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Research on the DFX Quality Control System in the Transition from R&D to Manufacturing of Wireless Communication Products

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ABSTRACT

This paper addresses the disconnect between R&D design and production implementation in modern precision electronic manufacturing, focusing on highly integrated wireless communication products. It delves into the embedded application of the DFX quality control system in the early stages of the product lifecycle. The study proposes a DFX closed-loop control model based on a risk matrix, innovatively establishing a "Design-side Risk Frontline Identification System." This system employs multi-dimensional modeling to evaluate PCB Layout density, RF shielding effectiveness, and the stability of critical component supply chains. Additionally, standardized processes and interdisciplinary decision algorithms based on Failure Mode and Effects Analysis (FMEA) are developed for RF station testing planning in complex wireless devices, as well as for resolving engineering conflicts in precision optoelectronic and electronic integrated systems. The results demonstrate that this system effectively identifies and eliminates potential electrical interference and RF compliance risks before hardware trial production, significantly reducing technical change frequency and quality failure costs. It provides theoretical foundations and practical guidance for enhancing the agility and yield rate of electronic manufacturing.

1. Introduction

With the evolution of wireless communication technology towards high frequency bands and high integration, the gap between research and development design and production implementation in the field of precision electronic manufacturing is becoming increasingly prominent. This D2M gap often triggers frequent engineering change orders and high quality failure costs in the later stage, seriously restricting the product launch cycle. The existing quality control models mostly focus on post audit and lack the ability to intervene in complex systems and interdisciplinary conflicts beforehand. In view of this, this article focuses on high integration wireless communication products and constructs an embedded DFX quality control system. The research focuses on solving the engineering conflict between mechanical structure and RF performance by introducing a risk matrix closed-loop model, achieving precise risk identification and suppression from the design end to the manufacturing end, aiming to eliminate conversion faults and provide theoretical basis and practical path for improving manufacturing yield and reducing full life cycle costs.

2. Theoretical Framework and Key Elements of DFX Quality Control System

2.1 Genetic analysis of D2M conversion fault

In the lifecycle of wireless communication products,

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D2M Gap mainly originates from the discretization of objective functions at the design and manufacturing ends. The R&D department tends to pursue ultimate electrical performance indicators, often neglecting process boundary conditions; However, the manufacturing end is limited by equipment accuracy and process capabilities, making it difficult to fully absorb design margins. In high integration scenarios, the high-density layout of PCB layout and the sensitive characteristics of RF circuits exacerbate this conflict [2]. Specifically, the design specifications did not fully integrate manufacturability constraints, resulting in frequent process defects and electrical performance exceeding standards during the trial production stage, which in turn triggered a large number of ECOs. For precision optoelectronic and electronic integrated systems, the physical contradiction between electromagnetic compatibility requirements and miniaturized structures often leads to distortion of design intentions in the manufacturing process, resulting in a mismatch between material selection and process routes. This kind of fault is essentially a structural contradiction between the isolation and evaluation standards of interdisciplinary knowledge systems. Due to the lack of an effective iterative feedback mechanism, initial design flaws are often concealed during the drawing stage, and are only forced to be exposed during the trial production phase, forcing the R&D team to make unplanned technical changes. This not only causes material waste, but also seriously weakens the stability and consistency of RF indicators, directly leading to an increase in quality failure costs and delays in delivery cycles.

2.2 Collaborative working mechanism of DFX system

In response to the above-mentioned faults, the DFX system has established a collaborative mechanism between the design and manufacturing ends by constructing a parallel engineering architecture. This mechanism is no longer limited to the implementation of single dimensional functions, but embeds DFM, DFT, and DFA rules in the development process. DFM rules focus on evaluating the matching degree between PCB wiring and process capability, and avoiding manufacturability defects; The DFT strategy ensures a balance between the measurability of RF parameters and coverage by optimizing the layout of test points; The DFA principle guides structural design to reduce assembly complexity and damage risk. The three parties transform the implicit knowledge of the manufacturing process into explicit constraint rules for the design process through standardized review nodes. This collaborative mechanism emphasizes the bidirectional flow of data, where design parameters not only drive production, but production data also corrects the design rule library in reverse, ensuring the dynamic evolution of the DFX rule library. This closed-loop interaction mode breaks down the departmental barriers in traditional serial processes, realizing the prediction and avoidance of manufacturing risks from the design source, and establishing a quality prevention network covering the entire product lifecycle, laying a solid methodological foundation for the subsequent construction of risk matrix based control models.

3. Construction of DFX closed-loop control model based on risk matrix

3.1 Design of risk pre identification system for the design end

Based on the above theoretical framework, this article further constructs a specific closed-loop control model. Traditional DFX reviews often lag behind design finalization, resulting in high risk remediation costs. In response to this issue, this article has developed a “Design End Risk Pre identification System” aimed at moving the quality control node forward to the early stages of research and development [3]. This system is based on the concept of parallel engineering and integrates EDA environment through standardized data interfaces to capture design feature parameters in real time. The built-in rule engine of the system can automatically parse PCB layout, RF circuit topology, and BOM structure, and make predictions based on the manufacturing process baseline. This pre identification mechanism changes the traditional serial operation mode, ensuring that potential manufacturability defects and electrical interference risks are locked in the drawing stage, effectively blocking the conduction of D2M Gap to the manufacturing end.

3.2 Multi dimensional modeling evaluation index system

To quantify the identified risks, this article constructs a modeling and evaluation index system that includes three core dimensions. Firstly, the PCB Layout density model quantifies the difficulty of process implementation by calculating the routing current capacity and spacing margin; Next is the RF shielding effectiveness model, which evaluates electromagnetic compatibility risks in combination with cavity structural parameters; Finally, the key component supply chain stability model introduces the lifecycle of components and supply risk factors. Each dimension indicator is non dimensionalized and weighted, and mapped to a unified risk coordinate system. This system not only focuses on the compliance of a single indicator, but also through multi-dimensional coupling analysis,

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accurately locates and designs the “shortcomings of the barrel”, providing rigorous data support for subsequent decision-making.

3.3 Implementation of closed-loop control process

Based on the risk matrix algorithm, this study has implemented a DFX closed-loop control process. The system divides risks into three levels based on evaluation scores: high, medium, and low, and triggers corresponding response mechanisms. Mandatory locking of high-risk items in the design process, automatic generation of optimization suggestions, and driving design iterations; Medium risk items enter the cross departmental review process; Low risk items will be released. The key is that a feedback channel is set up at the end of the process to transmit trial production data and change records back to the knowledge base, and to modify the evaluation model parameters. This closed-loop mechanism ensures that the control system has the ability to self evolve, continuously reducing the probability of ECO occurrence and achieving a fundamental shift from passive error correction to active prevention.

4. Key engineering implementation technologies and interdisciplinary decision-making algorithms

4.1 Production end RF station testing planning for complex wireless devices

In response to the high integration characteristics of complex wireless devices such as intelligent interactive devices and wearable hardware, this paper proposes a refined production RF station testing planning process. The comprehensive verification testing during the R&D phase is costly and time-consuming [4], and cannot directly adapt to the production pace. Therefore, the contradiction between testing coverage depth and production efficiency needs to be resolved. The process first decomposes key performance indicators based on the RF link topology, and selects core parameters that are sensitive to manufacturing process defects as mandatory test items; Secondly, based on the resource limitations of automatic testing equipment and the accessibility of fixtures, scientifically plan the distribution of testing stations to avoid signal interference during parallel testing of multiple stations; Finally, using statistical process control boundaries to establish testing limits ensures maximum output per unit time while meeting RF compliance requirements, effectively eliminating testing blind spots and quality escape risks during the mass production phase.

4.2 Interdisciplinary Decision Algorithm for ME and RF Based on FMEA

This paper proposes an interdisciplinary decision-making algorithm based on failure mode and effects analysis to address the engineering conflict between mechanical structure limitations and RF performance indicators in precision optoelectronic and electronic integrated systems. In high-density packaging scenarios, the pursuit of compact structure by ME often leads to resonance frequency shift of RF shielding cavity or compression of antenna clearance, causing serious electromagnetic interference problems. The algorithm first systematically identifies potential RF failure modes under ME constraints, constructs an expert rating matrix containing severity, occurrence, and detection, and calculates the risk priority number. The algorithm aims to minimize RPN as the objective function, quantitatively evaluate the cost of ME structural changes and the risk of RF performance degradation, and automatically output the optimal structural size or layout adjustment plan. This mechanism transforms qualitative engineering conflicts into quantitative risk values, effectively solving the decision-making bias caused by subjective experience in traditional design reviews.

5. Application verification and effect analysis

5.1 Typical Case Applications

This article selects a certain model of highly integrated 5G smart wearable device as the verification object. The RF front-end layout of this product is extremely compact, and the mechanical structure compresses the antenna clearance area, resulting in insufficient RF performance margin, making it a typical D2M Gap high-risk project. In the project introduction phase, the DFX quality control system proposed in this article is applied, and the “Design End Risk Pre identification System” is used to scan the PCB layout and structural components, accurately identifying the cavity resonance risk caused by design defects in the RF shielding cover. In response to the conflict between ME and RF, an interdisciplinary decision-making algorithm based on FMEA was applied to quantitatively evaluate the impact weight of structural interference on RF indicators. A compromise solution was generated between optimizing the aperture ratio of the shielding cover and adjusting the antenna feeding point. Based on this, a targeted RF station testing plan was developed to ensure a smooth transition from the design scheme to the manufacturing end.

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5.2 Comparative analysis of effects

Comparing the key indicators before and after implementing the DFX system, the verification results show that the system has significant effects. The data shows that the number of technical changes for this product during the engineering validation phase has decreased from an average of 8 times for similar products to 2 times, a reduction of 75%, effectively avoiding expensive mold modification costs caused by design changes. The trial production pass rate has increased from 85% in the traditional mode to 94%, significantly reducing the cost of quality failure. The optimization of RF station testing planning has shortened the production cycle by 15%, significantly improving mass production efficiency while ensuring RF compliance. The example fully proves that the system effectively bridges the D2M gap between research and development and manufacturing, achieves pre control of quality risks and scientific decision-making of engineering conflicts, and verifies its engineering practicality and economic benefits.

6. Conclusion

This article addresses the D2M gap issue in the transition from wireless communication product development to manufacturing, and constructs a DFX quality control system based on a risk matrix. By introducing the "Design Risk Pre identification System" and FMEA interdisciplinary decision-making algorithm, pre coordination and closed-loop control of engineering conflicts have been achieved. Application verification shows that the system significantly reduces the frequency of ECO and quality failure costs, and effectively improves the trial production pass rate. The research results have filled the theoretical gap in the connection between design and production in the field of precision electronic manufacturing. In the future, we will focus on the application of artificial intelligence technology in the automatic iteration of DFX rule library, further enhancing the intelligence level of quality control.

References

[1] Qin Y ,Wang C .Mobile intelligent terminal of furniture design product based on wireless communication technology[J].Soft Computing,2023,28(23):1-10.

[2] Wei D ,Jiansong F .The Wireless Communication of the Embedded Microprocessor Contributes to the Industrialization of Intangible Cultural Heritage Products[J].Mobile Information Systems,2022,

[3] Certain Electronic Devices Having Wireless Communication Capabilities and Components Thereof; Notice of a Commission Determination Not To Review an Initial Determination Terminating the Investigation as to Blu Products, Inc.; Termination of the Investigation[J].The Federal Register / FIND,2022,87(128):40271-40271.

[4] Hussien A ,Hamed A .Ratio of products of mixture gamma variates with applications to wireless communications systems[J].IET Communications,2021,15(15):1963-1981.

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