations analyses saying that the inductance is direct proportional with the number of the turns and inverse proportional with all the other geometrical parameters of the square spiral inductors. All the applications made for these variations studies were

Results

Parameter	L[nH]	dm[um]	di[um]
1,00	7,844	493,00	486,00
2,00	7,413	491,00	482,00
3,00	7,064	489,00	478,00
4,00	6,771	487,00	474,00
5,00	6,516	485,00	470,00
6,00	6,291	483,00	466,00
7,00	6,089	481,00	462,00
8,00	5,906	479,00	458,00
9,00	5,738	477,00	454,00
10,00	5,582	475,00	450,00

Results

Parameter	L[nH]	dm[um]	di[um]
1,00	100,935	445,00	390,00
2,00	92,273	435,00	370,00
3,00	84,714	425,00	350,00
4,00	78,003	415,00	330,00
5,00	71,968	405,00	310,00
6,00	66,490	395,00	290,00
7,00	61,480	385,00	270,00
8,00	56,873	375,00	250,00
9,00	52,616	365,00	230,00
10,00	48,671	355,00	210,00

a) Results of L vs. w for 2 turns inductor;   b) Results of L vs. w for 10 turns inductor;
L=f(W) min=1, max=10, pas=1 um

Results

Parameter	L[nH]	dm[um]	di[um]
1,00	18,141	457,00	414,00
2,00	17,601	454,00	408,00
3,00	17,092	451,00	402,00
4,00	16,609	448,00	396,00
5,00	16,150	445,00	390,00

Results

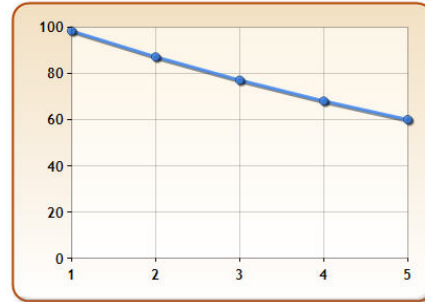| Parameter	L[nH]	dm[um]	di[um]
1,00	98,337	325,00	150,00
2,00	87,152	310,00	120,00
3,00	77,097	295,00	90,00
4,00	68,088	280,00	60,00
5,00	60,064	265,00	30,00

a) Results of L vs. s for 4 turns inductor;   b) Results of L vs. s for 16 turns inductor;
L=f(s) min=1, max=5, pas=1 um

c) L vs. w variation for square spiral inductor with 2 turns;
L=f(W) min=1, max=10, pas=1 um

c) L vs. s variation for square spiral inductor with 4 turns;
L=f(s) min=1, max=5, pas=1 um

d) L vs. w variation for square spiral inductor with 10 turns;
Fig. 5. Inductances versus the width of the turn obtain in *CIPGV* module of *CIBSOC* program.

d) L vs. s variation for square spiral inductor with 16 turns;
Fig. 6. Inductances versus the distance between the turns obtain in *CIPGV* module of *CIBSOC* program.

done for the exterior diameter of the inductors equal with 500(μm).

We consider that the spiral has to have the same area (imprint) on the integrated circuit in which it will be incorporate.

We design the program to draw, to calculate and to optimize only the effective spiral as component part of the spiral inductor, not with via, underpass, oxide and substrate, because we have analyzed those influence on the inductance and we find that in direct current have no effects on its value. So the program was design to analyze and to optimize the square, hexagonal, octagonal, and circular spiral inductors in direct current. In the program we impose the variations limits for the number of turns and for the geometrical parameters.

These limits are: for the turn width, from 1-100(μm), with pass 1; for the distance between the turns from 0.5-50(μm) with pass 0.1; the exterior diameter from 1-800(μm) and for the number of turns from 1-32(turns) with pass 0.25. We chose these limits to cover a wide range of square spiral inductors.

C. Applications in OCBS Module

The OCBS module was design in order to optimize the spiral inductor layout for a given value of the inductance and for a fixed area that the inductor need in the integrated circuit in which it will be used, i.e. and for a given exterior diameter. If the designer has a free area on an integrated circuit in which must to integrate one or more inductors, and he has some impose values for inductances, he can use this module of the program to find the optimal solutions with accuracy in a very short running time. He has to know only the geometrical shape of the inductor, the material used for spiral realization, the inductance value and the dimension of the exterior diameter.

We use the set of eight square spiral inductor in the applications, only that we want to find now the optimal layouts for these inductors by imposing the value of inductance to be one of those that we calculate in the first or in the second module, modules that are designed to calculate the exact inductance values. We keep the exterior diameter constant, 500(μm). We find the optimal layout of those eight square spiral inductors for the inductance values calculate in the CIPGC module, values that are collected in Table I.

1. Optimal Layout for L= 28,08(nH) and d_e=500(μm)

We continue the applications for spiral inductors with square geometrical shape and spiral made of cooper, Cu. We choose the input error for the optimization 0.1(%). In Fig. 7 are presented all the details of the OCBS module. The optimization algorithm of this program module displays all the possible optimal solution in the right part of the window.

The total number of possible optimal solutions that the program find are display in the bottom of the left side of the window (Fig. 7). Thus and so are found all the possible optimal layouts for the inductors of 28,08099(nH), that fill perfectly the area described by the exterior diameter of the spiral 500(μm). The program offers filters that can be applied
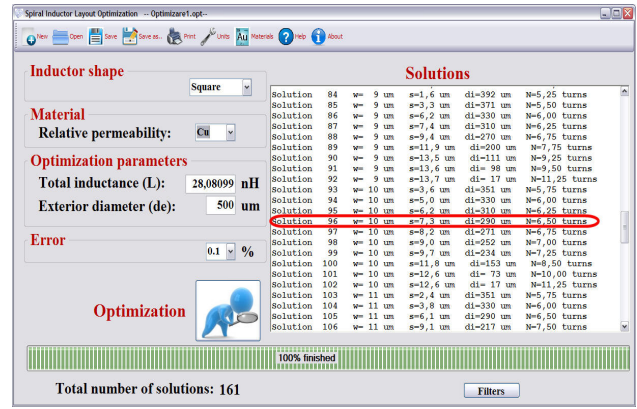

Fig. 7. Optimal solutions for square spiral inductor layout optimization for L=28,08099(nH) and d_e=500(μm).

to obtain only one optimal solution, depending of the technological restrictions or the uses' needs.

2. Optimal Layout for L=60,0635(nH) and d_e=500(μm)

Similar we want to find now the optimal solution for the square spiral inductor layout that has inductance value 60,06357(nH) and the exterior diameter 500(μm). The program finds 114 optimal solutions, obvious between them we retrieve that one for the square spiral inductor with sixteen turns from which we start the application, marked in Fig. 8.

The user will apply the filters that he chose from those that the program offers, taking into account his needs and the technological limitations.

D. Applications in OCBSIM Module

The OCBSIM module of CIBSOC software program let us to find directly the unique optimal solution for spiral inductor layout. We present only the applications for square spiral inductors to which we optimize theirs layouts for the maximal inductance of each one.

We can find the unique optimal solution of the spiral inductors for its maximal inductance and that use an area on an integrated circuit described by a fixed exterior diameter. It is known that the inductor has very good performances for the maximal value of its inductance. For this reason we consider useful to find the inductor optimal layout dependent on its maximal inductance value. So we consider some square spiral
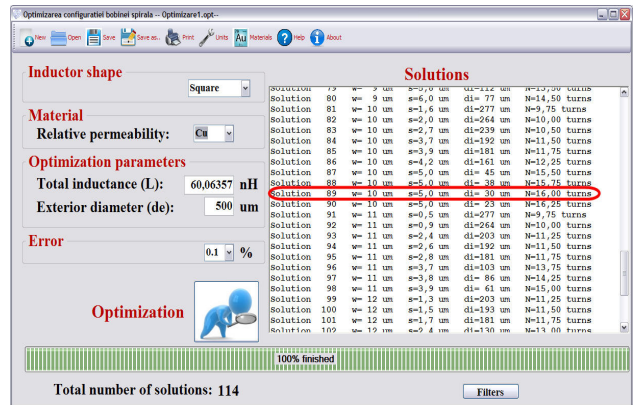

Fig. 8. Optimal solutions for square spiral inductor layout optimization for L=60,06357(nH) and d_e=500(μm)

inductor of 10(μm); 50(μm); 100(μm); 200(μm); 300(μm); 500(μm); 700(μm); 800(μm) exterior diameters and we want to find the optimal solution for their layout so that each one to have maximal inductance value. Keeping the same geometrical shape for the spiral inductors and the same material we found the square spiral inductor layout for the exterior diameters write above. So, the obtain results are detail presented only for the inductor with the exterior diameter 10(μm) in Fig. 9 for exemplification, and the other solutions are described in Table II.

TABLE II
OPTIMAL LAYOUT FOR MAXIMAL INDUCTANCE

Exterior diameter, d_e(μm)	Maximal inductance, L_{max} (nH)	Optimal Layout			
		Turn width, w(μm)	Distance between turns, s (μm)	Interior diameter, d_i (μm)	Number of turns, N(turns)
10	0,056	1	0,5	1	3,25
50	6,006	1	0,5	3	16
100	47,056	1	0,5	6	31,75
200	244,565	1	0,5	105	32
300	502,7375	1	0,5	205	32
500	1109,9387	1	0,5	405	32
700	1792,185	1	0,5	605	32
800	2153,348	1	0,5	705	32

All these studies and applications can be made with our program also for the other types of geometrical shapes used for spiral inductor. In this paper we treat only the spiral inductors with square geometrical shape.

IV. COMPARISON TO MEASUREMENTS

We calculate the inductance for some square spiral inductors from the literature for which we have experimental measurements to demonstrate the calculation accuracy of our software program CIBSOC and implicit of its four modules designed to calculate the inductance and to optimize the layout of spiral inductors.

We calculate the inductances for two sets of square spiral inductors detailed in Table III. So the results obtained with our program are compared with the measurements results from the literature. We find the relative errors, ε_r with the formula:

$$\varepsilon_r = \left| \frac{L_m - L_{CIBSOC}}{L_m} 100 \right| \; (\%) , \qquad (6)$$
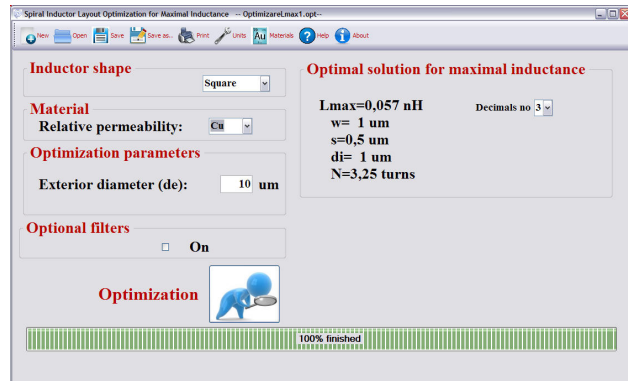

Fig. 9. The layout optimization for the inductor with the exterior diameter 10(μm) for maximal inductance.

where L_m is the measured inductance, and L_{CIBSOC} is the calculated inductance with cu *CIBSOC* program.

TABLE III
INDUCTORS PARAMETERS. COMPARISON OF THE RESULTS.

N (turn)	Ref..	d_e (μm)	w (μm)	s (μm)	t (μm)	L_m (nH)	L_{CIBSOC} (nH)	ε_r (%)
2.75	[12]	279	18,3	1,9	0,9	3,1	3,009	2,93
7.50	[12]	166	3,2	1,9	0,9	12,4	11,987	3,33
9.50	[12]	153	1,8	1,9	0,9	18,2	17,842	1,96
2.75	[12]	277	18,3	0,8	0,9	3,1	3,055	1,45
5,00	[12]	171	5,4	1,9	0,9	6,10	5,859	3,95
3,75	[12]	321	16,5	1,9	0,9	6,1	6,026	1,21
3.00	[13]	300	19	4	0,9	3,3	3,4977	5,99
5.00	[13]	300	24	4	0,9	3,5	3,7736	7,81
9.00	[13]	230	6,5	5,5	0,9	9,7	9,6791	0,21
8.00	[14]	226	6	6	0,9	9,00	9,143	1,58
16.00	[14]	300	5	4	0,9	34	36,544	7,48
6.00	[13]	300	9	4	0,9	11,7	12,444	6,36

It is obvious the concordance between the results. The program has high accuracy in calculation. The relative errors are from 0,21 % to 7,81%.

V. COMPARISON TO COMMERCIAL FIELD SOLVER

To validate our CIBSOC program we considered very good the opportunity to use a commercial field solver dedicate to extraction of the parameters from different complex types of integrated circuits. We implement in this program a wide range of square spiral inductors starting with the one we design for our applications. First we compare the results for the inductance variation in terms of the number of turns. To compare the obtained results we write them in Table IV.

TABLE IV
COMPARISON OF RESULTS. INDUCTANCE VS. NUMBER OF TURNS.

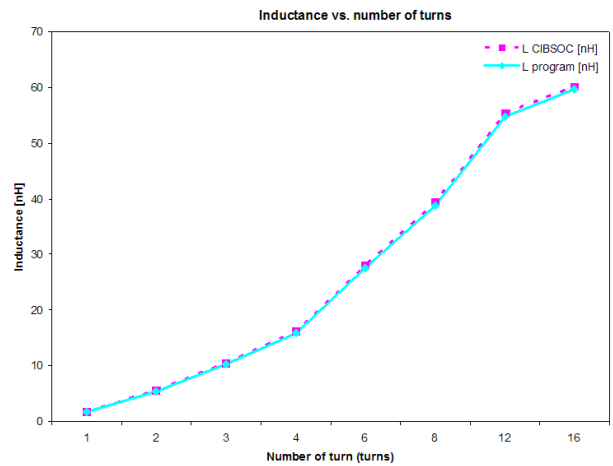| Number of turns	L_{CIBSOC} (nH)	$L_{program}$ (nH)
1	1,808	1,7309
2	5,582	5,4228
3	10,527	10,285
4	16,15	15,833
6	28,081	27,637
8	39,347	38,794
12	55,315	54,704
16	60,064	59,646

Fig. 10. The comparison of the results obtained with CIBSOC program and with the commercial field solver.

The inductance variation in terms of the number of the turns is plot in Fig. 10. We observe close agreement between the results. With dotted line are plot the results obtained with our CIBSOC program and with continuous line the results obtained with the commercial field solver. To obtain the results and the plots with our program was enough to implement the inductors parameters in the programs modules and all were solved in the same time, very quickly.

But for the simulations of the same inductors in the commercial field solver was necessary to implement effectively each inductor and to solve them separately. Then we copy the results in another program to plot theirs variation. The implementation time, the running time, and the postprocessor time are incomparable diminished with our program. For the inductance variation in terms of the turn width we present in detail only the results for the square spiral inductor with one turn in Table V and the plots in Fig. 11. We present the results comparison of all the analyzed inductors in Fig. 12, i.e. those obtained with commercial field solver and those obtained with our CIBSOC program.

TABLE V
THE RESULTS COMPARISON FOR THE INDUCTANCE VARIATION VS. THE TURN WIDTH FOR ONE TURN SQUARE SPIRAL INDUCTOR

t (μm)	d_e (μm)	s (μm)	w (μm)	L_{CIBSOC} (nH)	$L_{program}$ (nH)
2	500	5	1	2,764	2,3235
2	500	5	2	2,482	2,1861
2	500	5	3	2,316	2,096
2	500	5	4	2,196	2,0212
2	500	5	5	2,103	1,9571
2	500	5	6	2,026	1,9021
2	500	5	7	1,961	1,8518
2	500	5	8	1,904	1,8076
2	500	5	9	1,853	1,7676
2	500	5	10	1,808	1,7309

Similar we compare also de obtained results for the distance between the turns variation case. We choose the square spiral inductor with six turns for exemplification and we detail these results in Table VI and we represent them graphical in Fig. 13 for comparison.

TABLE VI
RESULTS COMPARISON FOR THE INDUCTANCE VARIATION VERSUS DISTANCE BETWEEN THE TURNS FOR THE SQUARE SPIRAL INDUCTOR WITH SIX TURNS

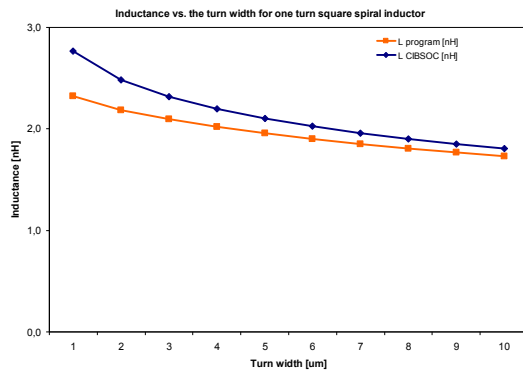| t (μm)	d_e (μm)	s (μm)	w (μm)	L_{CIBSOC}(nH)	$L_{program}$(nH)
2	500	1	10	33,218	32,812

Fig. 11. Results obtain with our program CIBSOC and with commercial field solver for the inductance variation versus the turn width
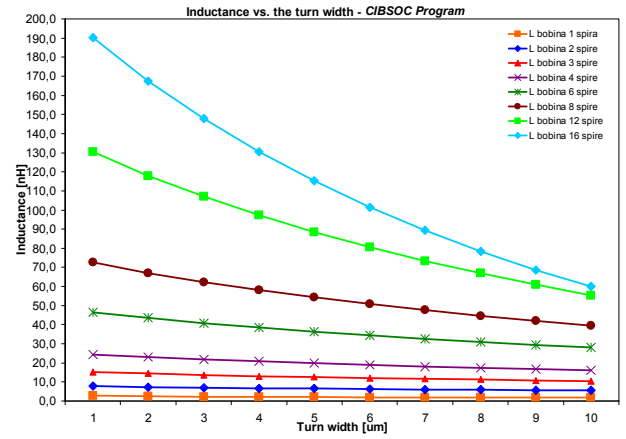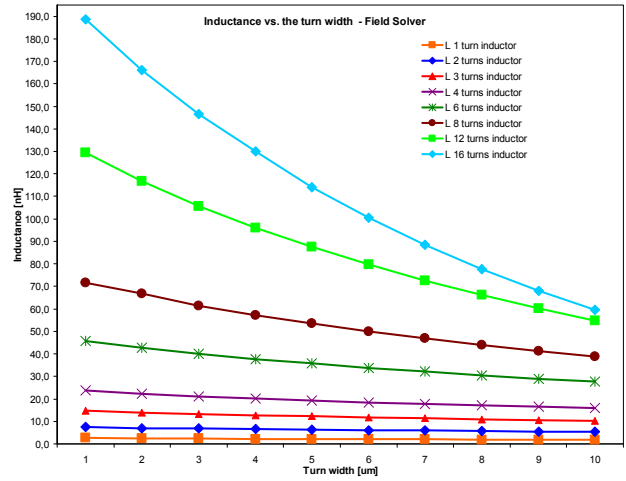
Inductance vs. the turn width - Field Solver

Inductance vs. the turn width - CIBSOC Program

Fig. 12. Results for inductance variation versus the turn width for all the analyzed square spiral inductors.

2	500	2	10	31,815	31,375
2	500	3	10	30,497	30,039
2	500	4	10	29,255	28,793
2	500	5	10	28,081	27,637

We consider that the distance between the turns varies form 1-5(μm) with pass one to keep the exterior diameter constant i.e. we want that the inductors to be implemented in the integrated circuit in the same area.
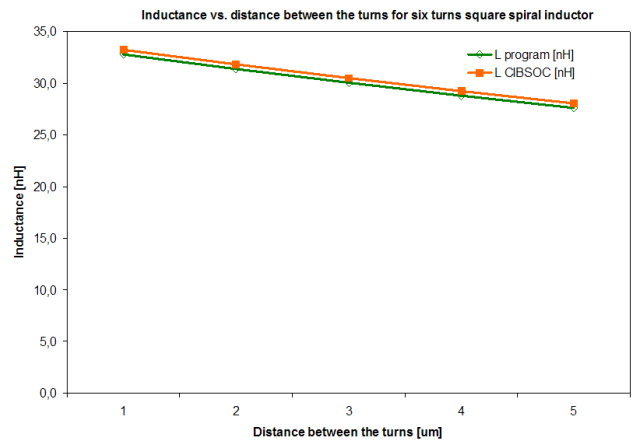
Fig. 13. The results obtain with CIBSOC program and with field solver program for inductance variation versus the distance between the turns

The errors are acceptable. The program is very simple and the obtained results are accurate. We compare the inductance variation versus the distance between the turns obtain with the commercial field solver and with CIBSOC program for all the studied square spiral inductors in Fig. 14.

Analyzing the graphical representations for these variations and for the others we can affirm without doubts that CIBSOC program is very good, very simple and very efficient. The program is well assembled and logic structured, each module is made for a kind of calculation type or optimization type.

The CIBSOC program results were compared with the measurements results form the literature and with simulations that we done with the commercial field solver, a program special create to extract the dc and ac circuits' parameters. We observe a very good agreement between the results with tolerate errors.

VI. CONCLUSIONS

The main aim of this paper was to present the inductance calculation and layout optimization for spiral inductors program, CIBSOC, designed by the authors.
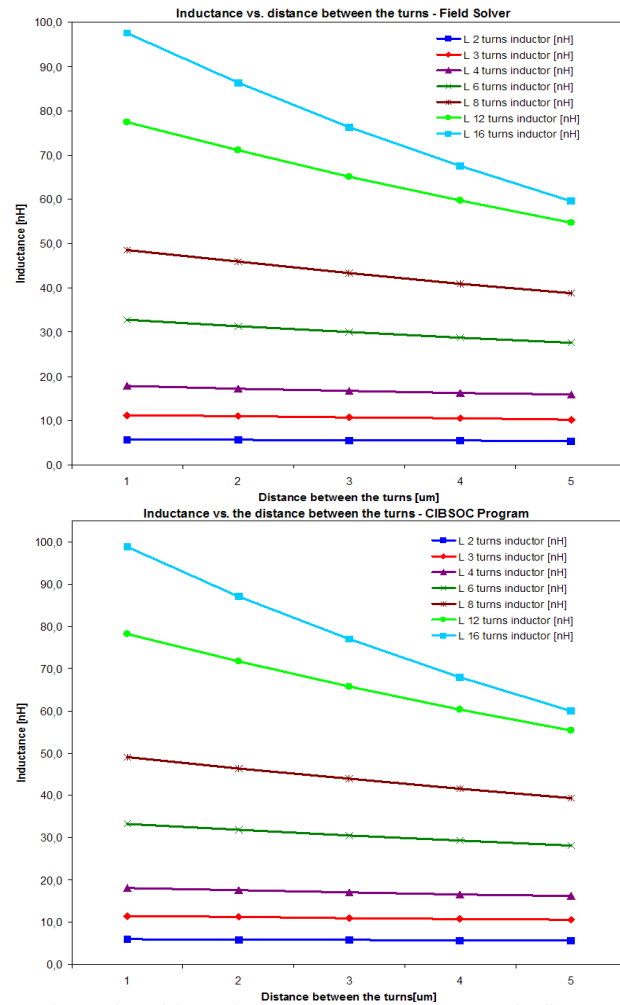

Fig. 14 Plots of the results for inductance variation versus the distance between turns for all the analyzed inductors.

The program validation was done by comparison of the applications results obtained with our CIBSOC program with the measurements results taken form literature and with the results obtained by modeling the square spiral inductors also with a commercial field solver design especially for parameters extraction. Analyzing the results obtained on three different ways we ascertain the results similitude, the small errors that prove the accuracy of our program.

We consider our program very useful for design and optimization of spiral inductors. It is easy to use; the running times are small compared with other similar programs. We want to extent our program also for ac inductance calculation, at high frequency.

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