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Review paper

# A fusion prognostics-based qualification test methodology for microelectronic products☆

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ABSTRACT

The global market for microelectronic products is projected to reach US$2.4 trillion per year by 2020. This growth has led to intense competition between manufacturers to minimize the time-to-market for their products. Unfortunately, however, qualification testing, which is time-consuming and resource-intensive, is a major bottleneck for the quick release of microelectronic products to the market. Hence, for both researchers and engineers considering the time with reliability issues during qualification testing, this paper provides a review of conventional methodologies in qualification testing and presents a fusion prognostics-based qualification test methodology that combines the advantages of physics-of-failure and data-driven methods.



**Contents**



## 1. Introduction

The objective of qualification testing is to verify whether a product meets or exceeds the reliability and quality requirements of its intended application [1]. Accordingly, inadequate qualification testing can lead to products failing in the field, which can result in significant financial losses. The following examples show the impact of inadequate qualification testing in industry.

Between 1983 and 1995, 22 million Ford vehicles were built with defective microelectronic ignition modules that could cause vehicles to stall while driving [2]. These ignition modules could fail intermittently when engines were hot but would function properly when the engines were cool, without leaving any physical evidence or symptoms of failure. Further, many of intermittent failures in the ignition modules led to high no-fault-found (NFF) rates. Ford initially projected warranty returns of 10 per 100 modules (10%), but instead saw actual field returns of 40%, resulting in large financial losses for Ford. Ford settled

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the lawsuit by agreeing to pay for repairs of defective ignition modules at a cost of approximately US$2.7 billion [2,3].

To produce encapsulant material for microelectronic products, Sumitomo Bakelite began mass production of red-phosphorus-containing epoxy-molding compounds around 1996. The reason why Sumitomo Bakelite selected phosphorus for their mold compounds was due to its superior properties compared to halide flame retardants and other halide replacements. However, although these mold compounds apparently passed the Joint Electron Device Engineering Council (JEDEC) qualification tests, microelectronic products packaged with Sumitomo Bakelite mold compounds began to fail after only a few months in the field. Fairchild semiconductor performed root cause analysis and found large red phosphorus particles between adjacent leads, which could create the potential for conductive paths [4]. Consequently, Sumitomo Bakelite lost hundreds of millions of dollars because of inadequate preliminary qualification testing for their mold compounds.

In July 2008, Nvidia Corporation announced that it would take a US$150 million to US$200 million charge against cost of revenue to cover anticipated customer warranty, repair, return, replacement, and other consequential costs and expenses arising from a weak die/packaging material set in certain versions of multi-chip processor (MCP) and graphics processing unit (GPU) products used in laptop computers [5, 6]. Specifically, certain notebook configurations of these MCP and GPU products failed in the field at higher than normal rates due to a weak material set of die/package combination and system thermal management designs [5], resulting in display problems such as overheating and blue screens.

In 2010, Toyota recalled 1.33 million vehicles because of failures in the engine control microelectronics module, which caused the vehicles to fail to start or to stall while driving [7]. These failures were caused by cracks that developed at certain solder joints or on the electronic products used to protect circuits against excessive voltage on the engine control unit's printed circuit board [8].

In 2012, First Solar, Inc., the largest producer of thin film panels, had to replace 232,000 solar panels due to premature power losses [9]. This resulted in warranty costs of US$164 million, and on August 30, 2012, the company's price per share dropped by 12%.

In 2014, General Motors (GM) announced the recall of over 30 million vehicles due to a problem with a $0.57-part used in its ignition switch [10], which could cause the affected vehicles to shut off while on the road and disable safety systems such as power steering, anti-lock brakes, and air bags. Over 120 deaths have been attributed to this faulty ignition switch [11]. GM has faced many lawsuits, including 100 class action suits in the US and 21 in Canada. Likewise, GM has been penalized US$625 million in compensation to the affected consumers and may also face a US$1.2 billion fine to settle the federal probe associated with the recall [11].

Mazda recalled approximately 5700 of its 2014 Mazda 3 and 2014–15 Mazda 6 model cars due to the power control module (PCM) to incorrectly assume failure of the charging system [12]. This incorrect assumption that the charging system failed resulted in poor acceleration, loss of steering assist and windshield wiper operation, and a possible engine stall, increasing the risk of a crash [13].

Proper qualification testing can avoid unexpected intermittent failures during field use. However, the rapid evolution of microelectronic products has led to intense competition between manufacturers to reduce the time-to-market for their products. Unfortunately, however, qualification testing takes time and is thus a major bottleneck for the early release of products to the market. To address this issue, a promising qualification test approach is introduced.

The remainder of this paper is organized as follows. Section 2 reviews conventional qualification test methodologies using standards-based and physics-of-failure (PoF)-based approaches. Section 3 introduces qualification test approaches using data-driven diagnostic techniques (e.g., machine learning), and Section 4 presents a fusion prognostics-based qualification test methodology that combines the advantages of PoF and data-driven methods. Finally, Section 5 gives conclusions.

## 2. A review of conventional qualification testing methodologies

The continuous evolution of consumer microelectronic products, the multitude of choices for customers, the increased complexity of supply chains, and the increased competition between manufacturers has forced manufacturers to shorten their development cycles. However, this is a challenging endeavor for manufacturers because they must ensure product reliability before mass production of the products [14].

As noted, intermittent product failures (leading to NFF cases) caused by improper qualification testing can result in huge financial losses for the companies involved. In addition to new products, qualification testing is performed for products that have undergone significant design or manufacturing changes, which are defined by JEDEC JESD 46C as changes that have an impact on the form, fit, function, or reliability of products [15]. For example, changes in die structure, packaging materials, or fabrication processes will warrant a product's requalification by the manufacturer.

Traditionally, the following two approaches have been extensively used for qualification testing: standards-based qualification testing and PoF-based (sometimes referred to as knowledge-based or use-condition-based) qualification testing. Standards-based testing is an approach that uses a predefined suite of reliability tests for a product, whereas PoF-based testing is an approach that requires information about failure mechanisms that the product will encounter during its operating life and how it is accelerated during testing. More details about these two test methodologies are given below.

### *2.1. Standards-based qualification testing*

In standards-based qualification testing, if a product survives a certain period of time (or meets a certain predefined pass criterion) per test conditions (e.g., load, cycles, or the like) specified in certain standards, then the product will be considered as having met its intended quality and reliability requirements [16]. More details about standards-based qualification test procedures are given in the JESD 22 series [17] and MIL STD 883 [18], and more information about test plans is given in JEDEC JESD 47H [19] and automotive AEC Q100 [20].

The problem with the standards-based qualification test approach is that it does not provide any assurance that the qualified product will be reliable in the field. This is because no failure mechanism models associated with the tests are employed in standards-based qualification testing, which is in fact considered as an application-independent approach. Additionally, standards-based testing does not even offer much of a baseline for comparison of the products, because the products consisting of different materials, structures, and performance (operational) characteristics will yield different load-life curves.

An example of standards-based qualification testing is given below. International Rectifier qualifies their insulated gate polar transistors (IGBTs) based on the JEDEC JESD 47 standard. For each test, the IGBTs are forced not to fail for a certain period of time, at least 1000 h at 175 °C, which is a requirement to pass the high-temperature reverse bias test [21]. Unfortunately, since each industrial application has its own unique environmental and operating conditions, and lifetime requirements, the test results may not aid in assessing the reliability of products in the field [22,23]. That is, although an IGBT has passed standards-based qualification tests, it may fail prematurely in the field; on the other hand, the IGBT that has failed the aforementioned standards-based qualification tests may be satisfactorily reliable in the field, depending on degradation reactions and field conditions. Hence, some industries (e.g., automotive) are requesting long test times [24], but without adequate failure mechanism models, the usefulness and economic value of the standards-based qualification testing approach remains highly questionable.