Risk Estimation for an Insufficient Number of Conduction Layers on the Assembly Field of Multilayer Printed Board

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***Abstract*—A method has been developed by using the probabilistic model where the mean value of the conduction layers of the assembly field of the printed circuit board (PCB) surface, the standard deviation and the insufficiency risk of the conduction layer have been determined.**

***Keywords*— Multilayer printed circuit board, assembly field, surface, number of conduction layers, distribution function, standard deviation.**

I. Introduction

As it is known, at an early stage of this project one of the most important problems has been to determine the number of conduction layers (CL) of the printed circuit board (PCB) surface [1-8].

It has been acknowledged that the increase of the PCB surface CL number is strongly conditioned by the increase of the element base integration degree, and is expressed by the overall growth of conduction layers. If potentialities of the PCB trajectory field surface are limited in terms of structural and technological aspects, conduction layers being performers of inter-element connections require larger surfaces. Designing printed board is considered challenging having the number of conduction layers as a restriction since parallel with the growth of the γ number of conduction layers the percentage of defects increases sharply.

II. Theory

The analysis of the CL number of existing PCB surfaces shows that not all potentialities of conduction layers are being utilized. It has been established that there is some average number of CLs of the PCB surface corresponding to each technical level where comparing a larger number of the CLs given to the technical level results in an incomplete utilization, while in the case of a smaller number the conduction layers are insufficient, that is, the number of CLs of the given PCB surface is not suitable (as there is a limitation). It induces to employ mathematical models to assist in analyzing the number of CLs of the PB surface and consequences of different solutions on the structural characteristics of the PCB surface.

The synthesis of CL number of the PCB surface and the number of elements on them is determined in two stages:
At the first stage, the number of elements, which can be placed on the surface of the PCB assembly field is being determined while at the second stage – the number of CLs of the PCB surface assembly field [1-8]. Let us present each of the stages in the form of a separate problem.

Numerous factors should be taken into account during the selection of the number of PCB elements. Acknowledging those factors, a definite number of the PCB elements is selected; however, regardless of the considerations and number of selected quantity of elements, it is invariably necessary to ensure the electric operation of wire connections between them in order to eliminate any failures.

As the results of the analysis [1-8] have shown, one of the main factors affecting the non-failure link of electric wirings between the PCB elements is the number of PCB surface conduction layers.

The problem lies upon the average number of conduction layers as the required number of elements is a random value. It implies that different quantities of CLs are required for the surfaces of different PCBs with the same number of elements. Therefore, when the number of the CLs required for the elements is larger than the number of CLs on the PCB surface, not all the wire length ties of the electric connections will be realized. Thus, the probability of satisfying the CLs of the PCB surface can be carried out when the number of conduction layers required for the quantity of elements are not more than the number of the PCB surface CLs [9]:

$$P_{\gamma} = P\left[\gamma\left(N_1\right) \le \gamma_1\right] = P\left(N = N_1\right). \quad (1)$$

where N is the number of elements on the PCB surface.
Articulating the above mentioned probability by the density distribution of the number of CLs required for the N_1 number of elements, we will have [9]:

$$P_\gamma = P[\gamma(N_1) \le \gamma_1] = \int_0^{\gamma_1} f(\gamma, N_1)dy =$$
$$= \frac{1}{\sqrt{2\pi\sigma}} \int_0^{\gamma_1} \ell^{-\frac{(\gamma-\bar{\gamma})^2}{2\sigma}} dy. \qquad (2)$$

where $f(\gamma, N_1)$ is the equation of the distribution density [9].

Let us introduce the concept of insufficiency risk of the CL number of the PCB surface along with a probability where the number of CLs required for the N_1 number of elements will be larger than that of the present CLs.

$$R = P[\gamma(N_1) \succ \gamma_1] = 1 - P_\gamma \qquad (3)$$

As it can be seen from (2) and (3), the larger the γ_1 number of CLs is, the smaller their insufficiency risk becomes, therefore – the probability of implementing the wire lengths of electrical ties of all the elements is greater. It is crucial to bring the insufficiency risk of CLs to zero in order to reliably implement the wire ties of different electrical links.

According to the probability model of dependence of the CL γ number of the PCB surface assembly field on the N number of elements, $\gamma(N_1)$ has a normal distribution of probabilities. It indicates that for any $\gamma(N_1)$ finite value from (2) and according to (3), we get: $P_\gamma \prec 1, R \succ 0$.

But it is known from [9] that for the x random values of any normal distribution, the mathematical expectation of which is γ_x, the standard deviation σ_x ,accurate to the decimal point of a percent, the following expressions are true:

$$\begin{cases} P(x \prec \gamma_x) = 0.5 \\ P(x \prec \gamma_x + \sigma_x) = 0.84 \\ P(x \prec \gamma_x + 2\sigma_x) = 0.98 \\ P(x \prec \gamma_x + 3\sigma_x) \approx 1 \end{cases} \qquad (4)$$

and

$$\begin{cases} \gamma_1(R = 0.5) = \bar{\gamma}(N_1) \\ \gamma_1(R = 0.16) = \bar{\gamma}(N_1) + \sigma_\gamma(N_1) \\ \gamma_1(R = 0.02) = \bar{\gamma}(N_1) + 2\sigma_\gamma(N_1) \\ \gamma_1(R = 0) = \bar{\gamma}(N_1) + 3\sigma_\gamma(N_1). \end{cases}$$

where $\bar{\gamma}(N_1)$ and $\sigma_\gamma(N_1)$ are the average numbers of CLs with the N_1 number of elements and standard deviation, respectively. As it follows from (4):

$$\gamma_1(R = 0) = \bar{\gamma}(N_1) + 3\sigma_\gamma(N_1). \qquad (5)$$

In this case, the insufficiency risk of the CL number is equal to zero, and, as a result the maximal coefficient of PCB filling is ensured. The further increase in the number of conduction layers does not make sense since the probability of the CL number of the PCB surface to be larger than $\lfloor \bar{\gamma}(N_1) + 3\sigma_\gamma(N_1) \rfloor$ is practically equal to zero.

On the other hand, without a significant loss, the number of CLs can be reduced by the size of the standard deviation. At that, according to (4), the probability of implementation of the electrical ties of the PCB with N_1 elements will be 0.98, while the insufficiency risk of the number of conduction layers- only 0.02. It means that only 2% of all the PCBs can have the number of conduction layers smaller than it is required for the wire lengths of the electrical links of the elements. In practical terms it does not affect the average filling of the PCB surface. Thus, the following principle for selecting the number of the PCB surface conduction layers can be recommended:

$$\gamma_1 = \bar{\gamma}(N_1) + (2 + 3)\sigma_\gamma(N_1). \qquad (6)$$

where $\bar{\gamma}(N_1)$ is the average value of the number of conduction layers with N_1 elements; $\sigma_\gamma(N_1)$ - the standard deviation of the conduction layers.

In case of such selection of the number of the PCB conduction layers, their insufficiency risk is $R \approx 0 \div 0.02$ and essentially ensures the reliable implementation of the wire connections of the PCB electric links for N_1 elements.

Example.

Determine the insufficiency risk for the number of conduction layers of the printed circuit board surface assembly field, if $a = b = 10_{mm},\ N = 100,$
$d = 0.5_{mm}, k = 0.5, m_0 = 16, t = 0.5,$
$p_1 = 0.3, p_2 = 0.5, p_3 = 0.75, p_4 = 0.8.$

Use [7-8] the number of conduction layers of the PCB assembly field:

$$\bar{\gamma} = \frac{(1-p)d_{\min} t m_0 (N + N^p) N^{0.5(p-1)}}{K\sqrt{ab}(1+p)(N^{0.5} - N^{0.5p})}. \qquad (7)$$

And the standard deviation:

$$\sigma_\gamma = \frac{t d_{\min}(m_0 - 2)(1-p)(N^2 + N^{2p})^{0,5} N^{0,5(p-1)}}{3K\sqrt{ab}(1+p)(N^{0,5} - N^{0,5p})}. \qquad (8)$$

where $\bar{\gamma}$ is the average number of conduction layers of the PCB assembly field; K - the density coefficient of the conduction layer wires; $d_{\min}$ - the wire width; $a \times b$ - are the distances between the elements in the horizontal and vertical directions, respectively; N - the number of the elements in the PCB; t - the circuit branching coefficient $(0.5 \le t \le 1)$; m_0 - the average quantity of the element outputs; the density coefficient of the inter-element links $(0.1 \le p \prec 1)$.

Referring (2), (7) and (8), the number of conduction layers is a random value and has a normal distribution. The graph of the insufficiency risk of the PCB surface assembly field conduction layers can be seen in Fig. 1.

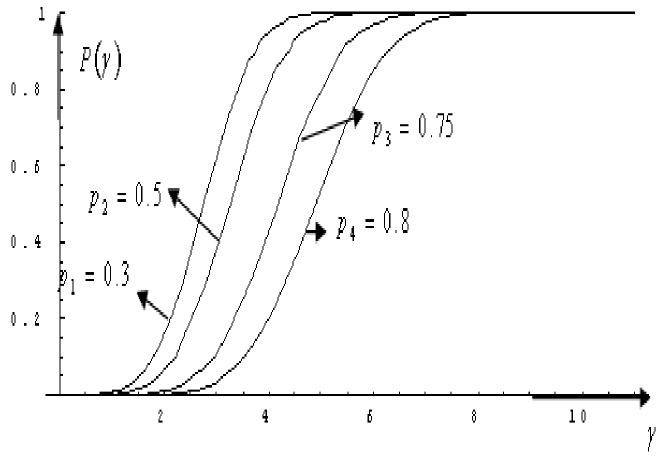

Fig. 1. The probabilistic distribution function of the random value of the CL number.

TABLE I. Comparison of the Statistical Data and the Calculated Average Values of Number of Number of Layers in BCB

/	m0	S[mm^2]	Dmin [mm]	N	t	γ_{calc}	γ	Δγ[%]
1	14	170 x 70	0.5	57	0.5	9.03	9	0.33
2	14	170 x 70	0.5	55	0.5	8.55	9	5.00
3	14	170 x 70	0.5	49	0.5	7.20	8	10.00
4	14	170 x 70	0.5	58	0.5	9.28	8	16.00
5	14	170 x 70	0.5	51	0.5	7.64	9	15.11
6	14	170 x 70	0.5	52	0.5	7.87	8	2.16

In order to compare the theoretical / calculated (γ_{calc}) and practical(γ) number of conduction layers γ of the multilayer PCB, we have presented Table 1 for several test cases.
As it can be seen from the comparison of the statistical data and the calculated average values, the equation (7) has high accuracy of estimation.

III. Conclusion

The probability that the γ number of conduction layers required for elements of the PCB is larger than that of the existing number of the PCB conduction layers can be considered as an insufficiency risk of the PCB conduction layers.

In case of the fixed number of PCB elements, parallel with the increase in the CL number, their insufficiency risk decreases, while in case of conduction layer number decrease, the risk increases.

In case of the synthesis of the PCB CLs, one should work for decreasing the insufficiency risks of the number of conduction layers.

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