An Automatic Macro Program developed for Characterization, Parameter Extraction and Statistic Analysis of Spiral Inductors

G.W. Huang, D.Y. Chiu and K.M. Chen

National Nano Device Laboratories
1001-1, Ta Hsueh RD, Hsinchu, 300, Taiwan, R. O. C., gwhuang@ndl.gov.tw

ABSTRACT

In the paper, a macro program based on Agilent IC-CAP software is developed for characterization, parameter extraction and statistic analysis of on chip spiral inductors. All procedures can be finished very easily in few buttons through the GUI(Graphical User Interface) technique.

Keywords: inductor, extraction, characterization, statistic, macro.

1 INTRODUCTION

Spiral inductor is a very important passive device for RFIC applications. However, it is very expensive because it costs much more wafer area than any other devices. Thus, it is extremely important that the performance of spiral inductors can be monitored and well controlled. Further statistic analysis is also very useful to RFIC designers for yield improvement.

2 PROGRAM DEVELOPMENT

This program is developed based on Agilent 85122A modeling system and Cascade Summit 12K semi-auto probe station. Whole program consists of several sub-programs designed for characterization, parameter extraction and statistic analysis. The wafer mapping plan can be edited in advanced using PCS or Nucleus software which is the standard package of Cascade semi-auto probe station. Figure 1 shows the flowchart of automatic characterization sub-program which can access the wafer mapping plan through the IC-CAP. Figure 2 shows the graphical interface of this automatic characterization sub-program. A special routine is designed in case the alignment of probe station is not so good that the moving of probes station is not well-matched with the measurement plan. Calculations of error compensation are implemented in the routine after users manually fine tuning the positions of the same DUT in each die and the positions of DUTs in only one die.

The schematic diagram of parameter extraction sub-program is shown in Fig. 3. The de-embedding procedure can be edited separately based on different design of dummy patterns. The algorithm of parameter extraction can also be changed depending on which structure of equivalent circuit is used while well-known 9 elements equivalent circuit is used in this program and the extraction algorithm is similar with Ref.[1]. The lumped-element equivalent model of a silicon spiral inductor is shown in Fig. 4. Rs and Ls are the series resistance and inductance of the inductor, respectively. Cp is the fringing capacitance of the adjacent metal traces. Cox1 and Cox2 represent the capacitance between spiral metal layers and the substrate. Rsub1 and Rsub2 represent the equivalent substrate parasitic resistance. Csub1 and Csub2 represent the equivalent substrate parasitic capacitance. Final optimization can be used for accuracy improvement of equivalent model parameters. Raw data and extracted parameters can be easily shown and compared using plot module and exported for other purposes. Figure 5 shows the graphical interface of parameter extraction sub-program and sliding bar of model parameters for fine-turning the fitting results. Users can decide to follow the procedure of parameter extraction step by step or just leave this work to the computer. If users are not satisfied with the automatic extraction results of computer, special design of sliding bar for each model parameter allows users to fine-tuning the final extraction results.

Inductance value, self-resonant frequency f_{SR}, maximum quality factor Q and the frequency where maximum Q located can be calculated and plotted for comparison in this sub-program. They can also be exported in text format or transfer to statistic analysis sub-program for further analysis. The deviation of wafer-to-wafer, die-to-die can be easily quantified for process controlled monitor. The quantification information and the statistic analysis of equivalent model parameters will be a powerful tool for RFIC designers to cross the barrier of production related difficulty such as yield, which will be directly related to cost of the end product.

3 CHARACTERIZATION RESULTS AND STATISTIC ANALYSIS

Figure 6 and 7 show the typical measured and simulated real part and imaginary part of the spiral inductor with port 2 grounded, respectively. The simulation results show very good agreement with the measured data. Figure 8 shows the measured and simulated S11 curves of the same two-port inductor at the frequency range of 0.1 – 20 GHz. The root mean square (RMS) errors between measured and simulated results are typically less than 7%. Figure 9 shows the measured and simulated quality factor of the spiral inductor at the frequency rangeof 0.1 – 20 GHz. As shown in Fig.9, relative large error exiets between the measured and simulated quality factor of the spiral inductor around the frequency where peak Q occurs. It is a optimization trade-off between real part of one-port inductor(port 2 grounded) and the quality factor of the inductor and also a limitation of the simple 9 elements equivalent circuit. Different equivalent circuit can be chosen to replace the original one for further improvement of the simulation results.

The statistic analysis sub-program is developed based on the statistic capability of the Nucleus software. The measured and extracted results are sent from IC-CAP to Nucleus program and stored based on the wafer mapping table. Figure 10 and 11 show the typical statistic results of measured quality factor and inductance for the spiral inductor over an 8 inch silicon wafer, respectively. Figure 12 and 13 show the typical extracted series resistance Rs and fringing capacitance Cp for the spiral inductor over the same wafer, respectively.

The deviation of die-to-die can be easily quantified as shown above. However, large deviation of measured quality factor is found in the above example. It seems to be influenced by the contact resistance between RF probes and metal pads. Thus, efficient method has to be found to solve this problem. Control ability of programmable positioner will be included for the measurement of the spiral inductor with different size(different distance between probes) in the future. On-wafer TRL calibration can also be adopted to improve the accuracy of intrinsic characteristics based on the programmable positioners.

4 CONCLUSIONS

The automatic macro program developed in this study is very suitable for characterization, parameter extraction and statistic analysis for spiral inductor. It will reduce the time consumption of characterization and parameter extractions effectively. The quantification information and the statistic analysis of equivalent model parameters will be very important for RFIC designers for yield improvement. Control ability of fully-auto probe station and programmable positioner will be included to increase the added value of this program in the future.

REFERENCES

[1] C.Y Su, *et.al*, "A Macro Model of Silicon Spiral Inductor," Solid-State Electronics, Vol.46, p.759-767, 2002.

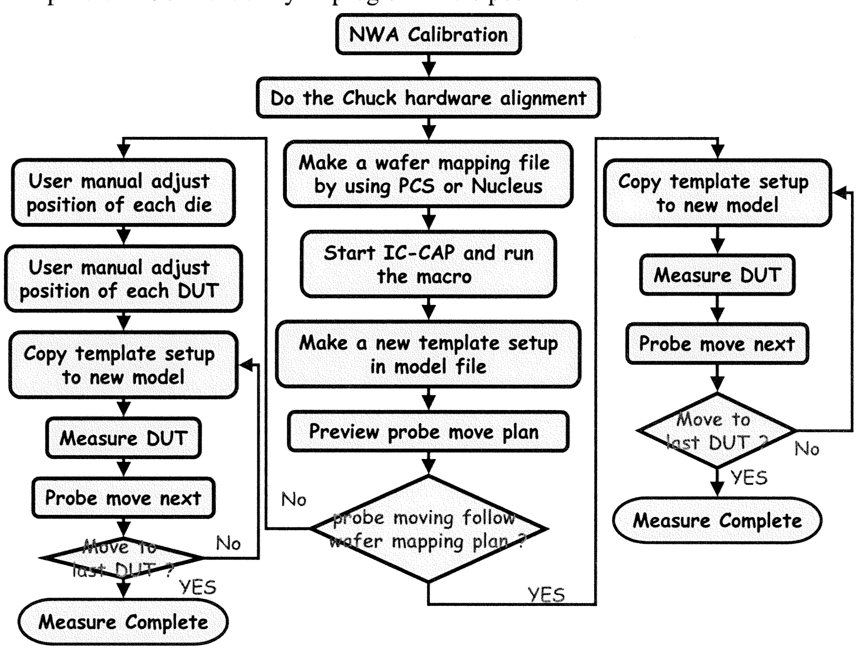

Fig. 1 Flowchart of automatic characterization sub-program which can access the wafer mapping plan through the IC-CAP

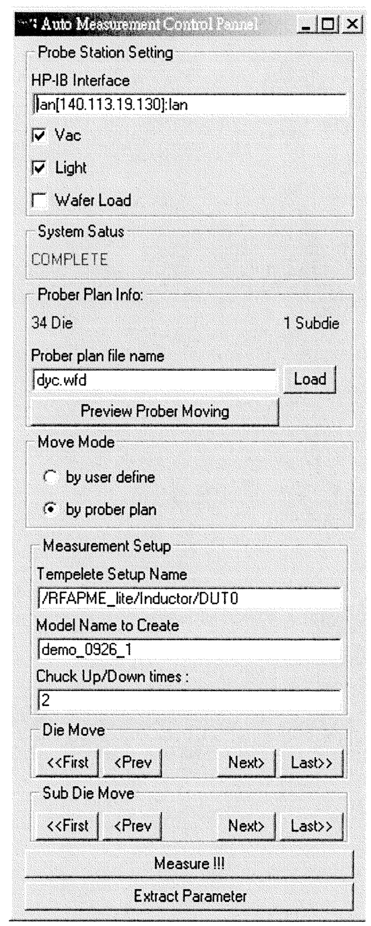

Fig. 2 Graphical interface of automatic characterization sub-program.

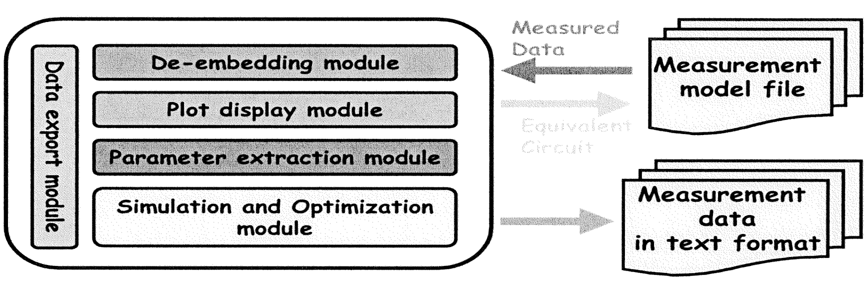

Fig. 3 The schematic diagram of parameter extraction sub-program.

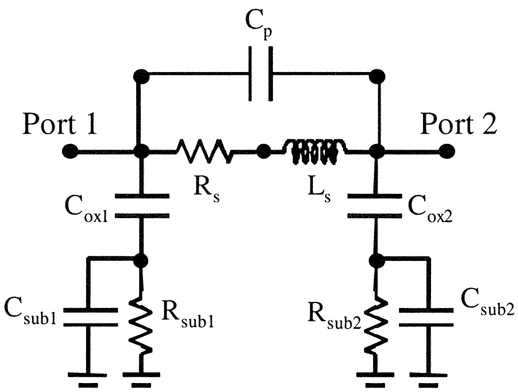

Fig. 4 A lumped-element equivalent model of a silicon spiral inductor.

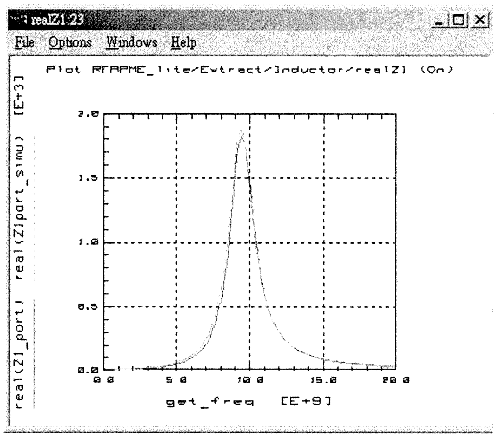

Fig. 6 The measured and simulated real part of the spiral inductor with port 2 grounded.

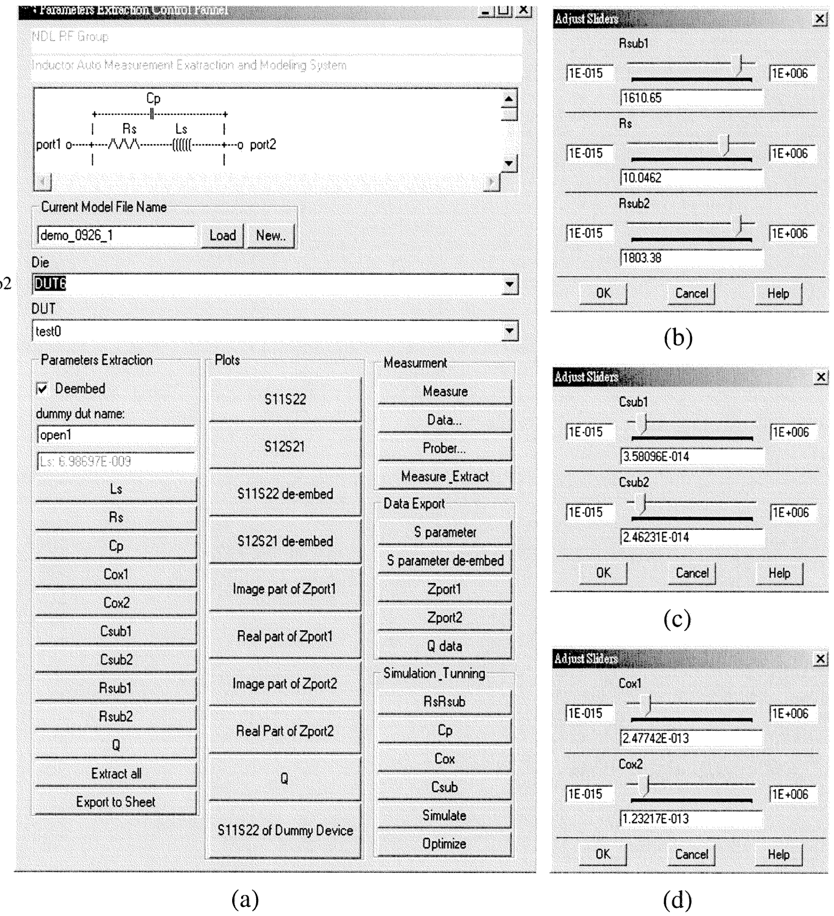

Fig. 5 (a)Graphical interface of parameter extraction sub-program and (b)(c)(d)Sliding bar of model parameters for fine-turning the fitting results.

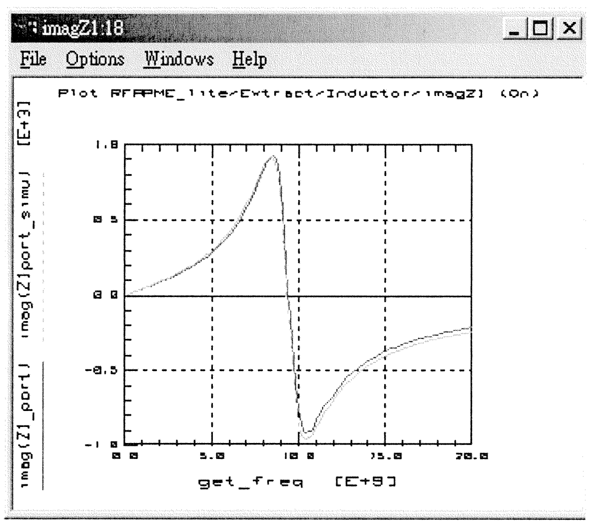

Fig. 7 The measured and simulated imaginary part of the spiral inductor with port 2 grounded.

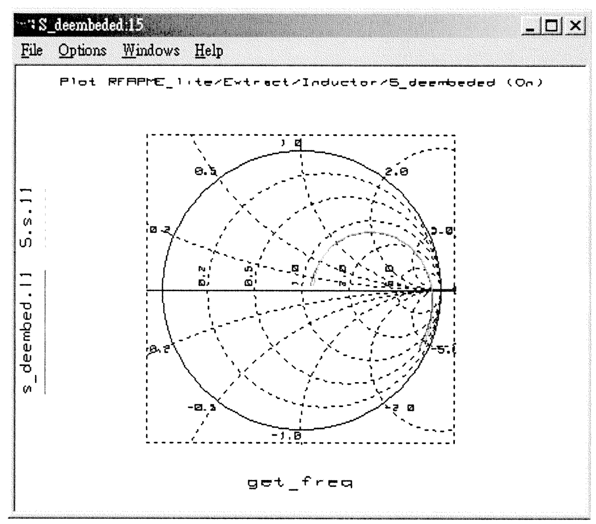

Fig. 8 The measured and simulated S11 curves of the two port inductor at the frequency range of 0.1 – 20 GHz.

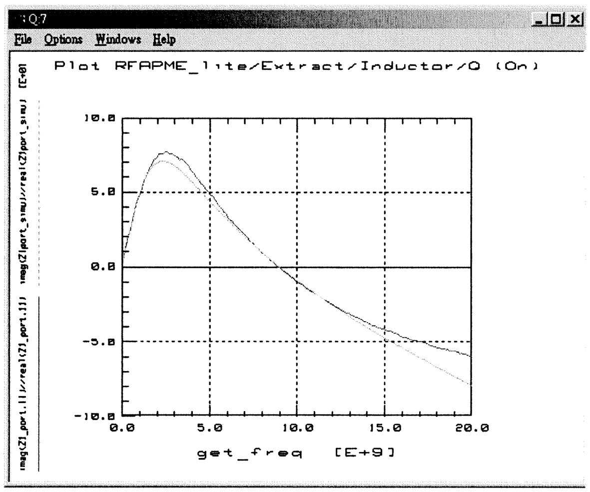

Fig. 9 The measured and simulated quality factor of the spiral inductor at the frequency rangeof 0.1 – 20 GHz.

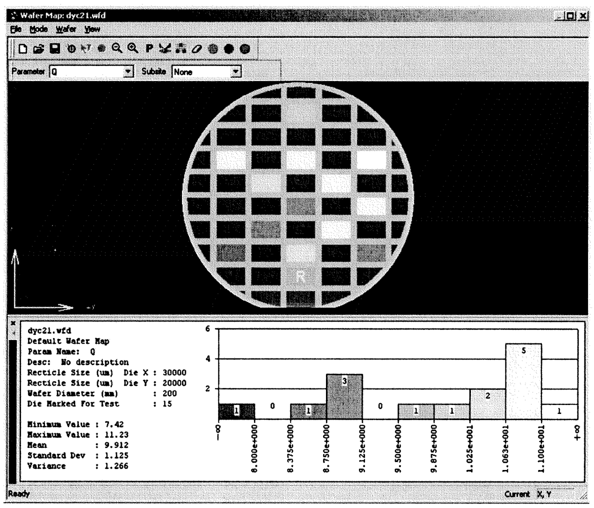

Fig. 10 Typical statistic results of measured quality factor for the inductors over an 8 inch silicon wafer.

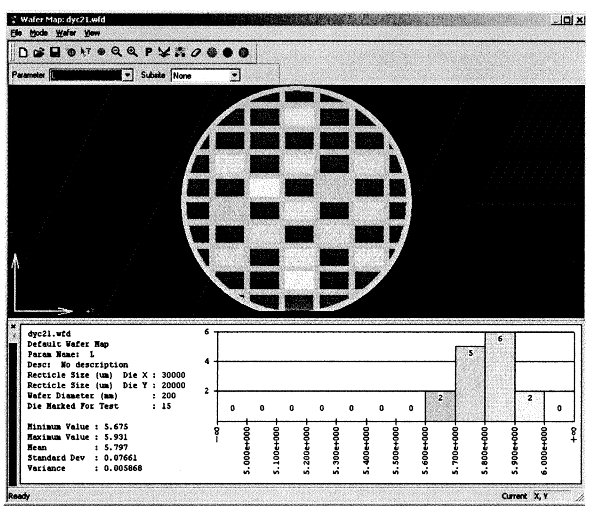

Fig. 11 Typical statistic results of measured inductance for the inductors over an 8 inch silicon wafer.

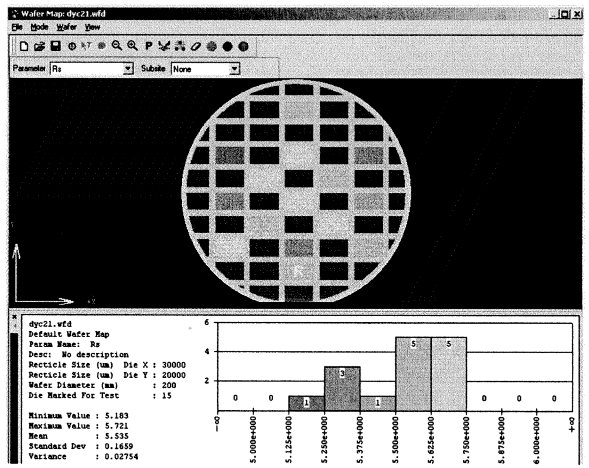

Fig. 12 Typical statistic results of extracted series resistance Rs for the inductors over an 8 inch silicon wafer.

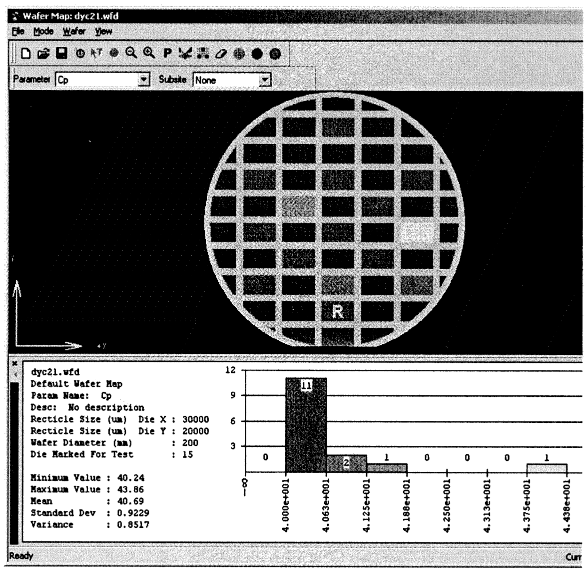

Fig. 13 Typical statistic results of extracted fringing capacitance Cp for the inductors over an 8 inch silicon wafer.