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Research of Design Technology of Printed Circuit Board

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Abstract:

This paper delves into various methodologies for enhancing the quality, design, and optimization of Printed Circuit Boards (PCBs). With the development of the technology, the importance of Printed Circuit Board(PCB) is recently mentioned by more and more people who is trying to make progress of human technology. The classification of PCB defects, a crucial step in ensuring product reliability, is discussed on several categories of defects in PCB, highlighting recent advancements such as fuzzy c-means segmentation, which significantly improves defect detection accuracy. When producing, the layout is quite significant. In a conference, a group of scientists used a thermal layout modelling and optimization routine to make the board having more space to put circuit on it. Methods to ensure PCB quality during production are examined, focusing on optical and electrical testing. The PCB design process is also explored, emphasizing the importance of those considerations before production. Finally, the paper reviews innovative approaches to PCB layout optimization, particularly in managing heat dissipation and dynamic behavior through advanced simulation techniques.

Keywords: Printed Circuit Board, Defects, Production

1. Introduction

Printed Circuit Boards (PCBs) play a significant role in modern electronic systems, serving as the foundational structure that connects electronic components and ensures their proper functioning. The quality of PCB design and manufacturing directly impacts the performance and reliability of the entire system. As electronic devices become increasingly complex and integrated, the challenges faced by PCBs also grow, encompassing various aspects such as defect detection, quality control, design optimization, and layout management. Traditional PCB defect detection methods, such as optical and electrical testing, are capable of identifying most common defects, but often struggle when dealing with complex and diverse defect types. This paper will talk about the solution of this issue.

In addition to defect detection, quality control during PCB manufacturing is equally critical. Methods such as flying probe testing can reveal defects like open circuits and short circuits, but more efficient testing methods are needed for large-scale production to ensure that every PCB meets strict quality standards. This includes testing the accuracy of geometric dimensions, the precision of component manufacturing, and the alignment between layers. Furthermore, the quality of hole metallization and the PCB's resistance to current loads are also essential aspects that must be tested.

In terms of design, PCB layout has a profound impact on the overall performance of electronic systems. From the selection of stackup configurations to the application of routing technologies like microstrip and stripline, and the control of electromagnetic interference (EMI), each step requires careful consideration to minimize issues such as noise, crosstalk, and transmission line effects. Meanwhile, with the increasing frequency of integrated circuits and the trend towards miniaturization, managing heat dissipation and evaluating dynamic behavior in PCBs have become more critical. By employing advanced simulation techniques and optimization algorithms, designers can achieve optimal PCB layouts while ensuring efficient heat management. This paper will delve into these key issues, presenting the latest research developments and technological methods related to PCB production and design.

2. Design Technology of Printed Circuit Board

2.1 Classification of PCB defects

There are 14 known defect categories of PCB, and researchers often use the existing defect inspection technology to test the defect type of PCB. However, traditional methods struggle to accurately classify all 14 types, including Breakout, Pin hole, Open circuit, Under etch, Mouse bite, Missing conductor, Spur, Short circuit, Wrong size hole, Conductor too close, Spurious copper, Excessive short, Missing hole, and Over etch, as shown in Figure 1 [1][2]. Recently, an developed algorithmic method , using fuzzy c-means for image segmentation via image subtraction as a preprocessing step before the actual defect detection. For defect classification, the method employs arithmetic and logic operations, the circle hough transform (CHT), morphological reconstruction (MR), and connected component labeling (CCL). In this case, the accuracy of defect classification improved to 99.05% and 100% defect detection [2].

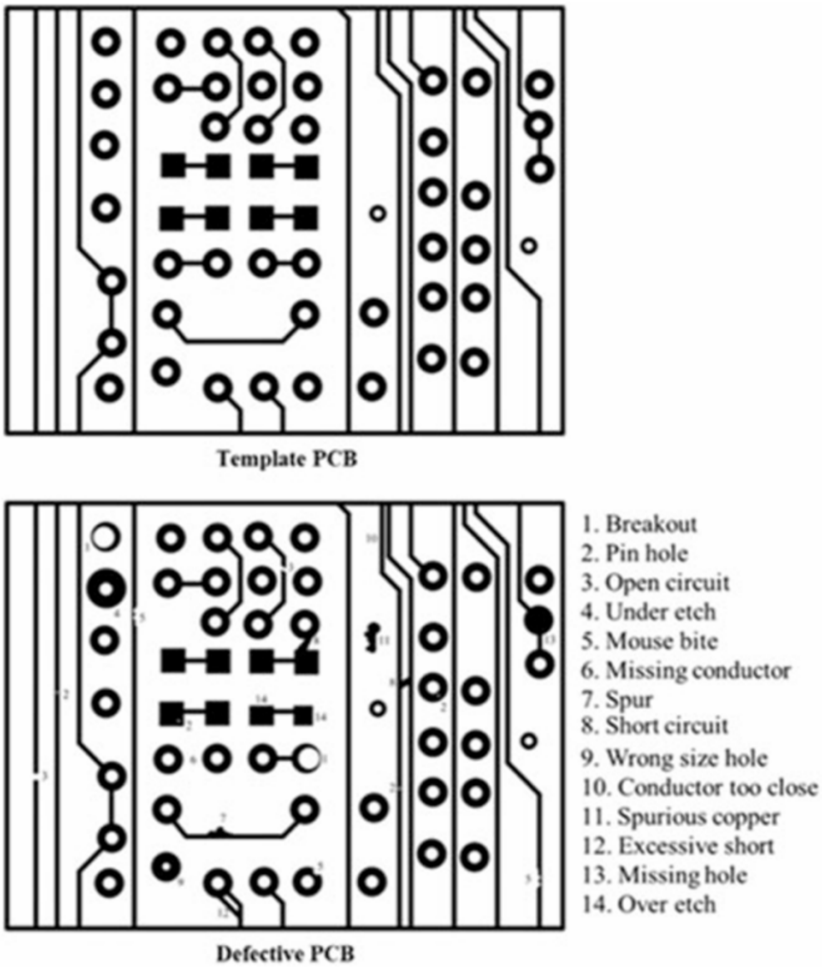

Fig. 1 Template and defective PCBs [1][2].

2.2 The method of making a PCB

2.2.1 The method of ensuring the quality of PCB

While PCB is producing, ensuring the quality of each board is crucial. Identifying the discontinuities is one of the most significant problems in manufacturing. In a flying probe test, it has unraveled the discontinuities as open circuit defects and short, which were caused by such defects like etching, foreign inclusions and the reduction of the distance between conductors, as well. Another significant problem is to keep each PCB reliable,which means every board must be examined. Therefore, several aspects need to be tested: the geometrical dimensions, the accuracy of individual component manufacturing, and level-to-level alignment. Additionally, it's important to check the metallization of holes and their resistance to current load. Finally, determining the continuity of circuits and the resistance of insulation is also crucial. In this case, a conference of Russian Young Researchers in 2019 has come up with a way that it is possible to use optical and electrical control to enhance the accuracy of the PCB manufacturing [3].

According to the experiment, a serious reason for the rejection of a PCB would be flaws as etching and scratches breaking the continuity of conductors. In this case, researchers could recognize the variety of discontinuity [3].

As the type of manufacturing is different, the choice of testing can be changed. There are several merits and demerits for optical testing and electrical testing.

Optical testing provides more reliable results for PCBs and can examine all types of boards. However, it is inefficient for mass manufacturing due to its 'flying mass' approach. On the other hand, electrical testing has lower equipment costs compared to automatic optical systems, but its results may require further verification by other methods [3]. Therefore, it is important to choose the correct method before testing.

During manufacturing, the challenge lies in cutting smaller circuit boards from larger rectangular panels, which is akin to the rectangular cutting stock problem in operations research. Existing solutions were unsuitable due to the unique requirements of PCB manufacturing. To address this, a new algorithm was developed, focusing on grouping similar pieces and patterns while minimizing trim losses. This algorithm is implemented in software that integrates design and manufacturing data, optimizing the PCB manufacturing process [4].

2.2.2 The method of designing a PCB

The layout of PCB is a crucial step in electronic design, particularly in minimizing noise, crosstalk, and transmission line effects. Effective PCB layout significantly impacts the performance of filtering circuits and overall system reliability.

When designing a PCB, one of the first and most crucial steps is determining the stackup. This process involves deciding the minimum number of layers required. In making this decision, designers must take into account various factors including high-speed signal shielding, differential impedance for buses like USB and Ethernet, and the manufacturer's specifications for trace width and spacing [5].

In the adjacent power and ground topology, the close proximity of these planes increases capacitance and reduces high-frequency impedance, making it suitable for high-frequency DSP systems. However, it might not be feasible for systems with complex routing needs. The non-adjacent topology, while offering more routing flexibility, results in lower capacitance and higher board impedance, necessitating additional high-frequency decoupling capacitors [5].

The article also covers Microstrip and Stripline routing technologies. Microstrip is easier to route with fewer vias and is generally less expensive but offers only acceptable signal quality and electromagnetic interference(EMI) performance. Stripline, while offering superior EMI shielding due to its routing between ground planes, is more expensive and complex to implement.

To reduce radiated emissions, the concept of an Image Plane is introduced. This is essentially a ground plane placed adjacent to the signal routing layer, providing low-inductance return paths for high-speed signals. Experimental results demonstrate that incorporating an Image Plane in PCB design can lead to a significant reduction in EMI, approximately 15dB across the frequency spectrum [5].

2.2.3 The optimization of PCB layout

The trend towards higher clock frequencies and miniaturization of integrated circuits has resulted in increased heat dissipation on PCBs. This necessitates innovative cooling solutions to maintain reliability and functionality while keeping designs compact and lightweight. A comprehensive review of studies from 1989 to 2002 by various researchers including Lee, Mahaney, Elias and Sridhar, Gerald, and Ying et al., revealed several key findings, listed below.

Firstly, a new method for optimization of the PCB meshing which is applicable not only for the PCB, but to other system meshing and can be improved to three-dimensional meshing was developed. This method is based on the mathematical optimization (Complex Method). The dual complex method is a new technique to control the PCB meshing and a good route to reach the optimum system mesh i.e. a unique system mesh with minimal CPU time [6].

Secondly, larger dimension of the PCB must oriented horizontally rather than vertically in free convection for the optimum total heat loss. For the same previous objective function and case of convection, the electronic components or sub-assemblies of larger power should located near the top of the PCB. Also, in the case of the horizontal-Upset-down, the electronic components of larger power must lie near the center of the PCB [6].

As PCB is an intricate system subjected to various external and internal loads, necessitating dynamic behavior evaluations early in their development. Modal finite element (FE) simulations are used to assess these behaviors across a broad frequency range. For accurate results, all geometrical features, including PCB assembly, copper layer thicknesses, and prepreg structures, must be considered with appropriate material properties. However, modeling a PCB in full detail, including elements like glass fiber-epoxy compounds and copper traces, is time-consuming.

To address this challenge, researchers developed a method that simplifies the modeling process without sacrificing accuracy [7]. This approach takes into account the functional board layout and assembly. It uses general composite theory, domain-specific mixture rules, and generalized laminate theory to approximate material properties. These approximated properties, including local stiffness and densities, are then applied to the meshed geometry of the PCB model. These approximated properties, such as local stiffness and densities, are then applied to the meshed geometry. This method was validated through operational modal analysis (OMA) up to 25 kHz using piezo patch transducers [7]. The comparison between simulated and experimental results showed a strong agreement in both mode shapes and natural frequencies of the non-assembled board [7].

3. Conclusion

In conclusion, the advancements in PCB defect classification, quality assurance, design, and layout optimization have significantly improved the reliability and performance of modern electronic systems. The use of algorithms for defect detection, alongside robust testing methods, ensures high-quality PCB manufacturing. Thoughtful design considerations, such as stackup configuration and EMI reduction, are crucial for optimizing PCB performance. Furthermore, innovative approaches to layout optimization, particularly in managing heat dissipation and dynamic behavior, are essential in meeting the growing demands of modern electronics. As the industry continues to evolve, these methodologies will play a crucial role in addressing the challenges of PCB production and design. These advancements underscore the importance of a holistic approach to PCB design and manufacturing, ensuring high-quality, reliable, and efficient electronic systems. Through such a set of methods which maintains the equilibrium of quality and a mass production, the industry of making printed circuit board seems to rise up. In this case, scientists are working on some further issues, such as environmental and sustainability concerns, high cost and high performance trade-offs, complexity and so on. These obstacles still need time to be solved. Once they are solved, the human technology will make progress much faster than before, as PCBs are and will be a vital device in human's daily life. Also, those resistors and capacitors can be embedded directly into the PCB layers, so that they can save the space for more denser connections and more finer lines of circuits.

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