

RESEARCH ON INTERDEPENDENCY OF IC VARIABLES

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Abstract – Analysis test (parameter analysis) is very important in measurement and test of IC parameters. The key to solve analysis test problems is how to find out optimal characteristic variable group. In this paper, the mathematical model and application method of choosing characteristic variable group are described with the obtained experimental results. It provides the interrelation of IC variables and their effects on the device operating state.

Keywords: Integrated Circuit Test, Parametric analysis, Interdependency

1. INTRODUCTION

In order to know the state and performance of ICs while running, an overall analysis test for device parameters must be performed. In general IC tests, only one state point is tested. However, IC analysis test is a regional test for ICs, which reflects their working performances in a wide range as well as effects caused by various factors. Analysis test enriches the IC measurement and test information greatly, and provides a reliable basis for design, debugging and production of devices and whole machines.

The essential of analysis test is that variables vary within a certain range to reflect the state changes of a device. It is a kind of simulation of device state. As there're plenty of variables, and each of them varies within a certain range to simulate different state^[1], it would take a large quantity of testing time. For a certain state variable of IC, different variable influences the state differently, and some of the variables have critical effects or direct influences. Therefore, tests should be optimized to find out the characteristic variable group composed by variables with relative characteristics. In this way, analysis test of devices could be realized by simulation of a characteristic variable group. Consequently, the key point of realizing analysis test is to find out optimized characteristic variable group^[2].

Characteristic variable group has close relationship with manufacture technology, internal logic structure and practical using circumstance. As a result, the characteristic variable group for each device may be different. We use factor analysis method to sort the interdependency between variable and characteristic state variable, and the characteristic variable group is composed of variables whose interdependency is greater. On the premise of reflecting the variable characteristics, reduce variables as much as possible. It is beneficial to analysis test and result analysis.

The organization of this paper is as follows. Section 2 introduces mathematical model and processing method. The applying method is discussed in Section 3. Section 4 describes the realization. Finally, Section 5 concludes this paper.

2. MATHEMATICAL MODELS AND PROCESSING METHOD

2.1. Mathematical Models

In higher algebra, the function (1) denotes that the value of Y varies with the value of X_i , $i=1, 2, \dots, n$.

$$Y = F(X_i, i = 1, 2, \dots, n) \quad (1)$$

In mathematical statistics, factor analysis is to modify the independent variables in equation (1) using proper invertible transform, eliminate insignificant factors and keep principle factors. The reserved factors can approximately replace all the factors.

Very large scale digital ICs belong to switching devices. However, the input conditions can affect output results at different degree while conducting. As a result, it is necessary to study the degree of the input-output effects deeper, in order to know more about the electrical characteristics of devices. This application of factor analysis is called interdependency analysis of IC variables.

In interdependency analysis of IC variables, we suppose Y is a function of VLSI (e.g. timing delay, VOL and VOH), X_i ($i=1, 2, \dots, n$) are factors that affect Y (VCC, VIL, VIH etc.). By means of factor analysis, we can definitely obtain X_i ($i=1, 2, \dots, l, l \leq n$), so that

$$F(X_i, i = 1, 2, \dots, l, l \leq n) \approx F(X_i, i = 1, \dots, l) \quad (2)$$

Accordingly we find the principle factors of Y , namely, the characteristic variable group of Y .

2.2. Stepwise Regression Method

There're various methods of factor analysis. As their mathematical derivations are rather complicated, this paper mainly introduces how to use the formulas rather than prove them. The process from original data to final results is described in detail.

The Stepwise Regression Method is chosen because it is an algorithm that can be simplified by skills. The basic thought is that for all the variables, introducing them into the variable group step by step based on the significance of

them to Y . Variables that are insignificant may not be introduced forever. Introduced variables may also be eliminated because of being less significant caused by new variables. Keep on the introduction and elimination process until none of the variables could be introduced or eliminated any more. Next we will describe the process and method in detail.

2.2.1 Original data

Suppose the function of original data is $Y=F(X_i)$ ($i=1,2,\dots,t$). The response of Y can be obtained by means of changing X_i for t times randomly. The following matrix of original data is obtained, denoted by X_{ij} ($i=1,2,\dots,t, j=1,2,\dots,n$).

$$(X_{ij}) = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1n} & Y_1 \\ X_{21} & X_{22} & \cdots & X_{2n} & Y_2 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{t1} & X_{t2} & \cdots & X_{tn} & Y_t \end{pmatrix} \quad (3)$$

Obviously, i is the varying times of independent variable, and j is the number of the independent variables, Y_i ($i=1,2,\dots,t$) is the changing result of the function. For better matrix operation, Y_i is denoted by $X_{1\ n+1}$ ($i=1,2,\dots,t$). So that,

$$(X_{ij}) = \begin{pmatrix} X_{11} & X_{12} & \cdots & X_{1n} & X_{1\ n+1} \\ X_{21} & X_{22} & \cdots & X_{2n} & X_{2\ n+1} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ X_{t1} & X_{t2} & \cdots & X_{tn} & X_{t\ n+1} \end{pmatrix} \quad (4)$$

2.2.2 Correlation Matrix

Correlation matrix is the starting point of Stepwise Regression to perform invertible transform. Correlation matrix in (3) can be solved using the formulas below, the correlation matrix is denoted by R_{ij} ($i,j=1,2,\dots,n+1$).

$$(R_{ij}) = \begin{pmatrix} R_{11} & R_{12} & \cdots & R_{1\ n+1} \\ R_{21} & R_{22} & \cdots & R_{2\ n+1} \\ \cdots & \cdots & \cdots & \cdots \\ R_{n1} & R_{n2} & \cdots & R_{n\ n+1} \end{pmatrix} \quad (5)$$

Where $R_{ij}=R_{ji}$, and it is calculated by (6):

$$R_{ij} = L_{ij} / (L_{ii} \cdot L_{jj})^{1/2} \quad i,j=1,2,\dots,n+1 \quad (6)$$

Where, L_{ij} is the sum of squares of coefficient, constant term and Y of a normal equation.

$$L_{ij} = \sum_{i,j=1}^{n+1} (X_i \cdot X_j) - \frac{(\sum_{i=1}^{n+1} X_i)(\sum_{j=1}^{n+1} X_j)}{N} \quad (7)$$

$$\sum X_i X_j = \sum_{k=1}^t (X_{ki} \cdot X_{kj}) \quad i,j=1,2,\dots,n+1$$

$\sum X_i X_j$ means the cross product of variables.
 $\sum X_i = \sum X_{kj}$ ($j=1,2,\dots,n+1, k=1,2,\dots,t$) means the sum

of variables, and N is the row number of original data matrix.

2.2.3 Significance Sign

How to determine whether a variable is significant to Y or not? Of course we need a significance sign value to compare with. Generally speaking, the significance sign value depends on the row number of original data and the number of variables that may be introduced into the equation. After the two numbers are determined (the latter number can be estimated), the significance sign value can be looked up in the F distribution table. In this paper the significance is denoted by F .

2.2.4 Stepwise Regression Process

The overall Stepwise Regression process is accomplished by the following four steps:

a) In all the variables that haven't been introduced into the variable group, find out the maximum significance value according to the significance formula, denoted by. If the maximum $F(i)$ is bigger than F , then the corresponding variable will be introduced in variable group, turn to step ②, otherwise end the Stepwise Regression.

Calculation formula for $F(i)$:

$$F(i) = \frac{(N-2-m) \cdot P(i)}{1 - P_q^1 - P_r^2 \cdots - P_s^m - P(i)} \quad (8)$$

$$P(i) = \frac{R_{m+1}^2}{R_{ii}}$$

$$i=1, 2, \dots, n+1, \quad i \neq q, r, \dots, s$$

Where $P(i)$ means the regression sum of squares of possibly introduced variables. N is the row number of original data, m is the number of introduced variables, $P_q^1, P_r^2, \dots, P_s^m$ are the regression sum of squares of m introduced variables, $1, 2, \dots, m$ are the introducing sequences of variables, and q, r, \dots, s are the column numbers of introduced relevant variables in relevant matrix (or original data matrix). If m equals 0, then $P_q^1, P_r^2, \dots, P_s^m$ all equal 0.

b) Perform matrix transformation and turn to step c). Suppose we have introduced a variable in column k , then the matrix transformation formula is shown in (9), where l stands for the new matrix, $l-1$ stands for the old matrix.

$$R_{ij}^l = \begin{cases} R_{ij}^{l-1} - \frac{R_{ik}^{l-1} \cdot R_{kj}^{l-1}}{R_{kk}^{l-1}} & i \neq k, j \neq k \\ R_{ik}^l = -\frac{R_{ik}^{l-1}}{R_{kk}^{l-1}} & i \neq k, j = k \\ R_{kj}^l = \frac{R_{kj}^{l-1}}{R_{kk}^{l-1}} & i = k, j \neq k \\ R_{kk}^l = \frac{1}{R_{kk}^{l-1}} & i = k, j = k \end{cases} \quad (9)$$

c) Perform significance detection for the introduced variables under new matrix, that is, solve the minimum $F(i)$ in the introduced variables in the variable group, compare it with F , if $F(i)$ is smaller than F , then turn to step d) for rejecting operation, otherwise turn to step a) for introduction operation.

Calculation formula of significance value of introduced variables:

$$F(i) = \frac{(N - 2 - m)R_{in+1}^2}{R_{n+n+1} \cdot R_{ii}} \quad (10)$$

where m is the number of introduced variables, N is the row number of original data.

d) Matrix transformation of rejected variables

As it is proved that the matrix transformation formulas of rejecting and introducing variables for Stepwise Regression are the same. Therefore, this step can turn to step b) to accomplish, except that k in the formula should be regarded as the column number of the rejected variable.

After finish the Stepwise Regression, observe the significance of the introduced variables again, and their significance degree are obvious.

3. APPLYING METHOD

The mathematical model we built is a method that finds out the essential relationships between a group of independent variables and dependent variables. This model applies to linear relationship between independent variables and dependent variables. If it is not linear, then linearization must be performed before using the model.

3.1. Linearization

There're two methods for linearization: one is variable substitution and the other is sectional treatment. The latter method is to section the domain of variables, make the relationship between variables linear or approximate linear. The sectional treatment method is used in this paper.

In the IC analysis test data, the changing trend of independent variables and dependent variables could be observed directly. If the relationship between an independent variable and a dependent variable is linear or approximate linear, then it can be applied to the presented

mathematic model. If there comes an inflexion or it is curvilinear, we should section the domain of the variable, which makes the relationship in every section linear or approximate linear.

3.2. Qualitative Change Factors and Quantitative Change Factors

In the problem we discuss, there're two kinds of relationship between variables: one is that the dependent variable changes smoothly caused by independent variable; the other is that the dependent variable changes suddenly caused by independent variable, i.e. state change. Therefore it is necessary to educe the following two concepts:

In a variable group, independent variables which vary in a specified domain and cause state change of dependent variables are called qualitative change factors.

In a variable group, independent variables which vary in a specified domain and cause only quantity change rather than state change of dependent variables are called quantitative change factors.

Qualitative change factors and quantitative change factors can transform from each other with the change of domain.

The definition of qualitative change factors and quantitative change factors make us to know the relationship between variables further. Different methods are applied according to different kinds of variable relationships, different physical transform rule in devices can be expressed, so that our mathematical model can reflect their principle contradiction.

3.3. State Approximation

During linearization of qualitative change factors and quantitative factors, section of domain makes the effect of independent variables different in each section. In order to reflect the validity of data, the domain of an independent variable must be the most effective section of all. That is, approximate the domain to the section which makes the dependent variable change significantly, and use the approximated section as domain. This domain is used to reflect the relationships between independent variables and dependent variables in the mathematic model. We call this method state approximation. Or we can say it is a weighted processing of interdependencies of variables, which consolidates the principle contradiction in our mathematical model and guarantees the validity of data.

For a qualitative change factor, a section that makes the dependent variable change significantly exists between the two smoothly changed lines. State approximation makes this section the domain of the variable in the mathematic model.

For a quantitative change factor, although its relationship between the dependent variable changes smoothly, the effect to dependent variable differs with different sections. State approximation will choose the most effective section as the domain.

3.4. Data Acquisition

The following steps in Figure 1 explain the process of obtaining variable relative analysis data from device under analysis.

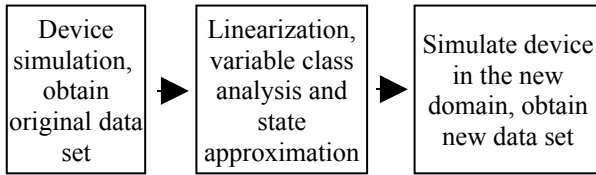


Figure 1 Steps of the process of obtaining variable

The simulation method in analysis test is used to obtain original data. The outside input change of device is simulated to obtain responses of dependent variables. Finally we can get the output response data for a variety of input combinations. These data are called original data.

Generally, the set of original data will be used for linearization, variable class analysis and state approximation. All these are processed to improve the adaptability and significance of data in the mathematical model.

The final result would be a set of new domain of independent variables. Simulate the device again in the new domain, and the obtained data is the effective data using in our mathematical model. This set of data is called effective data set.

4. REALIZATION

A suit of IC analysis test software is developed on V93000 test system that realizes the simulation of devices. In addition, a suit of software is developed on PC that analysis the interdependencies of IC variables, and our mathematical model is realized in the software. The process of the two sets of software is described in Figure 2.

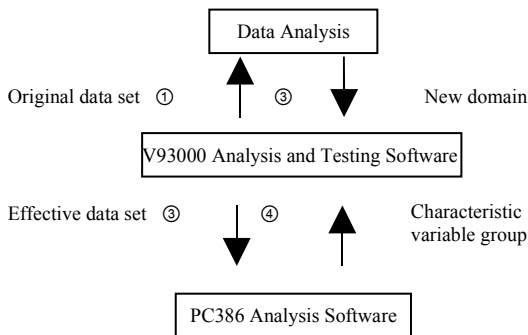


Figure 2 Description of the process of two sets of software

Next the processing result of a device is presented as an example. Device name is DP8303, the manufacturer is NSC, the production No. is B8930, and the original data set is omitted. Effective data set are shown in Table 1.

Table 1 Effective data set

No.	Vcc (V)	VIL (V)	VIH (V)	Temp (°C)	TPDLH (ns)
1	4.5	.6	2.4	25	11.87

2	4.75	.8	2.0	25	15.62
3	5.25	.4	2.8	25	11.87
4	5.5	.2	2.6	25	10.62
5	4.5	.8	2.0	50	12.50
6	5.0	.6	2.4	50	10.62
7	4.75	.2	2.8	50	10.62
8	5.5	.8	2.0	50	20.62
9	4.5	.2	2.0	70	10.62
10	4.75	.6	2.6	70	11.87
11	5.0	.8	2.4	70	20.62
12	5.25	.4	2.2	70	10.62
13	5.5	.4	2.2	70	10.62

According to 13 data items, Table 1 shows that there are 3 variables introduced in characteristic variable group. By estimating and looking up the F distribution table, if the value of F is set as 3.28. Then the processing results are the follows: the value of F(VIL) equals 11.39784, and the values of F (VIH), F(Vcc) and F(Temp) all equal 0.

The results indicate the significance degree of independent variables to dependent variables when the significance sign value is 3.28. For this device, the most significant variable to TPDH of all the four independent variables Vcc, VIL, VIH and Temp is only VIL.

Therefore, the characteristic variable group of TPDH is VIL.

If there're several variables exist in the characteristic variable group, then their interdependencies with independent variables are easy to get by comparing the value of their resulting significance.

If we care about the interdependencies of the independent variables that are not so significant, we can reduce F properly, making all the variables introduced into characteristic variable group, and compare their value of significance.

Processing results when F equals 0.02, then the value of F(VIL) equals 12.2909, F(Vcc) equals 1.654829, F(Temp) equals 0.1115712, and F(VIH) equals 0.

The results indicate that when F=0.02, three variables are interdependent with TPDH, obviously the significance of them is VIL>>Vcc>Temp. VIH is still independent with TPDH.

5. CONCLUSIONS

Interdependency analysis of IC variables is a research that indicates the relationships between IC variables with different measurement units. The objective rule is discovered by mathematical processing to original data.

The result of interdependency analysis of IC variables could improve the IC design criterion and technological process in production pertinently; improve the quality of IC products. Meanwhile, it could provide more comprehensive information about internal rules of device to electrical whole machine manufacturers; also provide a scientific basis for production and debugging of whole machine, thereby guarantees the stability and reliability of the whole machine system.

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