10

10 Failure Modes, Mechanisms, and Effects Analysis

This chapter presents a methodology called failure modes, mechanisms, and effects analysis (FMMEA), used to identify potential failures modes, mechanisms, and their effects. FMMEA enhances the value of failure modes and effects analysis (FMEA) and failure modes, effects, and criticality analysis (FMECA) by identifying the "high priority failure mechanisms" to help create an action plan to mitigate their effects. The knowledge about the cause and consequences of mechanisms found through FMMEA helps in efficient and cost-effective product development. The application of FMMEA for an electronic circuit board assembly is described in the chapter.

10.1 Development of FMMEA

The competitive market places demands on manufacturers to look for economic ways to improve the product development process. In particular, the industry has been interested in an efficient approach to understand potential product failures that might affect product performance over time. Some organizations are either using or requiring the use of a technique called FMEA to achieve this goal, but most of these companies are not completely satisfied with this methodology.

FMEA was developed as a formal methodology in the 1950s at Grumman Aircraft Corporation, where it was used to analyze the safety of flight control systems for naval aircrafts. From the 1970s through the 1990s, various military and professional society standards and procedures were written to define and improve the FMEA methodology (Bowles 2003; Guidelines for Failure Mode and Effects Analysis 2003; Kara-Zaitri et al. 1992).

In 1971, the Electronic Industries Association (EIA) G-41 committee on reliability published "Failure Mode and Effects Analysis." In 1974, the U.S. Department of Defense published MIL-STD 1629 "Procedures for Performing a Failure Mode, Effects and Criticality Analysis," which through several revisions became the basic

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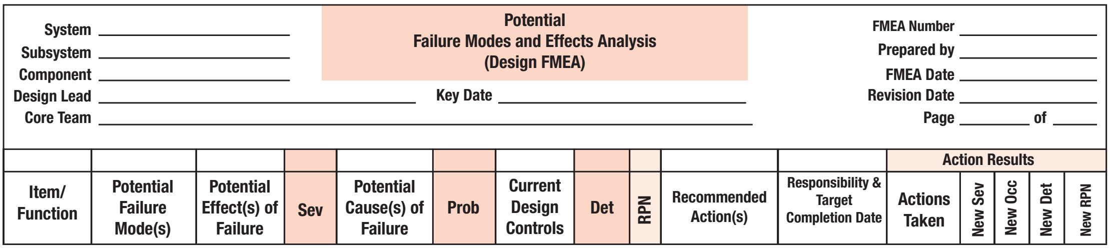
Reliability Engineering, First Edition. Kailash C. Kapur and Michael Pecht.

approach for analyzing systems. In 1985, the International Electrotechnical Commission (IEC) introduced IEC 812 “Analysis Techniques for System Reliability—Procedure for Failure Modes and Effects Analysis.” In the late 1980s, the automotive industry adopted the FMEA practice. In 1993, the Supplier Quality Requirements Task Force comprised of representatives from Chrysler, Ford, and GM, introduced FMEA into the quality manuals through the QS 9000 process. In 1994, the Society of Automotive Engineers (SAE) published SAE J-1739 “Potential Failure Modes and Effects Analysis in Design and Potential Failure Modes and Effects Analysis in Manufacturing and Assembly Processes” reference manual that provided general guidelines in preparing an FMEA. In 1999, Daimler Chrysler, Ford, and GM, as part of the International Automotive Task Force, agreed to recognize the new international standard “ISO/TS 16949” that included FMEA and would eventually replace QS 9000 in 2006.

FMEA is used across many industries as one of the Six Sigma tools. FMEA may be applied to various applications, such as System FMEA, Design FMEA, Process FMEA, Machinery FMEA, Functional FMEA, Interface FMEA, and Detailed FMEA. Although the purpose and terminology can vary according to type and the industry, the principle objectives of the different FMEA processes are to anticipate problems early in the development process and either prevent the problems or minimize their consequences (SAE Standard SAE J1739 2002).

An extension of FMEA, called FMECA was developed to include techniques to assess the probability of occurrence and criticality of potential failure modes. Today, the terms FMEA and FMECA are used interchangeably (Bowles 2003; Bowles and Bonnell 1998). FMEA is also one of the Six Sigma tools (Franceschini and Galetto 2001), and is utilized by the Six Sigma organizations in some form. The FMEA methodology is based on a hierarchical approach to determine how potential failure modes affect a product. This involves inputs from a cross-functional team having the ability to analyze the whole product life cycle. A typical design FMEA worksheet is shown in Figure 10.1.

Failure mechanisms are the processes by which specific combinations of physical, electrical, chemical, and mechanical stresses induce failure (Hu et al. 1993). Neither FMEA nor FMECA identify the failure mechanisms and models in the analysis and reporting process. In order to understand and prevent failures, failure mechanisms must be identified with respect to the predominant stresses (mechanical, thermal, electrical, chemical, and radiation) that precipitate these failures. Understanding the cause and consequences of failure mechanisms aid the design and development of a product, including virtual qualification, accelerated testing, root-cause analysis, and life consumption monitoring.



Potential
Failure Modes and Effects Analysis
(Design FMEA)

System ____________________
Subsystem ____________________
Component ____________________
Design Lead ______________________________
Key Date ____________________
Core Team ____

FMEA Number ______________
Prepared by ______________
FMEA Date ______________
Revision Date ______________
Page ________ of _____

											Action Results				
Item/ Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Sev	Potential Cause(s) of Failure	Prob	Current Design Controls	Det	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	New Sev	New Occ	New Det	New RPN

Figure 10.1 FMEA worksheet (Guidelines for Failure Mode and Effects Analysis 2003).

In virtual qualification, failure models are used to analytically estimate the times to failure distributions for products. Without knowledge of the relevant dominant failure mechanisms and the operating conditions, virtual qualification for a product cannot be meaningful. For accelerated testing design, one needs to know the failure mechanisms that are likely to be relevant in the operating condition. Only with the knowledge of the failure mechanism, one can design appropriate tests (stress levels, physical architecture, and durations) that will precipitate the failures by the relevant mechanism without resulting in spurious failures.

All the root-cause analysis techniques, including cause and effect diagram and fault tree analysis, require that we know how the conditions during an incident may have an impact on the failure. The hypothesis development and verification processes are also affected by the failure mechanisms analysis. Knowledge of failure mechanisms and the stresses that influence these mechanisms is an important issue for life consumption monitoring of a product. The limitations on physical space and interfaces available for data collection and transmission put a limit on the number of sensors that can be implemented in a product in a realistic manner. To make sure that the appropriate data are collected and utilized for the remaining life assessment during health monitoring, the prioritized list of failure mechanisms are essential.

The traditional FMEA and FMECA do not address the key issue of failure mechanisms to analyze failures in products. To overcome this, a FMMEA methodology has been developed. The FMMEA process merges the systematic nature of the FMEA template with the "design for reliability" philosophy and knowledge. In addition to the information gathered and used for FMEA, FMMEA uses application conditions and the duration of the intended application with knowledge of active stresses and potential failure mechanisms. The potential failure mechanisms are considered individually and are assessed using appropriate models for design and qualification of the product for the intended application. The following sections describe the FMMEA methodology in detail.

10.2 Failure Modes, Mechanisms, and Effects Analysis

FMMEA is a systematic approach to identify and prioritize failure mechanisms and models for all potential failures modes. High priority failure mechanisms determine the operational stresses and the environmental and operational parameters that need to be controlled or accounted for in the design.

FMMEA is based on understanding the relationships between product requirements and the physical characteristics of the product (and their variation in the production process), the interactions of product materials with loads (stresses at application conditions), and their influence on product failure susceptibility with respect to the use conditions. This involves finding the failure mechanisms and the reliability models to quantitatively evaluate failure susceptibility. The steps in conducting an FMMEA are illustrated in Figure 10.2. The individual steps are described in greater detail in the following subsections.

10.2.1 System Definition, Elements, and Functions

The FMMEA process begins by defining the system to be analyzed. A system is a composite of subsystems or levels that are integrated to achieve a specific objective.

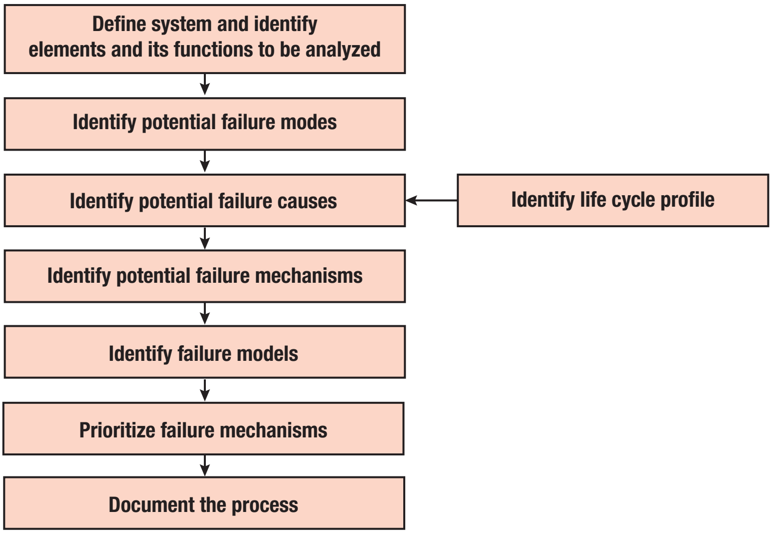


Figure 10.2 FMMEA methodology.

The system is divided into various subsystems or levels. These subsystems may comprise of further divisions or may have multiple parts that make up this subsystem. The parts are "components" that form the basic structure of the product.

Based on convenience or needs of the team conducting the analysis, the system breakdown can be either by function (i.e., according to what the system elements "do"), or by location (i.e., according to where the system elements "are"), or both (i.e., functional within the location based, or vice versa). For example, an automobile is considered a system, a functional breakdown of which would involve the cooling system, braking system, and propulsion system. A location breakdown would involve the engine compartment, passenger compartment, and dashboard or control panel. In a printed circuit board system, a location breakdown would include the package, plated though hole (PTH), metallization, and the board itself. Further analysis is conducted on each element thus identified.

10.2.2 Potential Failure Modes

A failure mode is the effect by which a failure is observed to occur (SAE Standard SAE J1739 2002). It can also be defined as the way in which a component, subsystem, or system could fail to meet or deliver the intended function.

For all the elements that have been identified, all possible failure modes for each given element are listed. For example, in a solder joint, the potential failure modes are open or intermittent change in resistance, which can hamper its functioning as an interconnect. In cases where information on possible failure modes that may occur is not available, potential failure modes may be identified using numerical stress analysis, accelerated tests to failure (e.g., HALT), past experience, and engineering judgment. A potential failure mode may be the cause of a failure mode in a higher level subsystem, or system, or be the effect of one in a lower level component.

10.2.3 Potential Failure Causes

A failure cause is defined as the circumstances during design, manufacture, or use that lead to a failure mode (IEEE Standard 1413.1-2002 2003). For each failure mode, the possible ways a failure can result are listed. Failure causes are identified by finding the basic reason that may lead to a failure during design, manufacturing, storage, transportation, or use condition. Knowledge of potential failure causes can help identify the underlying failure mechanisms driving the failure modes for a given element. For example, consider a failed solder joint of an electronic component on a printed circuit board in an automotive underhood environment. The solder joint failure modes, such as open and intermittent change in resistance, can potentially be caused due to fatigue under conditions such as temperature cycling, random vibration and/or shock impact.

10.2.4 Potential Failure Mechanisms

Failure mechanisms are the processes by which specific combination of physical, electrical, chemical, and mechanical stresses induce failure (Hu et al. 1993). Failure mechanisms are determined based on combination of potential failure mode and cause of failure (JEDEC Publication JEP 148 2004) and selection of appropriate available mechanisms corresponding to the failure mode and cause. Studies on electronic material failure mechanisms, and the application of physics-based damage models to the design of reliable electronic products comprising all relevant wearout and overstress failures in electronics are available in literature (Dasgupta and Pecht 1991; JEDEC Publication JEP 122-B 2003).

Failure mechanisms thus identified are categorized as either overstress or wearout mechanisms. Overstress failures involve a failure that arises as a result of a single load (stress) condition. Wearout failure on the other hand involves a failure that arises as a result of cumulative load (stress) conditions (IEEE Standard 1413.1-2002 2003). For example, in the case of a solder joint, the potential failure mechanisms driving the opens and shorts caused by temperature, vibration, and shock impact are fatigue and overstress shock. Further analyses of the failure mechanisms depend on the type of mechanism.

10.2.5 Failure Models

Failure models use appropriate stress and damage analysis methods to evaluate susceptibility of failure. Failure susceptibility is evaluated by assessing the time-to-failure or likelihood of a failure for a given geometry, material construction, environmental, and operational condition. For example, in case of solder joint fatigue, Dasgupta et al. (1992) and Coffin-Manson (Foucher et al. 2002) failure models are used for stress and damage analysis for temperature cycling.

Failure models of overstress mechanisms use stress analysis to estimate the likelihood of a failure based on a single exposure to a defined stress condition. The simplest formulation for an overstress model is the comparison of an induced stress versus the strength of the material that must sustain that stress. Wearout mechanisms are analyzed using both stress and damage analysis to calculate the time required to induce failure based on a defined stress condition. In the case of wearout failures, damage is accumulated over a period until the item is no longer able to withstand the applied load. Therefore, an appropriate method for combining multiple conditions must be determined for assessing the time to failure. Sometimes, the damage due to the individual loading conditions may be analyzed separately, and the failure assessment results may be combined in a cumulative manner (Guidelines for Failure Mode and Effects Analysis 2003).

Failure models may be limited by the availability and accuracy of models for quantifying the time to failure of the system. It may also be limited by the ability to combine the results of multiple failure models for a single failure site and the ability to combine results of the same model for multiple stress conditions (IEEE Standard 1413.1-2002 2003). If no failure models are available, the appropriate parameter(s) to monitor can be selected based on an empirical model developed from prior field failure data or models derived from accelerated testing.

10.2.6 Life-Cycle Profile

Life-cycle profiles include environmental conditions such as temperature, humidity, pressure, vibration or shock, chemical environments, radiation, contaminants, and loads due to operating conditions, such as current, voltage, and power (Society of Automotive Engineers 1978). The life-cycle environment of a product consists of assembly, storage, handling, and usage conditions of the product, including the severity and duration of these conditions. Information on life-cycle conditions can be used for eliminating failure modes that may not occur under the given application conditions.

In the absence of field data, information on the product usage conditions can be obtained from environmental handbooks or data monitored in similar environments. Ideally, such data should be obtained and processed during actual application. Recorded data from the life-cycle stages for the same or similar products can serve as input towards the FMMEA process. Some organizations collect, record, and publish data in the form of handbooks that provide guidelines for designers and engineers developing products for market sectors of their interest. Such handbooks can provide first approximations for environmental conditions that a product is expected to undergo during operation. These handbooks typically provide an aggregate value of environmental variables and do not cover all the life-cycle conditions. For example, for general automotive applications, life-cycle environment and operating conditions can be obtained from the SAE handbook (Society of Automotive Engineers 1978), but for specific applications more detailed information of the particular application conditions need to be obtained.

10.2.7 Failure Mechanism Prioritization

Ideally, all failure mechanisms and their interactions will be considered for product design and analysis. In the life cycle of a product, several failure mechanisms may be activated by different environmental and operational parameters acting at various stress levels, but only a few operational and environmental parameters, and failure mechanisms are in general responsible for the majority of the failures. High priority mechanisms are those select failure mechanisms that may cause the product to fail earlier than the product's intended life duration. These mechanisms occur during the normal operational and environmental conditions of the products application. High priority failure mechanisms provide effective utilization of resources and are identified

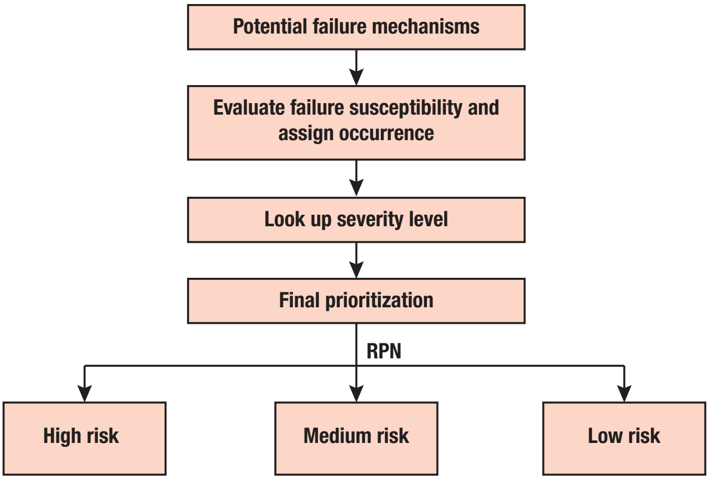


Figure 10.3 Failure mechanism prioritization.

through prioritization of all the potential failure mechanisms. The methodology for failure mechanism prioritization is shown in Figure 10.3.

Environmental and operating conditions are set up for initial prioritization of all potential failure mechanisms. If the load levels generated by certain operational and environmental conditions are nonexistent or negligible, the failure mechanisms that are exclusively dependent on those environmental and operating conditions are assigned a "low" risk level and are eliminated from further consideration.

For all the failure mechanisms remaining after the initial prioritization, the susceptibility to failure by those mechanisms is evaluated using the previously identified failure models when such models are available. For the overstress mechanisms, failure susceptibility is evaluated by conducting a stress analysis to determine if failure is precipitated under the given environmental and operating conditions. For the wearout mechanisms, failure susceptibility is evaluated by determining the time-to-failure under the given environmental and operating conditions. To determine the combined effect of all wearout failures, the overall time-to-failure is also evaluated with all wearout mechanisms acting simultaneously. In cases where no failure models are available, the evaluation is based on past experience, manufacturer data, or handbooks.

After evaluation of failure susceptibility, occurrence ratings under environmental and operating conditions applicable to the system are assigned to the failure mechanisms. For the overstress failure mechanisms that precipitate failure, the highest occurrence rating ,"frequent," is assigned. In case no overstress failures are precipitated, the lowest occurrence rating, "extremely unlikely," is assigned. For the wearout failure mechanisms, the ratings are assigned based on benchmarking the individual time-to-failure for a given wearout mechanism, with overall time-to-failure, expected product life, past experience and engineering judgment. Table 10.1 shows the occurrence ratings.

A "frequent" occurrence rating involves failure mechanisms with very low time-to-failure (TTF) and overstress failures that are almost inevitable in the use condition. A "reasonably probable" rating involves cases that involve failure mechanisms with low TTF. An "occasional" involves failures with moderate TTF. A "remote" rating

Table 10.1 Occurrence ratings

Rating	Criteria
Frequent	Overstress failure or very low TTF
Reasonably probable	Low TTF
Occasional	Moderate TTF
Remote	High TTF
Extremely unlikely	No overstress failure or very high TTF

Table 10.2 Severity ratings

Rating	Criteria
Very high or catastrophic	System failure or safety-related catastrophic failures
High	Loss of function
Moderate or significant	Gradual performance degradation
Low or minor	System operable at reduced performance
Very low or none	Minor nuisance

involves failure mechanisms that have a high TTF. An extremely unlikely rating is assigned to failures with very high TTF or overstress failure mechanisms that do not produce any failure.

To provide a qualitative measure of the failure effect, each failure mechanism is assigned a severity rating. The failure effect is assessed first at the level being analyzed, then the next higher level, the subsystem level, and so on to the system level (SAE Standard SAE J1739 2002). Safety issues and impact of a failure mechanism on the end system are used as the primary criterion for assigning the severity ratings. In the severity rating, possible worst case consequence is assumed for the failure mechanism being analyzed. Past experience and engineering judgment may also be used in assigning severity ratings. The severity ratings shown in Table 10.2 are defined later in the chapter.

A “very high or catastrophic” severity rating indicates that there may be loss of life of the user or un-repairable damage to the product. A “high” severity rating indicates that failure might cause a severe injury to the user or a loss of function of the product. A “moderate or significant” rating indicates that the failure may cause minor injury to the user or show gradual degradation in performance over time through loss of availability. A “low or minor” rating indicates that failure may not cause any injury to the user or result in the product operating at reduced performance. A “very low or none” rating does not cause any injury and has no impact on the product or at the best may be a minor nuisance.

The final prioritization step involves classification of the failure mechanisms into three risk levels. This can be achieved by using the risk matrix as shown in Table 10.3. The classifications may vary based on the product type, use condition, and business objectives of the user/manufacturer.

10.2.8 Documentation

The FMMEA process involves documentation. FMMEA documentation includes the actions considered and taken based on the FMMEA. For products already

Table 10.3 Risk matrix

		Occurrence				
		Frequent	**Reasonably probable**	**Occasional**	**Remote**	**Extremely unlikely**
Severity	Very high or catastrophic	High risk	High risk	High risk	High risk	Moderate risk
	High	High risk	High risk	High risk	Moderate risk	Low risk
	Moderate or significant	High risk	High risk	Moderate risk	Low risk	Low risk
	Low or minor	High risk	Moderate risk	Low risk	Low risk	Low risk
	Very low or none	Moderate risk	Low risk	Low risk	Low risk	Low risk

manufactured, documentation may exist in the form of records of root-cause analysis conducted for the failures that occur during product development and testing. The history and lessons learned contained within the documentation provide a framework for future product FMMEA. It is also necessary to maintain and update documentation about the FMMEA after the corrective actions so as to generate a new list of high priority failure mechanisms for future analysis.

10.3 Case Study

A simple printed circuit board (PCB) assembly used in an automotive application was selected to demonstrate the FMMEA process. The PCB assembly was mounted at all four corners in the engine compartment of a 1997 Toyota 4Runner. The assembly consisted of an FR-4 PCB with copper metallizations, plated through-hole (PTH) and eight surface mount inductors soldered into the pads using 63Sn-37Pb solder. The inductors were connected to the PTH through the PCB metallization. The PTHs were solder filled and an event detector circuit was connected in series with all the inductors through the PTHs to assess failure. Assembly failure was defined as one that would result in breakdown, or no current passage in the event detector circuit.

For all the elements listed, the corresponding functions and the potential failure modes were identified. Table 10.4 lists the physical location of all possible failure modes for the elements. For example, for the solder joint, the potential failure modes are open and intermittent change in resistance.

For sake of simplicity and demonstration purposes, it was assumed that the test setup, the board, and its components were defect free. This assumption can be valid if proper screening was conducted after manufacture. In addition, it must be assumed that there was no damage to the assembly after manufacture. Potential failure causes were then identified for the failure modes and are shown in Table 10.4. For example, for the solder joint, the potential failure causes for open and intermittent change in resistance are temperature cycling, random vibration, or sudden shock impact caused by vehicle collision.

Based on the potential failure causes that were assigned to the failure modes, the corresponding failure mechanisms were identified. Table 10.4 lists the failure mechanisms for the failure causes that were identified. For example, for the open and

Table 10.4 FMMEA worksheet for the case study

Element	Potential failure mode	Potential failure cause	Potential failure mechanism	Mechanism type	Failure model	Failure susceptibility	Occurrence	Severity	Risk
PTH	Electrical open in PTH	Temperature cycling	Fatigue	Wearout	CALCE PTH barrel thermal fatigue (Bhandarkar et al. 1992)	>10 years	Remote	Very low	Low
Metallization	Electrical short/open, change in resistance in the metallization traces	High temperature	Electromigration	Wearout	Black (1983)	>10 years	Remote	Very high	Moderate
		High relative humidity	Corrosion	Wearout	Howard (1981)	>10 years	Remote	Very high	Moderate
		Ionic contamination		Wearout					
Component (Inductors)	Short/open between windings and the core	High temperature	Wearout of winding insulation	Wearout	No Model		Remote[a]	Very high	Moderate
Interconnect	Open/intermittent change in electrical resistance	Temperature cycling	Fatigue	Wearout	Coffin–Manson (Foucher et al. 2002)	170 days	Frequent	Very high	**High**
		Random vibration		Wearout	Steinberg (1988)	43 days	Frequent	Very high	**High**
		Sudden impact	Shock	Overstress	Steinberg (1988)	No failure	Extremely unlikely	Very high	Moderate

PCB	Electrical short between PTHs	High relative humidity	CFF	Wearout	Rudra and Pecht (Rudra et al. 1995)	4.6 years	Occasional	Very low	Low
	Crack / Fracture	Random vibration	Fatigue	Wearout	Basquin (Steinberg 1988)	$>$10 years	Remote	Very high	Moderate
		Sudden impact	Shock	Overstress	Steinberg (1988)	No failure	Extremely unlikely	Very high	Moderate
	Loss of polymer strength	High temperature	Glass transition	Overstress	No model	No failure	Extremely unlikely	Very high	Moderate
	Open	Discharge of high voltage through dielectric material	EOS/ESD	Overstress	No model	Eliminated in first level prioritization			Low
	Excessive noise	Proximity to high current or magnetic source	EMI	Overstress	No model	Eliminated in first level prioritization			Low
Pad	Lift /crack	Temperature cycling/ random vibration	Fatigue	Wearout	No model		Remote	Very high	Moderate
		Sudden impact	Shock	Overstress			Extremely unlikely	Very high	Moderate

[a] Based on failure rate data of inductors in Telcordia (Telcordia Technologies 2001).

intermittent change in resistance in solder joint, the mechanisms driving the failure were solder joint fatigue and fracture.

For each of the failure mechanisms listed, the appropriate failure models were then identified from the literature. Information about product dimensions and geometry were obtained from design specification, board layout drawing, and component manufacturer datasheets. Table 10.4 provides all the failure models for the failure mechanisms that were listed. For example, in case of solder joint fatigue, a Coffin-Manson (Steinberg 1988) failure model was used for stress and damage analysis for temperature cycling.

The assembly was powered by a 3-V battery source independent of the automobile electrical system. There were no high current, voltage, magnetic, or radiation sources that were identified to have an effect on the assembly. For the temperature, vibration, and humidity conditions prevalent in the automotive underhood environment, data were obtained first from the Society of Automotive Engineers (SAE) environmental handbook (Society of Automotive Engineers 1978) as no manufacturer field data were available for the automotive underhood environment for the Washington, DC area. The maximum temperature in the automotive underhood environment was listed as 121°C (Society of Automotive Engineers 1978). The car was assumed to operate on average 3 hours per day in two equal trips in the Washington, DC area. The maximum shock level was assumed to be 45G for 3ms. The maximum relative humidity in the underhood environment was 98% at 38°C (Society of Automotive Engineers 1978). The average daily maximum and minimum temperature in the Washington DC area for the period the study was conducted were 27°C and 16°C, respectively.

After all potential failure modes, causes, mechanisms, and models were identified for each element; an initial prioritization was made based on the life-cycle environmental and operating conditions. In automotive underhood environment for the given test setup, failures driven by electrical overstress (EOS) and electrostatic discharge (ESD) were ruled out because of the absence of active devices, and the low voltage source of the batteries. Electromagnetic interference (EMI) was also not anticipated because the circuit function was not susceptible to transients. Hence, EOS, ESD, and EMI were each assigned a “low” risk level.

The time to failure for the wearout failure mechanisms was calculated using calcePWA.[1] Occurrence ratings were assigned based on comparing the time-to-failure for a given wearout mechanism with the overall time-to-failure with all wearout mechanisms acting together. For the inductors, the occurrence rating was assigned based on failure rate data obtained from Telcordia (Telcordia Technologies 2001). From prior knowledge regarding wearout associated with the pads, it was assigned a “remote” occurrence rating.

An assessment of a shock level of 45G for 3 ms using calcePWA produced no failure for interconnects and the board. Hence it was assigned an “extremely unlikely” occurrence rating. Since no overstress shock failure was expected on the board and the interconnects, it was assumed there would also be no failure on the pads. Hence overstress shock failure on pads was also assigned an “extremely unlikely” rating. The glass transition temperature for the board was 150°C. Since the maximum temperature in the underhood environment was only 121°C (Society of Automotive Engineers

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[1] A physics-of-failure-based virtual reliability assessment tool developed by CALCE, University of Maryland.

1978), no glass transition was expected to occur, and it was assigned an "extremely unlikely" rating.

A short or open PTH would not have had any impact on the functioning of circuit, as it was used only as terminations for the inductors. Hence, it was assigned a "very low" severity rating. For all other elements, any given failure mode of the element would have led to the disruption in the functioning of circuit. Hence, all other elements were assigned a "very high" severity rating.

Final prioritization and risk assessment for the failure mechanisms is shown in Table 10.4. Out of all the failure mechanisms that were analyzed, fatigue due to thermal cycling and vibration at the solder joint interconnect were the only failure mechanisms that had a high risk. Being a high risk failure mechanism, they were identified as high priority.

An FMEA on the assembly would have identified all the elements, their functions, potential failure modes, and failure causes as in FMMEA. FMEA would then have identified the effect of failure for each failure mode. For example, in the case of a solder joint interconnect, the failure effect of the open joint would have involved no current passage in the test set up. Next, the FMEA would have identified the severity, occurrence, and detection probabilities associated with each failure mode. For example, in case of a solder joint open failure mode, based on past experience and use of engineering judgment, each of the metrics, severity, occurrence and detection would have received a rating on a scale of ten. The product of severity, occurrence, and detection would then have been used to calculate RPN. The RPNs for other failure modes would have been calculated in a similar manner, and then all the failure modes would have been prioritized based on the RPN values. This is unlike FMMEA, which used failure mechanisms and models and used the combined effect of all failure mechanism to quantitatively evaluate the occurrence. The occurrence rating in conjunction with severity was then used to assign a risk level to each failure mechanisms for prioritization.

10.4 Summary

FMMEA allows the design team to take into account the available scientific knowledge of failure mechanisms and merge them with the systematic features of the FMEA template with the intent of "design for reliability" philosophy and knowledge. The idea of prioritization embedded in the FMEA process is also utilized in FMMEA to identify the mechanisms that are likely to cause failures during the product life cycle.

FMMEA differs from FMEA in a few respects. In FMEA, potential failure modes are examined individually and the combined effects of coexisting failures causes are not considered. FMMEA, on the other hand, considers the impact of failure mechanisms acting simultaneously. FMEA involves precipitation and detection of failure for updating and calculating the RPN, and cannot be applied in cases that involve a continuous monitoring of performance degradation over time. FMMEA on the contrary does not require the failure to be precipitated and detected, and the uncertainties associated with the detection estimation are not present. The use of environmental and operating conditions is not made at a quantitative level in FMEA. At best, they are used to eliminate certain failure modes. FMMEA prioritizes the failure mechanisms using the information on stress levels of environmental and operating conditions to identify high priority mechanisms that must be accounted for in the design or be controlled. This prioritization in FMMEA overcomes the shortcomings of RPN prioritization used in FMEA, which provide a false sense of granularity. Thus, the use of FMMEA provides additional quantitative information regarding product reliability and opportunities for improvement than FMEA, as it takes into account specific failure mechanisms and the stress levels of environmental and operating conditions into the analysis process.

There are several benefits to organizations that use FMMEA. It provides specific information on stress conditions so that that the acceptance and qualification tests yield useable result. Use of the failure models at the development stage of a product also allows for appropriate "what-if" analysis on proposed technology upgrades. FMMEA can also be used to aid several design and development steps considered to be the best practices, which can only be performed or enhanced by the utilization of the knowledge of failure mechanisms and models. These steps include virtual qualification, accelerated testing, root-cause analysis, life consumption monitoring, and prognostics. All the technological and economic benefits provided by these practices are realized better through the adoption of FMMEA.

Problems

10.1 How are failure mechanisms identified? Explain with realistic examples.

10.2 What are the differences between overstress mechanisms and wearout mechanisms?

10.3 Give an example of the life-cycle profile for an electronic product.

10.4 The steps in FMMEA are listed in random order.

- Prioritize failure mechanisms.
- Define system and identify elements and functions to be analyzed.
- Identify failure models.
- Identify potential failure modes.
- Identify potential failure causes.
- Identify life-cycle profile.
- Identify potential failure mechanisms.

(a) Arrange the steps listed in their proper order.

(b) Suggest another step that could be added to this list to make the process more useful. Explain and provide a realistic example.