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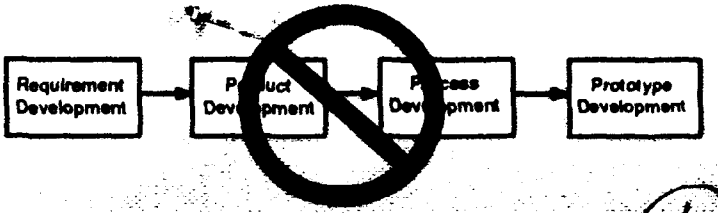

CRTA-FMECA

(1)

Failure Mode, Effects, and Criticality Analysis (FMECA)

FMEA

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Failure Mode, Effects and Criticality Analysis (FMECA)

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Prepared by:

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Reliability Analysis Center

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The Failure Mode, Effects and Criticality Analysis (FMECA) is a reliability evaluation/design technique which examines the potential failure modes within a system and its equipment, in order to determine the effects on equipment and system performance. Each potential failure mode is classified according to its impact on mission success and personnel/equipment safety. This document describes in detail, the approaches contained in MIL-STD-1629.

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1.0 INTRODUCTION

The Failure Mode, Effects and Criticality Analysis (FMECA) is a reliability evaluation/design technique which examines the potential failure modes within a system and its equipment, in order to determine the effects on equipment and system performance. Each potential failure mode is classified according to its impact on mission success and personnel/equipment safety. The FMECA is composed of two separate analyses, the Failure Mode and Effects Analysis (FMEA) and the Criticality Analysis (CA). The FMECA:

- Determines the effects of each failure mode on system performance
- Provides data for developing fault tree analysis and reliability block diagram models
- Provides a basis for identifying root failure causes and developing corrective actions
- Facilitates investigation of design alternatives to consider high reliability at the conceptual stages of the design
- Aids in developing test methods and troubleshooting techniques
- Provides a foundation for qualitative reliability, maintainability, safety and logistics analyses

The results of the FMECA:

- Highlight single point failures requiring corrective action
- Rank each failure according to the severity classification of the failure effect on mission success and personnel/equipment safety
- Provide estimates of system critical failure rates
- Provide a quantitative ranking of system and/or subsystem failure modes
- Identify reliability/safety critical components

1.1 FMECA Benefits

The FMECA facilitates identification of potential design reliability problem areas which must be eliminated or their effect minimized, by design modification or tradeoffs. Specific defects identified can include:

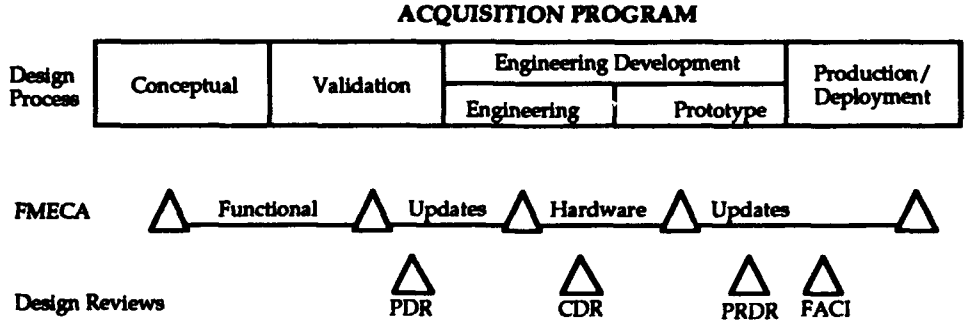
- Circuit failures that may cause the failure of a related critical circuit
- Areas where fail safe or fail soft features are required
- Primary failures which may cause costly secondary failures

Information and knowledge gained by performing the FMECA can also be used as a basis for trouble shooting activities, maintenance manual development and design of effective built-in test techniques.

The FMECA provides valuable information for maintainability, safety and logistic analysis.

1.2 FMECA Characteristics

The FMECA should be scheduled and completed concurrently as an integral part of the design process. This analysis should begin early in the conceptual phase of a design, when the design criteria, mission requirements and performance parameters are being developed. To be effective, the final design should reflect and incorporate the analysis results and recommendations. The following diagram depicts how the FMECA process should coincide with a typical acquisition program.



PDR - Preliminary Design Review
CDR - Critical Design Review
PRDR - Preproduction Design Review
FACI - First Article Configuration Inspection

The results of both the functional and hardware FMECA's must be presented at each of the design reviews. The design reviews then serve as a forum to modify, correct, or update the system design.

Since the FMECA is used to support maintainability, safety and logistics analyses, it is important to coordinate the analysis to prevent duplication of effort within the same program. FMECA is an iterative process. As the design becomes mature, the FMECA must reflect the additional detail. When changes are made to the design, FMECA must be performed on the redesigned sections. This ensures that the potential failure modes of the revised hardware will be addressed. If the FMECA is performed correctly, it becomes an important tool for making program decisions regarding trade-offs affecting design integrity.

The FMECA can be performed by a cognizant design engineer, reliability engineer, independent evaluator, or combination of the above, having a thorough understanding of the operation and application of the system being analyzed. The analysts then feed back appropriate data gained from the FMECA into the design process to drive effective and timely corrective action implementation.

1.3 FMECA Guidelines

A number of government standards require the performance of a FMEA or FMECA. These include:

MIL-STD-785, "Reliability Program for Systems and Equipment Development and Production," This standard imposes the requirement to perform Task 204, "Failure Mode, Effects and Criticality Analysis." It gives guidance as to when the task is to be performed and to what depth it should be done. It does not dictate how the analysis is to be performed.

MIL-STD-1543, "Reliability Program Requirements for Space and Launch Vehicles," This document is similar in many respects to MIL-STD-785. It also imposes the requirement to perform Task 204, "Failure Mode, Effects and Criticality Analysis." It gives guidance as to when the task is to be performed and to what depth it should be done but does not dictate how the analysis is to be performed.

NASA NHB 5300.4, "Reliability Program Provisions for Aeronautical and Space Contractors," This document is similar in some respects to MIL-STD-785. It imposes the requirement to perform an FMECA and gives guidance as to when the task is to be performed and to what depth it should be done but it does not dictate how the analysis is to be performed.

There are many published papers, especially those found in the Annual Reliability and Maintainability Symposium Proceedings, suggesting various unique approaches to FMECA. A comprehensive bibliographic listing of such papers may be found in Appendix B. The vast majority of FMEAs and FMECAs performed today are generally performed in accordance with MIL-STD-1629, "Procedure for Performing a Failure Mode, Effects and Criticality Analysis." Nevertheless, there are currently two other generally recognized FMEA/FMECA guideline documents which may be of interest to the reader. They are:

1) **IEEE Std 352-1975/ANSI N411.4 1976, "IEEE Guide for General Principles of Reliability Analysis of Nuclear Power Generating Station Protection Systems,"** provides a detailed example of an FMEA is given in Section 8 of this document.

2) **SAE G-11, "Reliability, Maintainability and Supportability Guidebook,"** closely parallels the techniques found in MIL-STD-1629.

1.4 Scope

The procedures called out in MIL-STD-1629A are the most widely accepted methods throughout the military and commercial industry. The primary objective of this document is to educate the reader on the analytical techniques and guidelines for performing a FMECA according to the methods described in MIL-STD-1629. These guidelines may be tailored to meet specific customer needs.

2.0 BACKGROUND AND DEFINITION

The FMECA was originally developed by the National Aeronautics and Space Administration (NASA) to improve and verify the reliability of space program hardware. MIL-STD-785, entitled "Reliability Program for System and Equipment Development and Production," Task 204, Failure Mode, Effects and Criticality Analysis calls out the procedures for performing a FMECA on equipment or systems. MIL-STD-1629 is the military standard that establishes requirements and procedures for performing a FMECA, to evaluate and document, by failure mode analysis, the potential impact of each functional or hardware failure on mission success, personnel and system safety, maintainability and system performance. Each potential failure is ranked by the severity of its effect so that corrective actions may be taken to eliminate or control design risk. High risk items are those items whose failure would jeopardize the mission or endanger personnel. The techniques presented in this standard may be applied to any electronic or mechanical equipment or system. MIL-STD-1629 is applicable during the development phases of all DoD systems and equipment as well as commercial and industrial products.

2.1 Definition of FMECA Terms

The following list describes important terms often used in FMECA.

Compensating Provision: Actions available or that can be taken to negate or reduce the effect of a failure on a system.

Corrective Action: A documented design, process or procedure change used to eliminate the cause of a failure or design deficiency.

Criticality: A relative measure of the consequences of a failure mode and the frequency of its occurrence.

Criticality Analysis (CA): A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence.

Damage Effects: The results or consequences a damage mode has upon system operation, or function.

Damage Mode: The way by which damage occurs and is observed.

Damage Mode and Effects Analysis: The analysis of a system or equipment to determine the extent of damage sustained from given levels of weapon damage mechanisms and the effects of such damage on the continued operation and mission of the specified system or equipment.

Detection Method: The method by which a failure can be discovered by the system operator under normal system operation or by a maintenance crew carrying out a specific diagnostic action.

End Effect: The consequence a failure mode has upon the operation, function or status at the highest indenture level.

Failure Cause: The physical or chemical processes, design defects, quality defects, part misapplication or other processes which are the basic reason for failure or which can initiate the physical process by which deterioration proceeds to failure.

Failure Effect: The consequence a failure mode has upon the operation, function or status of a system or equipment.

Failure Mode: The way in which a failure is observed, describes the way the failure occurs, and its impact on equipment operation.

Fault Isolation: The process of determining the location of a fault to the indenture level necessary to effect repair.

Indenture Levels: The levels which identify or describe the relative complexity of an assembly or function.

Local Effect: The consequence a failure mode has on the operation, function or status of the specific item being analyzed.

Maintainability Information: A procedure by which each potential failure mode in a system is analyzed to determine how the failure is detected and what actions will be needed to repair the failure.

Mission Phase Operational Mode: The statement of the mission phase and mode of operation of the system or equipment in which the failure occurs.

Next Higher Level Effect: The consequence a failure mode has on the operation, functions, or status of the items in the next higher indenture level above the specific item being analyzed.

Primary Damage Effects: The results or consequences a damage mode has directly on a system or the components of the system.

Redundancy: The existence of more than one means for accomplishing a given function.

Secondary Effects: The results or consequences indirectly caused by the interaction of a damage mode with a system, subsystem or component of the system.

Severity: Considers the worst possible consequence of a failure classified by the degree of injury, property damage, system damage and mission loss that could occur.

Single Point Failure: The failure of an item which can result in the failure of the system and is not compensated for by redundancy or alternative operational procedure

2.2 MIL-STD-1629 Tasks

MIL-STD-1629 is comprised of five major procedural tasks, Tasks 101-105.

Task 101 documents the procedure for performing the Failure Mode and Effects Analysis (FMEA). The purpose of the FMEA is to identify the results, or effects, of an item's failure on system operation and to classify each potential failure according to its severity. The FMEA provides quick visibility of obvious failure modes and identifies potential single failure points which can be eliminated or minimized with redesign. The procedure for completing the FMEA is as follows:

- Define system/functional requirements and modes of operation
- Develop reliability models (block diagrams) for each functional mode
- Define item parameters/functions required for success
- Define item failure mode effects on higher levels

Task 102 documents the procedure for performing the Criticality Analysis (CA). The purpose of the criticality analysis is to rank each potential failure mode identified in the FMEA Task 101, according to the combined influence of severity classification and its probability of occurrence. The criticality analysis supplements the FMEA and should therefore not be performed without first completing a FMEA.

Since the numbers derived during the CA are established subjectively, they should only be used as indicators of relative severity.

Task 103 documents the procedure for performing the FMECA-Maintainability Analysis. The FMECA-Maintainability Analysis supplies early criteria for Maintenance Planning Analysis (MPA), Logistic Support Analysis (LSA) and identifies maintainability design features that require corrective action. The FMECA-Maintainability Analysis is dependent upon data presented in the FMEA and should therefore not be performed without first completing a FMEA.

Task 104 documents the procedure for performing a Damage Mode and Effects Analysis (DMEA). The purpose of the Damage Mode and Effects Analysis is to provide early criteria for survivability and vulnerability assessments. The DMEA provides data related to damage caused by a specific threat mechanism upon system operation and mission essential functions.

Task 105 documents the procedure for developing a FMECA plan. The purpose of the FMECA plan is to document a contractor's planned activities while implementing the FMECA. The FMECA plan should include the description of the contractor's procedures for completing the assigned tasks as well as the following:

- Worksheet formats
- Ground rules and assumptions
- System description
- Mission phase
- Identification of indenture levels
- Failure definitions/distributions
- Mission time
- Mechanism for feeding FMECA results back into the design process

3.0 FMEA ANALYSIS TECHNIQUES

The FMEA can be implemented using a hardware or functional approach. Often, due to system complexity, the FMEA will be performed as a combination of the two types. The complexity of each design, its state of development and the data available, will dictate the analysis approach that should be used. Each analysis can begin at any level of indenture and progress in an upward fashion.

3.1 Hardware Approach

This approach lists individual hardware items and analyzes their possible failure modes. This approach is used when hardware items can be uniquely identified from the design schematics and other engineering data. The hardware approach is normally used in a bottom-up manner. Analysis begins at the lowest indenture level and continues upward through each successive higher indenture level of the system. The hardware approach should be used after the design process has delivered a schematic diagram, mechanical drawing or blueprint with each part and item defined. This type of analysis is usually the final FMEA for the design. To perform a hardware FMEA the analyst will need:

- Complete theory or knowledge of the system
- Reliability Block Diagrams/Functional Block Diagrams
- Schematics
- Bill of Materials/Parts list
- Definitions for indenture levels

The analyst must identify each part under analysis and record its identification number in an FMEA worksheet. A sample FMEA worksheet is presented in Figure 1. The failure mode and effects analysis will be completed by identifying the potential failure mode and cause of failure of each hardware item in the system.

The effects of each failure mode are then determined by propagating that failure through each level of indenture (local, next higher assembly and system level). The failure detection and isolation method and compensating provisions are then recorded. After each functional block at the system level has been analyzed, outputs can be produced.

SYSTEM_____ DATE_____

PART NAME_____ SHEET_____ OF_____

REFERENCE DRAWING_____ COMPILED BY_____

MISSION _____ APPROVED BY_____

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				

FIGURE 1: FMEA WORKSHEET (TASK 101)

The information obtained from the hardware FMEA output must include a list of hazard risks to be eliminated or reduced, a list of critical single point failures and a list of failures which are not detectable by visual inspection or built-in-test techniques.

3.2 Functional Approach

This approach considers the function of each item. Each function can be classified and described in terms of having any number of associated output failure modes. The functional approach is used when hardware items cannot be uniquely identified. The functional method should be employed when the design process has developed a functional block diagram of the system, but has not yet identified specific hardware to be used. This method is utilized early in the design process and should be updated as the design matures or corrective actions are taken. To perform a functional FMEA the analyst will need:

- System definition and functional breakdown
- Block diagrams of the system
- Theory of operation
- Ground rules and assumptions
- Software specifications

The analyst performing a functional FMEA must be able to define and identify each system function and its associated failure modes for each functional output. The failure mode and effects analysis is completed by determining the potential failure modes and failure causes of each system function. The failure mode probability and modal failure rate can then be approximated if a criticality analysis is necessary. The failure mode probability is the percentage of time (expressed in decimal format) that the function will fail in a given mode. The modal failure rate is defined as the functional failure rate (in failures per million hours) multiplied by the probability that the failure mode will occur.

The effects of each functional failure mode are then determined by propagating the effect of the failure through each higher level of indenture. The failure detection and isolation method and compensating provisions are then recorded. After each functional block of the system level of indenture has been analyzed,

outputs can be produced. All information is recorded on a FMEA worksheet (Figure 1).

The information derived from the functional FMEA output must include a list of hazard risks to be eliminated or reduced, a list of critical single point failures and list of undetectable failures.

3.3 FMEA Tailoring

The complexity or application of many systems may require a combination of hardware/functional analysis. The FMEA may be tailored to address any type of system at any stage of development.

Such tailoring can include, changes in the type of analysis, level of analysis (card, system, card output, assemblies), and method used to perform the analysis. An immature system may consist of partially designed subassemblies, completed subassemblies, or conceptual designs. In the case of conceptual and partially designed subassemblies, card outputs can be analyzed using the functional approach. The completed subassembly can be analyzed using the hardware approach down to the component level.

4.0 CRITICALITY ANALYSIS (CA)

The criticality analysis (CA), like the FMEA, is performed concurrently as part of the system design process. The CA begins as an integral part of the early design process and is updated as the design evolves. The CA produces a relative measure of significance of the effect a failure mode has on the successful operation and safety of the system. The CA is completed after the local, next higher level and end effects of a failure have been evaluated in the FMEA. When the FMEA is combined with the CA, the analysis is called the Failure Mode, Effects and Criticality Analysis. The calculation of criticality numbers is accomplished by completing a CA worksheet (See Figure 2).

The CA worksheet must be traceable to the FMEA worksheet at the same indenture level. Information developed for the FMEA such as identification numbers, item function, failure modes and causes, mission phase and severity classification are directly transferred to the CA worksheets.

To perform a quantitative criticality analysis, it is necessary to have the completed FMEA as well as information on the system such as system mission, definition of failures, severity categories and part failure rate information. Alpha and Beta values representing failure mode ratio and failure effect probability respectively, are also entered on the CA worksheet in a quantitative criticality analysis.

Alpha represents the probability, expressed as a decimal fraction, that the given part or item will fail in the identified mode. Beta represents the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs.

The CA can be completed using either a qualitative or quantitative approach. The level of availability of part configuration and failure rate data will determine the analysis approach to be used. The qualitative approach is used when specific part or item failure rates are not available. The quantitative approach is used when there is sufficient failure rate data available to calculate item criticality numbers.

SYSTEM_____ DATE_____

PART NAME_____ SHEET_____ OF_____

REFERENCE DRAWING_____ COMPILED BY_____

MISSION_____ APPROVED BY_____

Identification Number	Item/ Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda_p t$	Item CRIT # $C_r = \Sigma (C_m)$	Remarks

FIGURE 2: CRITICALITY ANALYSIS WORKSHEET (TASK 102)

4.1 Qualitative Approach

The FMEA identifies failure modes in terms of probability of occurrence levels when failure rate data is not available. Therefore, failure mode ratio and failure mode probability are not used in this type of analysis. The probability of occurrence of each failure is grouped into discrete levels. An example is given below (Items A-E). These values are based on the analyst's judgment of how often the failure mode will occur. These levels establish the qualitative failure probability level for entry into the CA worksheet format. The failure mode probability of occurrence levels (frequency) are defined as:

A) **Level A - Frequent:** A high probability of occurrence during the item operating time interval. High probability may be defined as a single failure mode probability greater than .20 of the overall probability of failure during the item operating time interval.

B) **Level B - Reasonably Probable:** A moderate probability of occurrence during the item operating time interval. Probability may be defined as a single failure mode probability of occurrence which is more than .1 but less than .20 of the overall probability of failure during the item operating time interval.

C) **Level C - Occasional:** An occasional probability of occurrence during the item operating time interval. Occasional probability may be defined as a single failure mode probability of occurrence which is more than .01 but less than .1 of the overall probability of failure during the item operating time interval.

D) **Level D - Remote:** An unlikely probability of occurrence during the item operating time interval. Remote probability may be defined as a single failure mode probability of occurrence which is more than .001 but less than .01 of the overall probability of failure during the item operating time interval.

E) **Level E - Extremely Unlikely:** A failure whose probability of occurrence is essentially zero during the operating time interval. Extremely unlikely may be defined as a single failure mode probability of occurrence which is less than .001 of the overall probability of failure during the item operating time interval.

It should be noted that the overall probability of occurrence for item failure is not known. Therefore, MIL-STD-1629 incorrectly defines the probability of occurrence

levels. To be useful, the analyst must realize the defined levels are for reference only. These levels must be tailored for each analysis based on the analysts judgment of failure mode frequency for each specific application. The analyst should tailor the analysis to focus on significant components or subassemblies where failures will result in undesirable system level effects. Since frequency of failure is dependent on failure rate, and failure rate is not used in this type of analysis, the analyst must approximate the anticipated probabilities.

The failure probability levels should be modified as the system becomes mature. As part configuration and failure rate data become available, actual criticality numbers should be derived using the quantitative approach and entered into the analysis.

4.2 Quantitative Approach

The part or item failure rate data is required for the quantitative approach to criticality analysis. Failure rates can be derived or extracted from numerous data sources including:

- MIL-HDBK-217 "Reliability Prediction of Electronic Equipment"
- Bell Communications TA 000-23620-84-01 "Reliability Prediction Procedure for Electronic Equipment"
- Nonelectronic Parts Reliability Data (NPRD-91), Reliability Analysis Center (RAC)
- Vendor test data
- Contractor in-house test or field experience data

The value of each failure mode criticality number is defined as:

$$Cm = \beta\alpha\lambda_p t$$

where

C_m = Failure mode criticality

β = The conditional probability of mission loss

α = Failure mode ratio
λ_p = Part failure rate (in failures per million hours)
t = Duration of applicable mission phase expressed in hours or number of operating cycles

Since the failure mode ratio (α) and failure effect probability (β) are needed to perform this analysis, it is necessary to determine how and why each variable is used as well as where these variables were derived. In this manner, alpha and beta can be applied correctly. Many systems contain parts that have different duty cycles during a mission. The factor "t" is used to express the duration of time a particular item functions during a specific mission phase.

4.3 Derivation of Alpha

Alpha (failure mode ratio, α) is defined by MIL-STD-1629, as "the fraction of the part failure rate (λ_p) related to the particular failure mode under consideration...". This definition is confusing as it seems to say that α is a portion of the failure rate. This is actually the definition of modal failure rate, which will be discussed later. Alpha is the probability, expressed as a decimal fraction, that the given part or item will fail in the identified mode. If all of the potential failure modes for a device are considered, the sum of the alphas will equal one. Determining alpha is done as a two part process for each component being analyzed. First, the failure modes are determined and secondly, modal probabilities are assigned.

Modal failures represent the different ways a given part is known, or has been "observed", to fail. It is important to make the distinction that a failure mode is an "observed" or "external" effect so as not to confuse failure mode with failure mechanism. A failure mechanism is a physical or chemical process flaw caused by design defects, quality defects, part misapplication, or other processes. It describes the basic reason for failure or the physical process by which deterioration proceeds to failure. For example, a cracked die within a transistor may cause an open circuit from the collector to emitter. In this example, the failure mode would be the "open circuit from the collector to emitter" while the failure mechanism would be the "cracked die within the transistor". Each part type has a set of associated failure

modes. For example, a Bipolar transistor, NPN type, has been observed to exhibit the following failure modes:

- Low collector to emitter breakdown voltage
- Excessive emitter to base leakage
- Open circuit, collector to emitter

Common part failure modes can be derived from a variety of sources, of which several are presented in Section 4.4.

Once common part failure modes have been identified, modal probabilities (α) are assigned to each failure mode. This number represents the percentage of time, in decimal format, that the device is expected to fail in that given mode. This number is statistically derived and is given as a percentage of the total observed failures. Using the Bipolar transistor example, the probabilities of occurrence for each failure mode are as follows:

PART FAILURE MODES	FAILURE MODE RATIO (α)
Low collector to emitter breakdown voltage	.34 or 34%
Excessive emitter to base leakage	.57 or 57%
Open circuit, collector to emitter	.09 or 9%
The sum of the modal probabilities is	1.00 or 100%

The Modal Failure Rate is the fraction of the devices total failure rate based on the probability of occurrence of that failure mode. This allows for the apportionment of the total device failure rate into device failure mode failure rates. The sum of the modal failure rates for an item will equal the total item failure rate providing all part failure modes are accounted for. The modal failure rate is given by the equation:

$$\lambda_m = \alpha \lambda_p$$

where:

λ_m = the modal failure rate

α = the probability of occurrence of the failure mode

λ_p = the component failure rate

For example, assume that a Bipolar transistor has a failure rate of .12345 failures/million hours. Using this information in conjunction with the failure mode distributions previously presented, modal failure rates for each transistor failure mode can be calculated as follows:

PART FAILURE MODES	α		λ_p		λ_m
Low C to E breakdown voltage	.34	x	.12345	=	.04197
Excessive E to B leakage	.57	x	.12345	=	.07036
Open circuit, C to E	.09	x	.12345	=	.01111
TOTALS	1.00	Item Failure Rate			.12345

4.4 Sample Sources of Failure Mode Distribution Data

Component failure mode distribution information is available from a variety of sources. Many FMECA's are accomplished with failure mode distributions based on a compilation of in-house failure analysis from actual field failure returns. This type of information is typically a better indicator of field performance than the generic data found in published sources. Most often, data specific to an exact part type or exact part number item can not be obtained. In these cases, published literature should be used as sources for generic failure mode distribution data. Some are listed here:

- Chandler, Gregory, William Denson, Michael Rossi, and Richard Wanner. Failure Mode/Mechanism Distributions 1991, Report No. FMD-91, Reliability Analysis Center, 201 Mill St., Rome, NY: 1991.

- Gubbins, L.J. Study of Part Failure Modes, Report No. RADC-TR-64-377, Rome Air Development Center, Griffiss AFB, NY 13441: 1964.

- Electronic Reliability Design Handbook, MIL-HDBK-338, Rome Air Development Center, Griffiss AFB, NY, 13441: 1982.

- Nonelectronic Reliability Notebook. Report No. RADC-TR-75-22, Rome Air Development Center, RADC/RBRS, Griffiss AFB, NY, 13441: 1975.

- Smith, D.J. Reliability and Maintainability in Perspective, New York: John Wiley and Sons, 1985.

- David, S.E. and A.R. Granier. "Specification of Hybrid Microcircuits for Use of European Space Projects," International Microelectronic Symposium, (1975), p. 412-416.

Most of these sources contain limited failure mode distribution data on generic part types. Most often, sources for this type of data cover a wide range of common part types but very limited coverage is given for application specific devices. There are a number of sources dealing with failure mode distributions of unique part types such as:

- Collins, J.A., C.M. Eallonardo, and J.W. Hansen. Reliability Design Criteria for High Power Tubes-Review of Tube and Tube Related Technology, Report No. RADC-TR-88-304, Rome Air Development Center, RADC/RBET, Griffiss AFB, NY, 13441: 1989.

- Denson, W.K. and P. Brusius. VHSIC/VHSIC-Like Reliability Prediction Modeling, Report No. RADC-TR-89-177, Rome Air Development Center, RADC/RBRA, Grissiff AFB, NY, 13441: 1989.

- Bowman, L.S. and W.H. Tarn. "Reliability and Failure Mechanisms of GaAs FETs," Proceedings of the International Symposium for Testing and Failure Analysis (ISTFA), (1981), p. 69-74.

In each of the previously mentioned sources, data is summarized from field failure data using basic statistical methods to provide the user with baseline distributions for each component type. Often, failure distribution data is not available for component types utilized in a design. In cases where failure mode distributions are unknown, alpha values should be derived by the FMECA analyst based upon engineering judgment and the item's functionality.

The most recently developed source for failure mode distribution data is "Failure Mode/Mechanism Distributions," FMD-91, published by the Reliability Analysis Center (RAC). This document is one of the most comprehensive sources of part level failure distribution information available. It covers a wide variety of component types. This document was compiled from approximately 50 sources of failure mode information including failure analysis reports, reliability modeling studies, RAC data summarization activity and published distributions from private research organizations.

Appendix A lists example failure mode distributions which may be used in a FMECA. This data was derived from FMD-91 data tables.

4.5 Derivation of Beta (β)

Beta (β) is defined as the failure effect probability and is used to quantify the described failure effect for each mode indicated in the FMECA. The β values represent the conditional probability that the described failure effect will result in the identified criticality classification, given that the failure mode occurs. The β values represent the analyst's best judgment as to the likelihood that the loss will occur. MIL-STD-1629 states that values for Beta be quantified in general accordance with Table 1.

TABLE 1: TYPICAL FAILURE EFFECT PROBABILITIES (β)

FAILURE EFFECT	β VALUE
Actual Loss	1.00
Probable Loss	> 0.10 to < 1.00
Possible Loss	> 0 to 0.10
No Effect	0

This table is meant to provide a means of standardizing failure effect probabilities based on a relative confidence in the failure effect's occurrence.

Though the methodology behind assigning β for a given failure mode seems straightforward, this value is often misinterpreted. There are two opposing interpretations of the definition as indicated in the military standard. This confusion is caused by the conflict between the written definition, and the table of

failure effect probabilities. The written definition states that β is the conditional probability that the failure effect actually falls in the stated classification, assuming that the failure mode occurs. This value is implied as being a percentage value of confidence that the individual performing the FMECA has in his stated failure effects. The second interpretation comes from the table of failure effect probabilities listed in the standard, which defines β as the probability of incurring a system loss. This approach assigns a numerical severity classification to the listed effect.

4.6 Proper Use of β

The proper use of β in a FMECA is more closely related to the first of the two definitions given in the previous section, representing the engineers judgment of the percentage of time that the identified failure mode will cause the indicated failure effect. It is the analyst's determination, based on his knowledge of the system, whether the occurrence of the failure mode in question will consistently cause the same end effect. If it cannot be reasonably stated that a resulting failure effect will occur for a given failure mode, the FMECA analyst must indicate this by assigning a relative probability of occurrence to the resultant effect. When a β value of less than one is observed for a specific failure mode's failure effect, additional failure effects for the same failure mode must be indicated and weighted such that the sum of the β values adds up to one. In these instances, β is used to quantify multiple system level failure effects for a given single failure mode. Beta is a percentage based upon the FMECA analyst's judgment of the probability of occurrence of each failure mode's system level failure effect. By quantifying the system level failure effects for a specific failure mode, the FMECA provides a more accurate view of an item's failure mode severity. This also illustrates that there can be multiple system level failure effects for a single failure mode.

To illustrate of the proper use of beta, consider a brake system on a train. If a failure mode were to occur which caused the brakes on the train to lock, what potential failure effects could occur? Most analyst's would consider only the most mission critical failure effect; the train derailing. Without understanding the proper use of Beta, the FMECA analyst might only consider the worst case scenario and overlook other "potential system" effects. By considering only the worst case scenario, an accurate portrayal of the actual system effects for this failure mode is not given. The most probable system level effect under normal operating conditions is

that the train would suddenly come to a screeching halt. However, there is a chance that the train could skip the tracks depending upon when and where this failure occurred. If β is applied properly, the most accurate presentation of this data is as follows:

FAILURE MODE	FAILURE EFFECT	β
Brakes Lock	1) Train skids on tracks and comes to a stop	.9
	2) Train derails	.1

Since the severity of these two effects are greatly different, the failure mode criticality number can now be weighted based on probability of occurrence.

If β were applied incorrectly, modal criticality numbers (C_m) for the device in question would be skewed. A common error made by FMECA analysts is to use β to address the probability of occurrence of only the most severe system level effect while ignoring the other possible system level effects resulting from that failure mode. Using the train brake example and assuming λ_p = .01 failures per million hours, α = .5, and t = 20 hours for the "Brakes Lock" failure mode, the modal criticality would be calculated as follows:

$$C_m = \beta \alpha \lambda_p t$$
$$C_m = (.1)(.5)(.01 \times 10^{-6})(20)$$
$$C_m = 1 \times 10^{-8} \text{ (failure effect \#2)}$$

This is only part of the modal criticality as it considers only one of the known failure effects. The other portion of the modal criticality number is calculated as follows:

$$C_m = \beta \alpha \lambda_p t$$
$$C_m = (.9)(.5)(.01 \times 10^{-6})(20)$$
$$C_m = 9 \times 10^{-8} \text{ (failure effect \#1)}$$

Therefore, the total failure mode criticality for the "Brakes Lock" failure mode is the sum of these two values; 1×10^{-7}.

4.7 Distribution of Failure Rate Across Multiple Device Packages

For most of the devices listed in Appendix A, the calculation for modal failure rate is straightforward. It is defined as the probability that the device will fail in the indicated mode. Therefore, the modal failure rate is calculated by multiplying the item failure rate by the modal probability (α) for that failure mode. When summing the modal failure rates for all possible modes, the result is equal to the total part failure rate. A slightly different approach must be taken when dealing with multiple device packages. A multiple device package is any uniquely classified component type that is internally made up of a group of two or more devices. The failures of these internal devices can have different effects on system operation.

An example of a multiple device package is a resistor network. When the failure rate for this device is determined, it is based on evaluating the device as a whole. However, the effects of the modal failures of the device are unique to each resistor in the network. To accurately weight the analysis, the failure rate must be apportioned among the individual components within the resistor network. Failure modes and modal probabilities are then identified for each of the resistors within the network. These are typically consistent from one resistor to the next within the network, assuming that they are of the same type, size, and quality rating. The modal failure rate is then calculated by multiplying the portion of the total device failure rate applicable to the individual resistor in question by the modal probability for that specific resistor. The sum of all modal failure rates will equal the total device failure rate. The following example illustrates this process:

Component type: Resistor Network

Part Number: Rnet

Number of Resistors in Network: 10

Failure Rate (λ_p) of Resistor Network: .5

Failure Mode Probability (α): Open (.75)
Short (.25)

Failure Rate of Each Resistor Within Network:

λ_p of Rnet(i) = (.5/10) = .05 failures per million hours

Modal Failure Rate of Each Resistor Within Network:

λ_p of the Rnet(i) (open) = .05 x .75 = .0375

λ_p of Rnet(i) (short) = .05 x .25 = .0125

Failure Rate Summation:

DEVICE	FAILURE RATE ($\lambda_{p(i)}$) FAIL/E^6 HRS.	MODAL PROB. (α)	MODAL FAILURE RATE
Rnet (1)	.05	Open .75 Short .25	.0375 .0125
Rnet (2)	.05	Open .75 Short .25	.0375 .0125
Rnet (3)	.05	Open .75 Short .25	.0375 .0125
Rnet (4)	.05	Open .75 Short .25	.0375 .0125
Rnet (5)	.05	Open .75 Short .25	.0375 .0125
Rnet (6)	.05	Open .75 Short .25	.0375 .0125
Rnet (7)	.05	Open .75 Short .25	.0375 .0125
Rnet (8)	.05	Open .75 Short .25	.0375 .0125
Rnet (9)	.05	Open .75 Short .25	.0375 .0125
Rnet (10)	.05	Open .75 Short .25	.0375 .0125
TOTALS	.50		.5000

This scenario commonly applies to transistor arrays, diode arrays, digital or analog integrated circuits with multiple outputs, multi-pole/multi-throw switches, etc.

Hybrid devices may be handled a number of different ways. The hybrid can be treated as a subsystem with its internal components being analyzed as components within that subsystem. The failure effects of each internal component failure mode are then carried out to the package pins to determine the effects on next higher and system levels. Another approach used when analyzing hybrid devices is to treat the hybrid like a microcircuit and analyze the outputs. In this case, each output is given the failure mode distributions relating to the internally connected component.

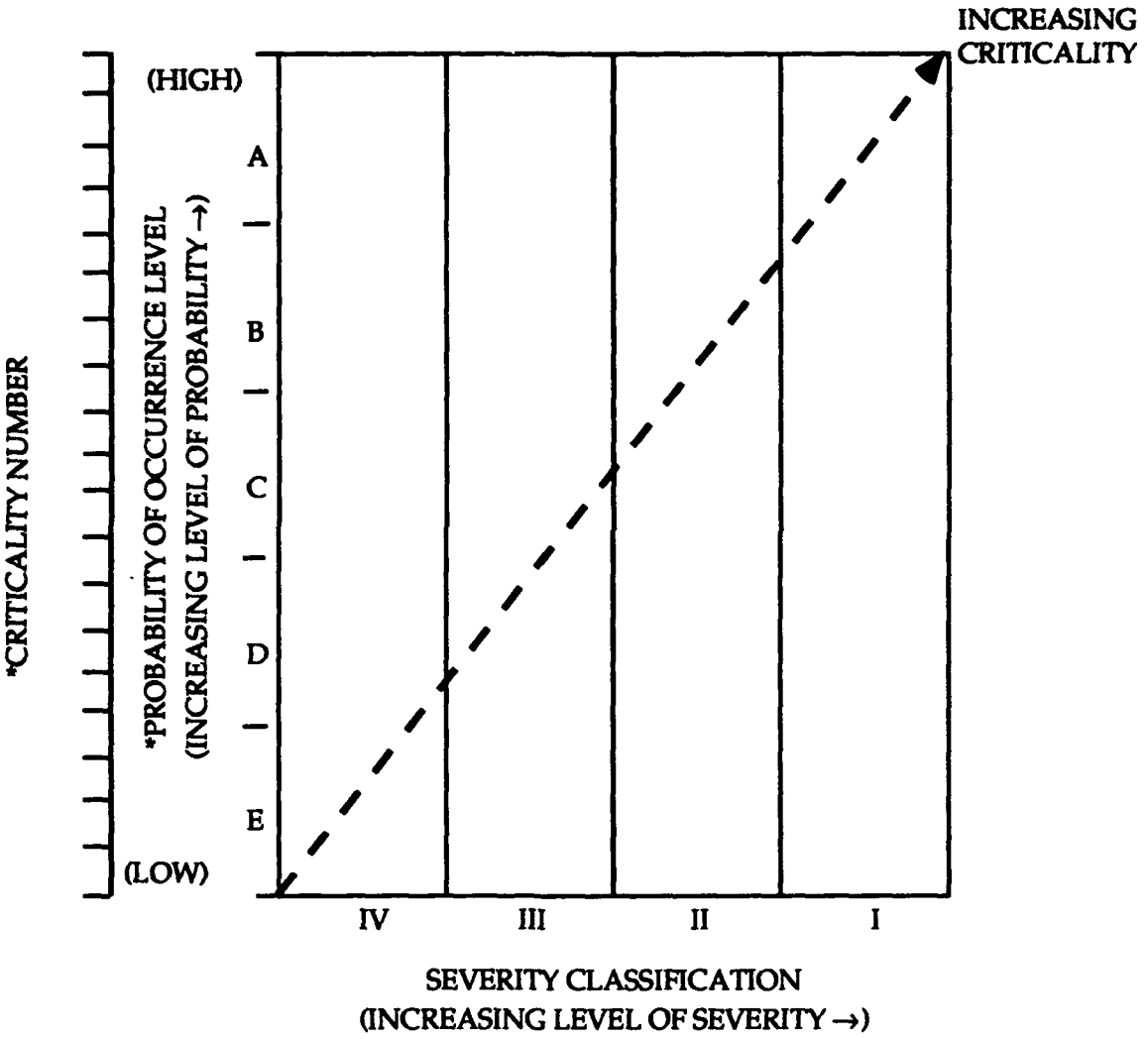
4.8 Definition of a Criticality Matrix

The Criticality Matrix provides a graphical means of identifying and comparing failure modes for all components within a given system or subsystem with respect to severity. Severity is classified in four categories with Level I being the most severe (catastrophic) and Level IV being the least severe (minor). These levels are specified as follows:

DESCRIPTION	CATEGORY	MISHAP DEFINITION
Catastrophic	I	Death or system loss.
Critical	II	Severe injury, severe occupational illness, or major system damage.
Marginal	III	Minor injury, minor occupational illness, or minor system damage.
Minor	IV	Less than minor injury, occupational illness, or minor system damage.

Severity pertains to and ranks the consequences of system level failure mode effects. The matrix is constructed by inserting item reference designators or failure mode identification numbers into matrix locations which represent severity classification category and either probability of occurrence level or criticality number for each item's failure modes. The resulting matrix shows the relative ranking of criticality for each item's failures. The matrix is a useful tool for assigning corrective

action priorities. As shown in Figure 3, the further along the diagonal line from the origin that the failure mode is recorded, the greater the criticality and the more urgent the need for corrective action implementation. The figure also illustrates how either the criticality number used in a quantitative criticality analysis, or probability of occurrence level used in a qualitative criticality analysis can be used for the vertical axis.



* NOTE: BOTH CRITICALITY AND PROBABILITY OF OCCURRENCE ARE SHOWN FOR CONVENIENCE

FIGURE 3: CRITICALITY MATRIX

4.9 Construction of Criticality Matrix

There are two methods to organize data for a criticality matrix. As shown in Figure 3, severity classification is plotted on the X-axis in order of increasing magnitude from a Level IV failure (minor) to a Level I failure (catastrophic). What differs is the presentation of information to be plotted in terms of severity. The Y-axis can be used to plot criticality or probability of occurrence based upon whether a quantitative or qualitative criticality analysis was performed. This is typically governed by the amount of detailed engineering data available at the time of analysis.

Though item criticality (C_r, the sum of a part's modal criticalities for like severity classifications) is a factor commonly calculated during the criticality analysis and used in the criticality matrix, it is also logical to use modal criticality (C_m) in the criticality matrix. Item criticality is calculated using the following formula:

$$C_r = \sum_{n=1}^{j} (\beta\alpha\lambda_p t)_n \qquad n = 1,2,3,\ldots j \qquad \text{or} \qquad C_r = \sum_{n=1}^{j} (C_m)_n$$

where:

C_r = Criticality number for the item being analyzed

n = The current failure mode of the item being analyzed for a particular severity classification

j = The number of failure modes for the item being analyzed for a particular severity classification

C_m = Criticality number for a particular failure mode

β = Probability of occurrence of the resulting failure effect

α = Failure mode ratio

λ_p = Part failure rate

t = Duration of applicable mission phase usually expressed in hours or number of operating cycles.

Item criticality (C_r) is the summation of an items individual failure mode criticality numbers for each unique severity classification. However, using C_r in the criticality matrix can cause single point failures to be improperly ranked. When plotting C_r in a criticality matrix, the user must understand that each data point may

represent multiple failure entires causing a particular part, not failure mode, to stand out. MIL-STD-1629 is a bit unclear in its discussion of criticality analysis and criticality matrices regarding the use of (C_r) and (C_m). Failure mode criticality (C_m) is the parameter RAC recommends using in the criticality matrix because it immediately identifies the severity and criticality of each individual failure mode so that accurate re-design decisions can be made to eliminate the most severe and likely failure modes.

Figure 4 shows an example of a quantitative criticality matrix with failure mode criticality being plotted. Failure mode criticality is calculated using the following formula:

$$C_m = \beta\alpha\lambda_p t$$

where:

C_m = Criticality number for each failure mode

β = Conditional probability of failure effect

α = Failure mode ratio

λ_p = Part failure rate

t = Duration of applicable mission phase usually expressed in hours or number of operating cycles.

This number, C_m, expresses criticality by modal elements. The resultant graph provides a systematic breakdown of this data and allows the ranking of severity as a function of modal failure rate and specific failure effects of the failure mode indicated. The graphical result highlights potentially catastrophic conditions making them readily apparent for redesign consideration.

Figure 5 shows another example of a quantitative criticality matrix with failure mode criticality being plotted. However, this example considers the probability of occurrence of the stated failure effect, (β). Failure mode criticality is calculated in the same way as was previously described; however, in this case the failure modes are further detailed based upon multiple failure effects through the use of β. In this example, it was determined that the "open" failure mode of the resistor could realistically cause two potential failure effects. The first having a .9 probability of causing a minor effect and the second having a .1 probability of causing a catastrophic effect.

Component type: Metal Film Resistor

Part Number: R1

Failure Rate: (λ_p): .5 failures per million hours

Failure Mode Probability (α): Open (.75)
Short (.25)

Time (t): 1 hour

Failure Effect Probability (β): 1

Failure Mode Criticality: $Cm = (\beta)(\alpha)(\lambda_p)(t)$

$$Cm(open) = (1 \times .75 \times [.5 \times 10^{-6}] \times 1)$$
$$= .375 \times 10^{-6}$$

$$Cm(short) = (1 \times .25 \ [.5 \times 10^{-6}] \times 1)$$
$$= .125 \times 10^{-6}$$

- assume a "open" failure mode could cause a catastrophic effect
- assume a "short" failure mode could cause a minor effect

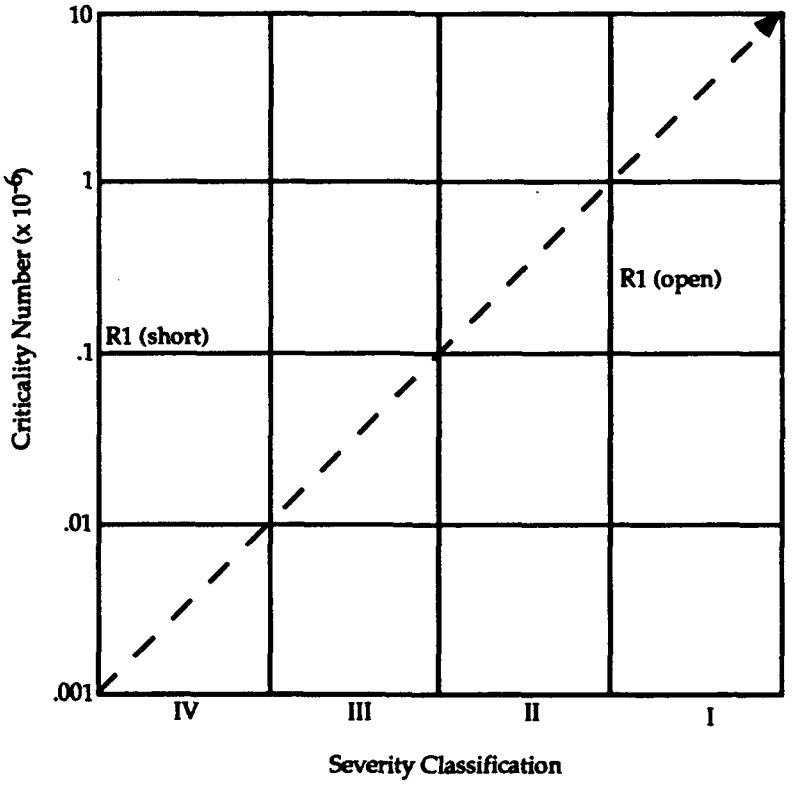


FIGURE 4: CRITICALITY MATRIX (EXAMPLE 1)

Component type: Metal Film Resistor

Part Number: R1

Failure Rate: (λ_p): .5 failures per million hours

Failure Mode Probability (α): Open (.75)
Short (.25)

Time (t): 1 hour

Failure Effect Probability (β): .9, .1

Failure Mode Criticality per Failure Effect: $Cm = (\beta)(\alpha)(\lambda_p)(t)$

$$Cm1(open) = (.9 \times .75 \times [.5 \times 10^{-6}] \times 1)$$
$$= .3375 \times 10^{-6}$$

$$Cm2(open) = (.1 \times .25 \ [.5 \times 10^{-6}] \times 1)$$
$$= .0375 \times 10^{-6}$$

$$Cm(short) = (1 \times .25 \times [.5 \times 10^{-6}] \times 1)$$
$$= .125 \times 10^{-6}$$

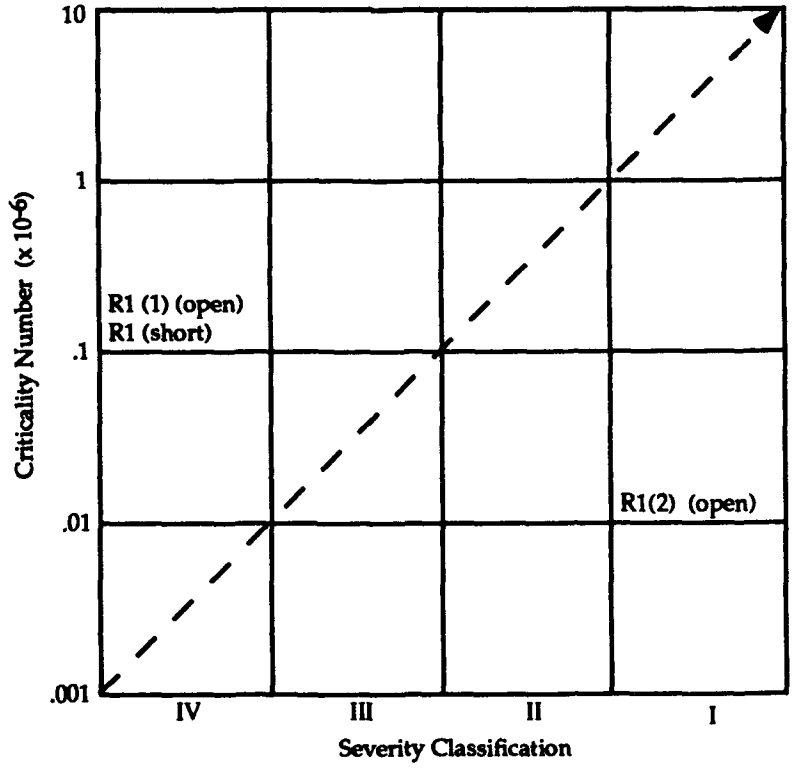


FIGURE 5: CRITICALITY MATRIX (EXAMPLE 2)

This number, $C_m(i)$, further defines the modal criticality based on the multiple effects of each failure mode and the corresponding severities associated with them. The resultant matrix provides a more specific breakdown of the FMECA data allowing the ranking of severity as a function of the probability of occurrence for each effect multiplied by the modal failure rate causing the indicated mode effect.

Figure 6 shows an example of the qualitative approach to developing a criticality matrix. In the qualitative approach, probability of occurrence levels are defined for each component analyzed and are used in place of the criticality numbers on the Y-axis. Probability of occurrence is divided into 5 levels, A through E, as defined in Section 4.1 of this report. These levels refer to the relative probability of failure occurrence of the item being analyzed. (The term "Probability of Occurrence" is not to be confused with the definition of Beta (β), which is the probability of occurrence of a specific failure effect.) The matrix shows the severity of the effect of the item's failure vs. the probability of occurrence of that item's failure. As indicated in Section 4.1, the qualitative analysis method attempts to quantify its results. A useful qualitative criticality analysis must be tailored to each specific item/system. The overall failure mode probability of occurrence level for a given item must be based on sound engineering judgment for that particular system/item. The levels defined in MIL-STD-1629 are meant to be guidelines, not defined levels. The qualitative criticality matrix will display the relative probability of occurrence of failure for the item being analyzed based on those predetermined levels defined by the analyst, and stated in the FMECA plan.

4.10 How to Use and Read a Criticality Matrix

The criticality matrix provides a visual representation of the critical areas of a system. By knowing how to properly use and read a criticality matrix, the user can make educated decisions when addressing potentially hazardous single point failures. Regardless as to which of the types of data are presented in the criticality matrix, the relative order of importance for items of concern remains the same. Items displayed in the upper most right hand corner of the matrix require the most immediate attention. These failures have a high probability of occurrence and a catastrophic effect on system operation or personnel safety. As you move diagonally towards the lower left hand corner of the matrix, the criticality and severity of potential failures decreases. In cases where failures display the same relative

COMPONENT PART NUMBER	PROBABILITY OF OCCURRENCE	SEVERITY OF FAILURE EFFECT
R1	Level A	I
C1	Level D	I
U4	Level D	IV
C22	Level B	II
Q7	Level C	III

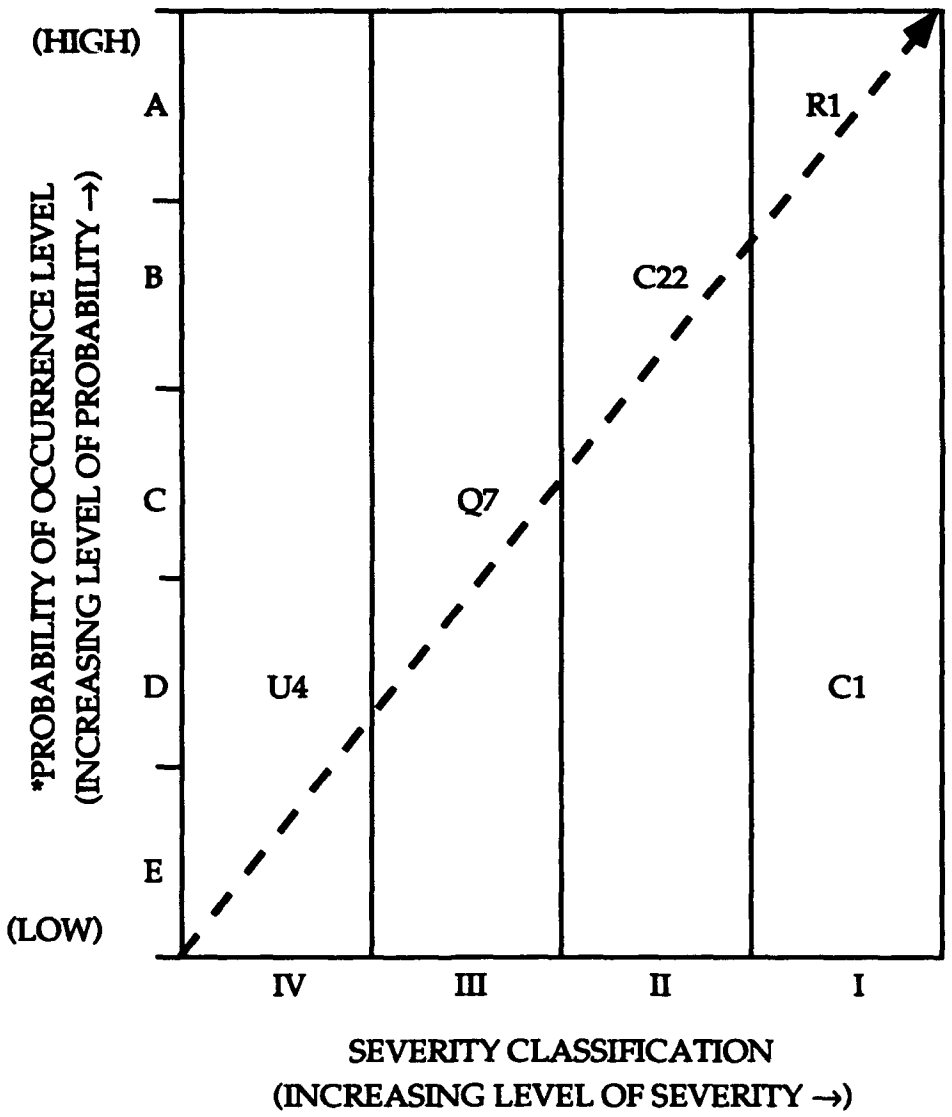


FIGURE 6: CRITICALITY MATRIX (QUALITATIVE APPROACH)

severity and criticality, it must be determined whether safety or cost is the driving factor of the analysis. If safety is more of a concern, items shown on the right of the diagonal line require the most re-design attention, because the effects of their failures are more severe even though their criticality ranking may be less. If cost is a major concern, items to the left of the diagonal line require attention, because the high criticality numbers reflect higher failure probability. However, in situations where human life is a risk, safety is always the primary consideration.

When items are deemed critical by their location in the criticality matrix, some means of corrective action must be employed to eliminate or reduce the chance or effects of their failures. One option is to replace the component in question with one of a higher quality rating. This would reduce the failure rate of the device and thus the probability of this catastrophic effect. If it can be determined that the device's high criticality ranking is due to an overstress condition, replacing the component with one which has greater power handling capability would solve the problem.

If the quality level or power rating of the device is not the problem, a circuit redesign may be necessary. This could be costly and time consuming depending on how far the design process has progressed and may in fact lead to more reliability problems. The use of redundancy in the circuit may provide a simple and cost effective solution. By employing redundancy, duplicate circuitry is constructed such that it serves as a backup for a critical single point failure. Though the initial failure of the component cannot be avoided, the effect of the failure will no longer be catastrophic since a compensating provision (the redundant circuit) will serve to operate in its place. However, the ideal situation, is to feedback and utilize FMECA results during the initial stages of the design process, so that early iterations of the design contain the "right" solution.

5.0 FMECA ANALYSIS PROCESS

The following logical steps should be followed when performing an FMECA:

- Define the system
- Define ground rules and assumptions in order to help drive the design
- Construct system block diagrams
- Identify failure modes (part level or functional)
- Analyze failure effects/causes
- Feed results back into design process
- Classify the failure effects by severity
- Perform criticality calculations
- Rank failure mode criticality
- Determine critical items
- Feed results back into design process
- Identify the means of failure detection, isolation and compensation
- Perform maintainability analysis
- Document the analysis, summarize uncorrectable design areas, identify special controls necessary to reduce failure risk
- Make recommendations
- Follow up on corrective action implementation/effectiveness

5.1 Procedure

In FMECA, each single item failure is analyzed and its resulting effects documented. Each single item failure is assumed to be the only failure in the system. However, MIL-STD-1629 states that if a single item failure is non-detectable, the analysis should be continued to include the effects of any secondary failures

which, when combined with the original failure, presents a critical failure condition. If a redundant or back-up design has been utilized in the system, the analysis should include the failure conditions which resulted in the need for that redundant or back-up design. It is inconceivable to analyze every possible multi-failure scenario resulting in adverse operating conditions due to time and cost constraints. This type of analysis is better accomplished using Fault Tree Analysis (FTA). RAC has published a fault tree analysis handbook which discusses this analytical technique in great detail. See Appendix C for ordering information. All single point failures identified during the FMECA analysis should be identified on the FMECA worksheets. Figure 1 (Section 3.1) shows an example worksheet. A typical "quick" reference FMECA flow diagram is illustrated in Figure 7.

5.2 System Definition

The necessary first step in completing the FMECA is to define the system to be analyzed. The complete system definition includes the identification of internal and interface functions, the performance of the system at each indenture level, system restraints, and failure definitions. Functional descriptions should be developed for each mission, mission phase, mission times, operational modes and primary and secondary mission objectives. These descriptions should describe the service use profile, equipment utilization, expected mission time, function and output of each item. Conditions which constitute system failure and part failure should also be determined.

The system indenture levels must be identified to complete the FMECA. Figure 8 depicts typical system indenture levels. Both functional and hardware FMECA methods apply to this example. However, the hardware approach is more applicable to lower system levels while the functional approach is more applicable at higher system levels.

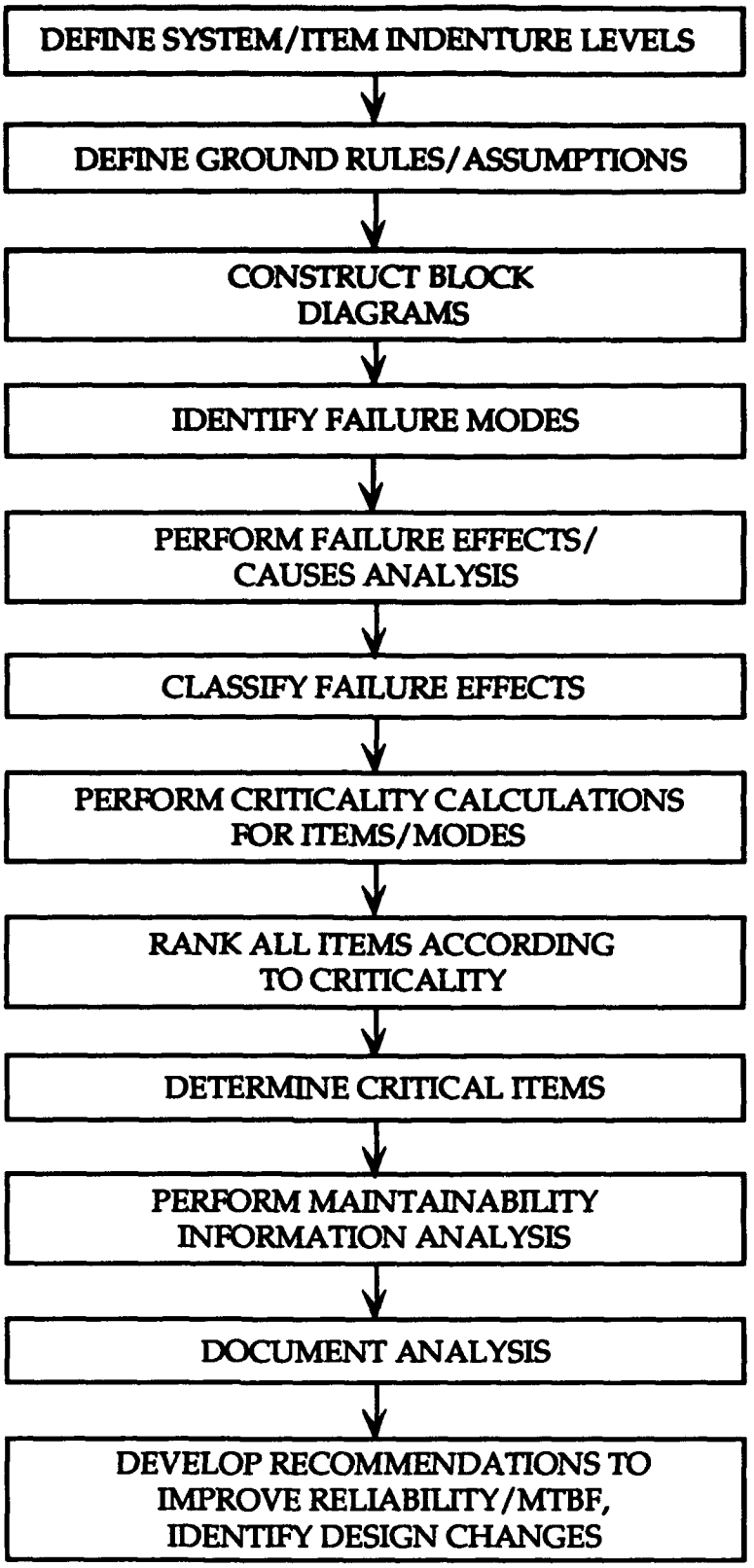


FIGURE 7: TYPICAL FMECA FLOW

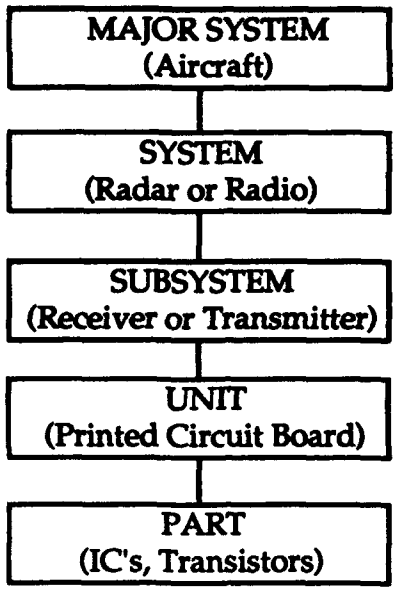


FIGURE 8: TYPICAL INDENTURE LEVELS

5.3 Ground Rules and Assumptions

To help the reader understand FMECA results, the analyst must clearly document the ground rules and/or assumptions made when performing each part of the analysis. The ground rules generally apply to the system/equipment, it's environment, mission and analysis methods. Ground rules require customer approval and generally include:

- The mission of the item being analyzed (Aircraft-Bombing Run)
- The phase of the mission the analysis will consider (Bomber-Takeoff)
- Operating time of the item during the mission phase (Time to Takeoff)
- The severity categories used to classify the effects of failure (When categories in MIL-STD-1629 must be tailored)
- Derivation of failure mode distributions (Vendor Data, Statistical Studies, Analyst's judgment)
- Source of part failure rates when required (NPRD, MIL-HDBK-217, Vendor Data)
- Fault detection concepts and methodologies. (BIT, Alarms, Warnings)

Often, a FMECA is tailored to a specific product or type of customer. Therefore, the analysis and results are not necessarily in accordance with MIL-STD-1629. When the analysis deviates from the standard guidelines each deviation must be thoroughly documented.

5.4 Block Diagrams

A functional and reliability block diagram representing the operation, interrelationships and interdependencies of functional entities of the system should be constructed. The block diagrams provide the ability to trace the failure mode effects through each level of indenture. The block diagrams illustrate the functional flow sequence as well as the series or parallel dependence or independence of functions and operations.

Each input and output of an item should be shown on the diagrams and labeled. A uniform numbering system which is developed for the functional system breakdown order is essential to provide traceability thorough each level of indenture. Figures 9 and 10 depict examples of functional and reliability block diagrams respectively.

The functional block diagram shows the operation and interrelationships between functional parts of the system as defined by the schematic drawings and engineering data. The functional block diagram depicts the system functional flow, the indenture level of analysis and the present hardware indenture level. This type of diagram can be used for hardware and functional FMEA's. Additional information on the construction of functional block diagrams can be found in MIL-STD-24100 entitled "Manual, Technical; Functionally Oriented Maintenance Manuals for Systems and Equipment".

The reliability block diagram is used to illustrate the relationship of all the functions of a system or functional group. Information on the construction of reliability block diagrams may be found in to MIL-STD-756 entitled "Reliability Prediction."

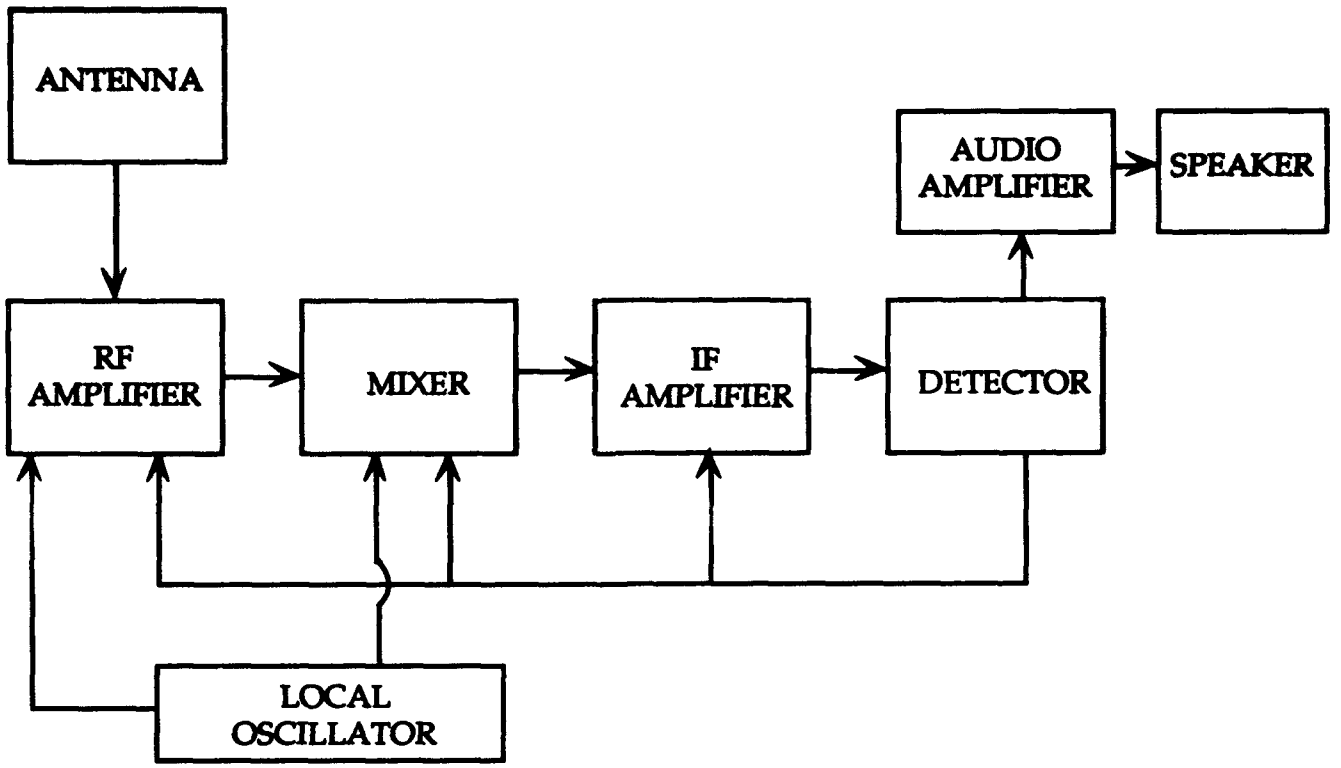


FIGURE 9: EXAMPLE OF FUNCTIONAL BLOCK DIAGRAM (COMMUNICATION RECEIVER)

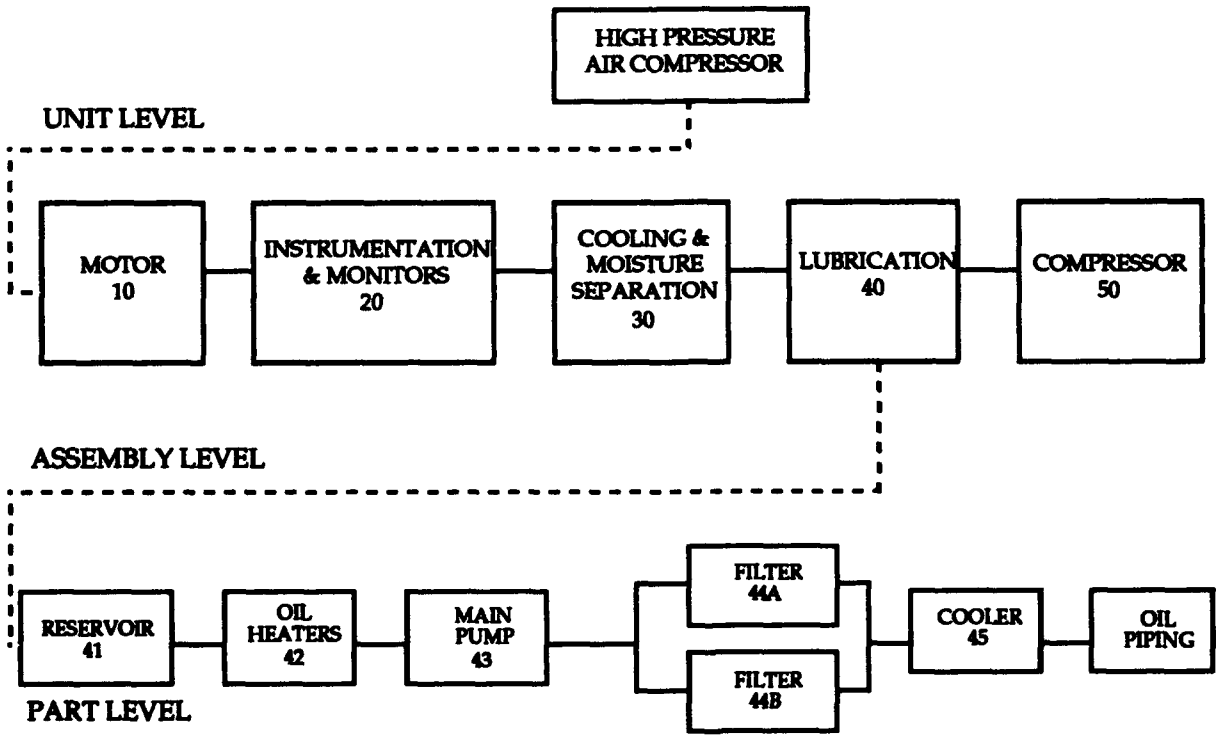


FIGURE 10: EXAMPLE OF RELIABILITY BLOCK DIAGRAM (AIR COMPRESSOR)

5.5 Failure Mode Identification

All item and interface failure modes must be identified and their effect upon the immediate function or item, system and mission must be determined. The potential failure modes are determined by examining item outputs and functional outputs identified when constructing the system block diagrams. Item failure mode effects are based on and should be consistent with the definitions of failure developed in the system definition. All probable independent failure modes for each item should be identified. To assure that a complete analysis has been performed, each component failure mode and/or output function should be examined for the following conditions:

A) Premature operation

B) Failure to operate at the proper time

C) Intermittent operation

D) Failure to stop operating at the proper time

E) Loss of output

F) Degraded output or reduced operational capability

When a qualitative CA is performed, the failure mode probability of occurrence level must be determined (from analyst's judgment). The failure mode probability of occurrence must be determined for the quantitative CA (from vendor data, reliability prediction, etc.). A list of commonly used component level failure mode distributions is presented in Appendix A.

5.6 Failure Effects Analysis

A failure effects analysis is performed on each item of the reliability block diagram. The consequence of each failure mode on item operation, and the next higher levels in the block diagram should be identified and recorded. The failure under consideration may affect several indenture levels in addition to the indenture level under analysis. Therefore, local, next higher and end effects are analyzed. Failure effects must also consider the mission objectives, maintenance

requirements and system/personnel safety. Failure effect levels are defined as follows:

Local: Effects that result specifically from the failure mode of the item in the indenture level under consideration. Local effects are described to provide a basis for evaluating compensating provisions and recommending corrective actions. The local effect can be the failure mode itself.

Next Higher Level: Effects which concentrate on the effect a particular failure mode has on the operation and function of items in the next higher indenture level.

End: Effect of the assumed failure on the operation, function and/or status of the system.

The end or system level effects of item failures generally fall within one of the following categories:

A) **System failure:** the failed item has a catastrophic effect on the operation of the system.

B) **Degraded operation:** the failed item has an effect on the operation of the system but the system's mission can still be accomplished.

C) **System status failure:** the failed item causes the operator to lose the true status of the system or equipment.

D) **No immediate effect:** the failed item causes no immediate effects on the system operation.

Should end effects of item failure not fall within one of the categories above, the analyst must tailor these categories as needed.

Failures at the system level are those failures which hinder the performance or actual completion of the specified mission. An example of failures at each indenture level would be defined as:

Major System: An example is a bomber aircraft. A failure at the major system level would be defined as the inability of the aircraft to deliver its bombs to a specific target.

System: An example is the weapons control system onboard the aircraft. A failure at the system level could be defined as the inability of the aircraft to identify the target during an active mission.

Subsystem: An example is an electronic countermeasures pod onboard an aircraft whose mission is to counter enemy radar threats. A failure at the subsystem level could be defined as the inability of the pod to handle mission specific threats.

Unit: An example is the power output amplifier in the transmitter of an aircraft radar system. A failure at the unit level could be defined as the inability of the power output amplifier to amplify and pass the transmitter carrier signal to the radar antenna.

Part: An example is a power transistor in the power output amplifier in the transmitter of an onboard aircraft radar system. A failure at the part level could be defined as the inability of the transistor to amplify and pass the carrier signal through the power amplifier output.

5.7 Severity Classification

Each item failure mode is evaluated in terms of the worst potential consequences upon the system level which may result from item failure. A severity classification must be assigned to each system level effect. Severity classifications provide a qualitative measure of the worst potential consequences resulting from an item failure. A severity classification is assigned to each identified failure mode and each item analyzed in accordance with the following categories.

A) **Category I - Catastrophic:** A failure which may cause death or weapon system loss (i.e., aircraft, tank, missile, ship, etc.)

B) **Category II - Critical:** A failure which may cause severe injury, major property damage, or major system damage which will result in mission loss.

C) **Category III - Marginal:** A failure which may cause minor injury, minor property damage, or minor system damage which will result in delay or loss of availability or mission degradation.

D) **Category IV - Minor:** A failure not serious enough to cause injury, property damage or system damage, but which will result in unscheduled maintenance or repair.

These categories have been developed in MIL-STD-882 entitled "System Safety Program Requirements". It may not be possible to categorize an item or failure mode according to the four categories listed. Loss statements can be developed to account for the results of item failure. These modified classifications should be approved by the procuring activity and included in the FMECA ground rules. For example, consider a home furnace controller containing printed circuit cards. Customized severity classifications might be as follows:

A) **Category I:** Loss of furnace or structure

B) **Category II:** Major damage to printed circuit board or external devices as a result of a board failure, system disabled

C) **Category III:** Minor damage to printed circuit board or external devices as a result of a board failure, system degraded

D) **Category IV:** Insignificant failure, but maintenance or repair required

5.8 Failure Detection Methods

The FMECA identifies the methods by which occurrence of a failure is detected by the system operator. Visual or audible warning devices and automatic sensing devices are examples of failure detection means. Any other indications which serve as evidence to the system operator that a system has failed should be identified. If no indication exists, it is important to determine if the failure will jeopardize the system mission or safety. MIL-STD-1629 states if no indication exists, the analysis must determine whether or not the undetected failure will jeopardize the mission objectives or personnel safety, and if the undetected failure allows the item to remain operational in a safe state, a second failure situation shall be explored to determine whether or not an indication will be evident to the operator or maintenance technician. Indications to the operator can be described as:

Normal: An indication to the operator indicating the system is operating normally.

Abnormal: An indication to the operator that the system has malfunctioned or failed.

Incorrect: An erroneous indication to the operator that a malfunction has occurred when there is no fault or an indication that the system is operating normally when, in fact, there is a failure.

5.8.1 Failure Isolation Methods

Once a failure is detected, it must be isolated. The failure isolation method describes the most direct approach that allows the operator to identify and locate the failure. When an item fails, the operator can only see initial failure symptoms until further action is taken. Such action can be a detailed built-in-test (BIT) or troubleshooting flow. Fault isolation requires an action or series of actions by the operator, in an attempt to zero-in on the root failure cause. Use of technical orders, maintenance manuals or automated test software can be used to accomplish this. Automatic built-in-test-equipment (BITE) can often detect and isolate failures concurrently to various ambiguity levels.

5.8.2 Compensating Provisions

Compensating provisions are design characteristics or operator actions which can circumvent or reduce the effects of item failure. Any compensating provision built into a system that can nullify the effects of a malfunction or failure or deactivate or activate circuitry to halt or negate the effects of a failure must be identified. Design compensating provisions include:

A) Redundant items that allow continued and safe operation.

B) Safety devices such as monitors or alarm systems that permit effective operation or limit damage.

C) Alternative means of operation such as backup or standby items or systems.

All compensating provisions that require operator action to reduce or negate the effects of a failure should also be identified and recorded. When multiple compensating provisions exist, the compensating provision which best satisfies the fault indication observed by the operator must be highlighted. The consequences of the operator taking the wrong action in response to an abnormal indication should be considered and the effects of this action should be recorded in the remarks column of the worksheet.

5.9 Criticality Ranking

When failure modes are analyzed in terms of probability of occurrence, failure probability levels must be listed (qualitative analysis). When failure rate data is used to calculate criticality numbers (quantitative analysis) the data source for failure rates must be listed (i.e., MIL-HDBK-217, NPRD-91, etc.) along with the failure rate. To successfully complete the FMECA, it is necessary to determine both the failure mode criticality (C_m) of each failure mode and the criticality of each item. The failure mode criticality is derived based on the methodologies described in Section 4.2 of this document. The criticality of each item (C_r) is the sum of the item's individual failure mode criticality numbers having the same severity classification. For this example, both failure modes result in level III severities (refer to Section 4.9). A ranking can be developed to help determine item failures critical to mission or system safety. The following examples illustrate the calculation of item criticality and failure mode criticality.

Failure Mode Criticality:

Component type: Carbon Film Resistor

Part Number: R14

Failure Rate (λ_p): .25673 failures per million hours

Failure Effect Probability (α): Open (.75)
Short (.25)

Time (t): 1 hour

Failure Mode Probability (β): 1

Failure Mode Criticality (C_m):

$$C_m = \beta \alpha \lambda_p t$$

C_m (open) = (1 x .75 x .25673 x 1)
C_m (open) = .192548 x 10^{-6}

C_m (short) = (1 x .25 x .25673 x 1)
C_m (short) = .064183

Item Criticality:

Component type: Carbon Film Resistor

Part Number: R14

Failure Rate (λ_p): .25673 failures per million hours

Failure Effect Probability (α): Open (.75)
Short (.25)

Time (t): 1 hour

Failure Mode Probability (β): 1

Item Criticality (Cr):

$$C_r = \sum_{n=1}^{j} (\beta\, \alpha\, \lambda_p\, t)_n \quad N = 1, 2, 3, \ldots j \text{ or } C_r = \sum_{n=1}^{j} (C_m)\, n$$

$$C_r = (1 \times .75 \times .25673 \times 1) + (1 \times .25 \times .25673 \times 1)$$

$$C_r = .25673$$

5.10 Critical Item/Failure Mode List

The purpose of the critical item list is to rank the effects of each item failure with respect to severity of the failure effect and probability of the failure occurrence. The most critical failure modes are those modes with high criticality and high severity of end effect. The critical item/failure mode list will aid in safety and fault tree analysis, thereby enabling improvements in the design.

5.11 Recommendations

At the conclusion of the FMECA, critical items/failure modes are identified and corrective action recommendations made. Typical recommendations call for design modifications such as; the use of higher quality components, higher rated components, design redundancy or compensating provisions.

Recommendations cited must be fed back into the design process as early as possible in order to minimize iterations of the design. The FMECA is most effective when exercised in a proactive manner to drive design decisions, rather than to respond after the fact. In this context, the analyst is cautioned not to get so absorbed in the details of the FMECA that proactive opportunities to improve the design are over-looked. A reactive FMECA may satisfy a data item requirement, but may cause an unnecessary drain on resources, or a negative impact on cost and schedule if recommendations come late.

6.0 MAINTAINABILITY/DAMAGE MODE ANALYSIS

6.1 Maintainability Information

The Maintainability Analysis supplies early criteria for maintenance planning analysis, logistic support analysis (LSA), test planning, and helps identify maintainability design features that require corrective action.

The Maintainability Analysis is used to determine and influence the level of Built-in-Test (BIT) and fault detection provided by the system. Information on faults that are detectable and isolatable is used as an input to system testability analysis and maintainability prediction.

The Maintainability Analysis requires data from the FMEA. Therefore, the Maintainability Analysis cannot be completed before the FMEA is completed.

Documentation of the Maintainability Analysis is accomplished by completing a Maintainability Information Worksheet. An example of a maintainability information worksheet is given in Figure 11. Information required for the Maintainability Analysis extracted from the FMEA is:

A. Item Identification Number (identical to FMEA, for traceability)
B. Item Nomenclature
C. Function
D. Functional Failure (Failure Mode from FMEA)
E. Engineering Failure Mode (Failure Causes from FMEA)
F. Failure Effects (Local, Next Higher, End)
G. Severity Class
H. Mission Phase
I. Compensating Provisions
J. Failure Detection Method

When recording functional failures, each functional failure should be lettered alphabetically on the maintainability analysis worksheet. Each functional failure may have multiple hardware failure modes. Therefore, each hardware failure

SYSTEM/SUBSYSTEM NOMENCLATURE		SYSTEM IDENTIFICATION NUMBER		DATE:	PREPARED BY:
INDENTURE LEVEL	NEXT HIGHER LEVEL		MISSION	SHEET of	APPROVED BY:
SYSTEM/SUBSYSTEM DESCRIPTION:				COMPENSATING PROVISIONS	

Item I.D. No.	Item Nomenclature	Function No.	Function	Functional Failure LTR	Functional Failure	Engineering Failure Mode No.	Engineering Failure Mode	Mission Phase	Failure Effects Local Effects	Failure Effects Next Higher Level	Failure Effects End Effects	Failure Detection Method	Sev. Class	Min Equip List	Engineering Failure Mode MTBF & Remarks

FIGURE 11: MAINTAINABILITY INFORMATION WORKSHEET (TASK 103)

mode should be numbered beginning with "1" and placed on the maintainability analysis worksheet.

In addition to the information derived from the FMEA, minimum equipment list, and Engineering Failure Mode MTBF information must be obtained.

The Minimum Equipment list determines whether the equipment end item can be dispatched on its assigned mission with the particular item under analysis being inoperative.

The Engineering Failure Mode MTBF is determined by calculating the MTBF for each hardware failure mode or (cause) developed from the FMEA.

6.2 Damage Mode and Effect Analysis

The Damage Mode and Effects Analysis (DMEA) is used to provide survivability and vulnerability assessments. The DMEA expands the FMEA to include data required for vulnerability assessments. This type of analysis is primarily applicable to new weapon system acquisitions. However, the DMEA can be expanded to include existing weapon systems where data is required to provide criteria for survivability.

Documentation of the DMEA is accomplished by completing a customer-approved DMEA worksheet.

The DMEA, like the maintainability analysis, requires data from the FMEA. Therefore, the Damage Mode and Effects Analysis cannot be completed before the FMEA is completed.

Information required for the DMEA extracted from the FMEA is:

A. Item Identification Number
B. Item nomenclature
C. Function
D. Failure Modes and Causes
E. Mission phase/operation
F. Severity Class

In addition to the information derived from the FMEA, all possible damage modes which could result from exposure to the specified threat mechanism(s) must be determined by analyzing each subsystem, component or part.

The consequences of each assumed damage mode on item operation, function and status must be identified. Since the damage mode under consideration can affect several indenture levels, the analysis is carried out for local, next higher level and end effects. An example of an approved DMEA worksheet is given in Figure 12.

SYSTEM_____ DATE_____

ASSEMBLY NAME_____ SHEET_____ OF_____

REFERENCE DRAWING_____ COMPILED BY_____

MISSION _____ APPROVED BY_____

I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class.	Damage Mode	Failure Effects			Remarks
							Local Effects	Next Higher Level	End Effects	

FIGURE 12: DMEA WORKSHEET (TASK 104)

7.0 FMECA REPORT

The FMECA report documents the level of analytical detail, summarizes results and identifies data sources and techniques used in performing the analysis. The FMECA report must include a description of the system, resultant analysis data, assumptions and the required task worksheets. The worksheets are to be organized such that the highest indenture level of the system is displayed first. The report should also be organized by system or assembly indenture levels or by logical functions for a functional FMECA.

Ground rules and assumptions are to be clearly documented. The report must describe and explain all steps involved in the FMECA process. These include the system definition, analysis type, severity classifications, methods for determining and using α and β, part failure rate data, and data sources. The report must explain what the analysis is, its uses, its benefits and any shortcomings. A synopsis of how to read each section of the report should also be included. Block diagrams for each indenture level should be included when applicable. All failure modes that result in category I or II severities should be separately listed. All mission critical items must be identified and highlighted.

The FMECA report will contain a system summary, as well as conclusions and recommendations based upon the analysis. The summary section includes a complete design evaluation, a list of any critical design deficiencies, and rationale for excluding items from the FMECA. Recommendations for eliminating or reducing the risks associated with each component failure must be documented. Corrective actions will be identified to resolve documented recommendations.

7.1 FMECA Review

When reviewing an FMECA report, it is important to be able to identify weaknesses in the analysis and documentation. Some common errors frequently seen by RAC engineers in FMECA reports include:

- No defined failure causes listed
- Incorrect failure classification
- Failure rate data sources not listed or included

- Lack of recommendations/corrective actions
- Incorrect system description or definition
- No ground rules or assumptions stated
- No block diagrams, where applicable
- Incorrect approach used for analysis
- Failure mode data sources not listed
- No worksheets provided
- Reckless, improper or no severity classifications provided
- Results not clearly summarized
- Beta used incorrectly
- No apportion of multiple device packages
- Mission time not used or listed
- Narrow scope of analysis

The FMECA, if performed properly, is a stand-alone document with many applications. Often, external organizations with little actual knowledge of the system, assist a program office in analyzing data items. These organizations depend heavily on the stand-alone attributes of the FMECA. Additionally, the FMECA provides valuable training and troubleshooting in-sight to technical staff learning the operation and function of that system. These reasons further warrant that a conscientious effort be placed on carefully documenting and performing the FMECA.

8.0 FMECA EXAMPLES

The following examples illustrate the most widely used methods for performing a FMECA on equipment/systems.

8.1 FMECA Example - Qualitative Approach

The communication receiver depicted in Figure 13 will be used to illustrate the functional FMECA. This example is intended to give the design/reliability engineer ideas on how to approach different types of designs. Methods similar to the one that follows can be used or combined with other analysis techniques to analyze more complex systems.

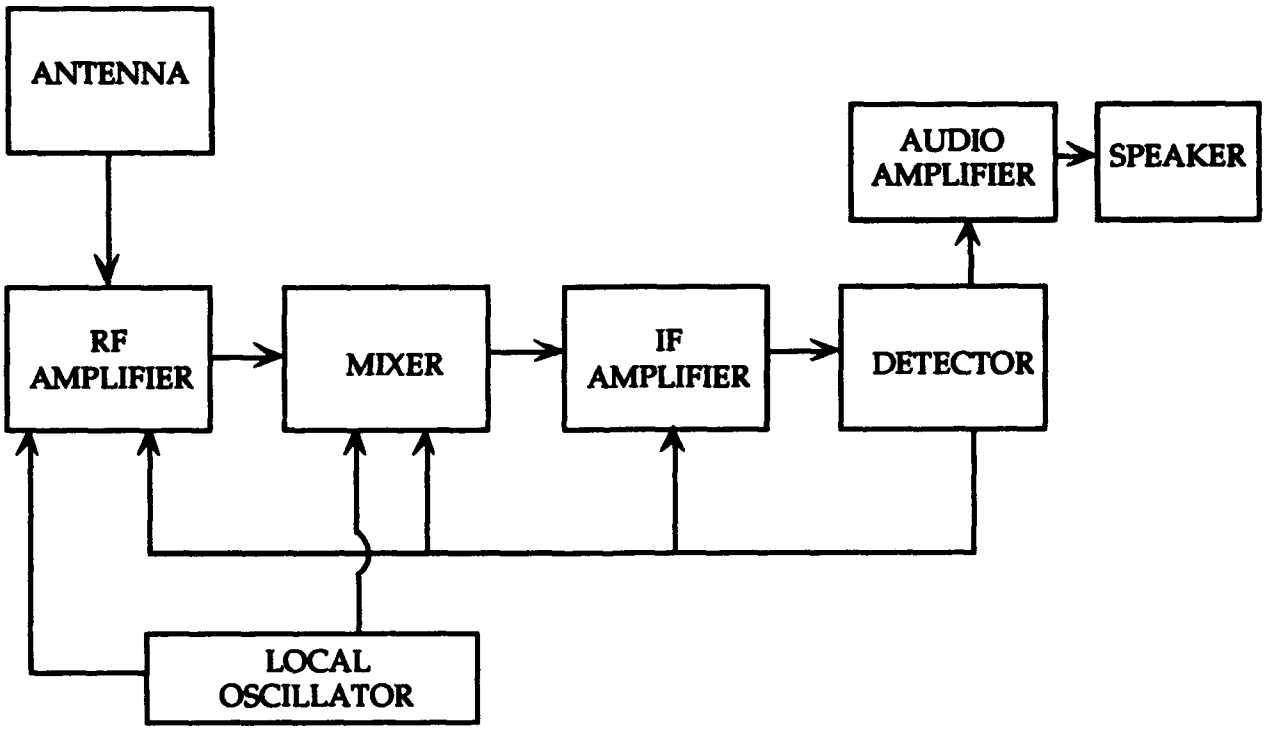


FIGURE 13: COMMUNICATION RECEIVER

8.1.1 System Definition

To start the functional FMECA, the analyst must clearly define the system. In this example, the communication receiver exists in an aircraft, and is used to receive messages transmitted from an airport control tower. The receiver is constantly

monitored by Built-In-Test-Equipment (BITE) to detect certain failures and alert the pilot by means of an audible alarm.

The system indenture levels are defined as:

Communication System	(Major System)
Receiver	(System)
Antenna	(Function)

The "Major System" is defined as the complete communication system between the tower and the aircraft (Receiver & Transmitter). This sample analysis will concentrate on the receiver design and the effects of functional failure upon the entire communication system (Major System). It should be noted that the "Major System" could have been defined as the Receiver itself (instead of the entire Communication System). In this case, the effects of functional failure would be propogated to the receiver level, not the entire communication system. The definition of the communication receiver includes the identification of each internal connection, interface connection and indenture levels.

Using the diagram in Figure 13, the following functional definitions are given to each element in the diagram.

Antenna	Responsible for conducting the transmitted signal and passing it to the RF amplifier stage.
RF Amplifier	Responsible for receiving, amplifying and delivering the incoming signal to the mixer stage of the design.
Local Oscillator	Responsible for providing a constant frequency sine wave to the RF amplifier and mixer.
Mixer	Responsible for mixing the incoming signal with the local oscillator signal to produce a signal with a constant carrier frequency.
IF Amplifier	Responsible for amplification of the intermediate frequency signal produced by the mixer.
Detector	Responsible for extracting the "intelligence" signal from the radio signal.
Audio Amplifier	Responsible for amplifying the "intelligence" signal to drive the speaker.
Speaker	Responsible for transducing the electrical "intelligence" signal into an audible signal.

The mission phase is defined as the process of receiving an incoming communication transmission. The primary mission objective is to accurately receive a transmission signal, decode the signal and allow the user to detect the signal in audible form. The primary function of the receiver is to receive and decode messages between the control tower and the aircraft pilot. The mission may be accomplished during takeoff, normal flight, and landing.

8.1.2 Ground Rules and Assumptions

The analysis ground rules and assumptions must be developed next. This analysis will be a functional FMECA performed in accordance with MIL-STD-1629A, Tasks 101 and 102, on the receiver design. Since the design is in conceptual development, a Task 103 maintainability information worksheet will not be developed at this time. All failure effects will be evaluated based on severity classifications developed by the analyst and approved by the customer. System and part failures will be categorized as such:

Classification I - System Failure - Complete loss of communication reception from control tower

Classification II - Degraded Operation - Communication reception degraded or intermittent

Classification III - Status Failure - Inability to report to the operator the correct state of the receiver

Classification IV - No Effect - No effect on communication reception, but unscheduled maintenance must be performed.

All failure modes will be derived from FMD-91 (a RAC publication), historical system data and analytical judgment of relevant potential failure modes. Only the most likely failure modes will be considered. Less likely failure modes may occur, but analysis of each could increase cost and impact schedule without having a substantial impact on the results. Built-in-test-equipment (BITE) monitors the system. Detection of a failure is announced immediately by means of an audible alarm.

A qualitative approach to criticality analysis will be used. Probability of occurrence level is defined as:

A) **Level A - Frequent:** A high probability of occurrence during the item operating time interval. High probability will be defined as a single failure mode probability greater than .20 of the overall probability of failure during the item operating time interval.

B) **Level B - Reasonably Probable:** A moderate probability of occurrence during the item operating time interval. Probability will be defined as a single failure mode probability of occurrence which is more than .10 but less than .20 of the overall probability of failure during the item operating time interval.

C) **Level C - Occasional:** An occasional probability of occurrence during the item operating time interval. Occasional probability will be defined as a single failure mode probability of occurrence which is more than .01 but less than .10 of the overall probability of failure during the item operating time interval.

D) **Level D - Remote:** An unlikely probability of occurrence during the item operating time interval. Remote probability will be defined as a single failure mode probability of occurrence which is more than .001 but less than .01 of the overall probability of failure during the item operating time interval.

E) **Level E - Extremely Unlikely:** A failure whose probability of occurrence is essentially zero during the operating time interval. Extremely unlikely probability will be defined as a single failure mode probability of occurrence which is less than .001 of the overall probability of failure during the item operating time interval.

8.1.3 FMEA

Figure 14 shows an example form of the MIL-STD-1629A, Task 101 FMEA worksheet. Each of the columns in this figure contain a letter referencing proceeding paragraphs which discuss the information required in that column. Figure 15 shows the completed Task 101 worksheets for the communication receiver example.

A) **Identification Number:** A unique number given to each entry on the FMEA worksheet used for record keeping purposes. For example, the receiver has been labeled with identification numbers, 001, 002, 003, etc...

SYSTEM_____ DATE_____

PART NAME_____ SHEET_____OF_____

REFERENCE DRAWING_____ COMPILED BY_____

MISSION _____ APPROVED BY_____

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
(A)	(B)	(C)	(D)	(E)	(F)	(G)	(H)	(I)	(J)	(K)	(L)

FIGURE 14: FMEA WORKSHEET (TASK 101)

SYSTEM Receiver DATE 3/25/92

PART NAME Unit SHEET 1 OF 3

REFERENCE DRAWING Example COMPILED BY RJB

MISSION Reception APPROVED BY AR

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
001	Antenna Output	Conducts Transmitted Signal	No Reception	Reception	Antenna Cannot Receive Incoming Trans.	Loss of Signal to Receiver	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	II	
002			Signal Leakage	Reception	Antenna Not Receiving Proper Signal	Incorrect or Incomplete Signal to Receiver	System Degraded Poor Reception	None	None	II	
003			Spurious Reception	Reception	Intermittent Signal Reception	Incomplete Signal to Receiver	System Degraded Poor Reception	None	None	II	
004	RF Amplifier Output	Amplifies RF Signals From Antenna	No Output	Reception	Loss of Antenna Signal	No Signal to Mixer	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	I	
005			Limited Voltage Gain	Reception	Weak Signal Reception	Signal to Mixer too Low or Weak	System Degraded Poor Reception	None	None	II	
006			Loss of RF Tuning Capability	Reception	Cannot Tune Antenna Signal	Incorrect Frequency to Mixer	System Disabled Loss of Reception	None	None	II	
007	Mixer Output	Mixes Incoming Local Oscillator Produces Intermed Freq.	No Output	Reception	Loss of Mixer Output Signal	Loss of Signals to IF Amp	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	II	

FIGURE 15: FMEA WORKSHEET (RECEIVER EXAMPLE)

SYSTEM Receiver
PART NAME Unit
REFERENCE DRAWING Example
MISSION Reception

DATE 3/25/92
SHEET 2 OF 3
COMPILED BY RJB
APPROVED BY AR

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
008	Mixer Output		Incorrect Output	Reception	Incorrect Mixer Signal Output	Incorrect Frequencies to IF Amp	System Disabled Loss of Comm. w/Tower	None	None	II	
009	IF Amplifier Output	Amplifies Intermediate Frequencies	No Output	Reception	Loss of Intermediate Frequency Signal	Loss of Signal to Detector	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	I	
010			Limited Voltage Gain	Reception	Weak IF Amplification	Weak Signal to Detector	System Degraded Poor Reception	None	None	II	
011			Loss of Tuning Intermediate Frequencies Capability	Reception	Cannot Tune in IF Signal	Incorrect IF to Detector	System Disabled Loss of Reception	None	None	I	
012	Detector Output	Detects Envelope of Incoming Signal	No Output	Reception	Loss of Comm. Signal	Loss of Comm. Signal to Audio Amp	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	I	
013			Intermittent Output	Reception	Intermittent Comm. Signal	Intermit Signal to Audio Amp	System Degraded Poor Reception	None	None	II	
014		Provides Feedback Sign for ACG	Loss of Feedback Signal	Reception	No Feedback Signal to Other Stages	Loss of ACG Function	System Degraded Poor Reception	None	None	II	

FIGURE 15: FMEA WORKSHEET (RECEIVER EXAMPLE) (CONT'D)

SYSTEM Receiver
PART NAME Unit
REFERENCE DRAWING Example
MISSION Reception

DATE 3/25/92
SHEET 3 OF 3
COMPILED BY RJB
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Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
015	Local Oscillator Output	Provides Constant Freq. to RF Amp & Mixer	No Output	Reception	Local Oscillator Disabled	Mixer Output Incorrect	System Disabled Loss of Comm. w/Tower	Bite Sounds Alarm	None	I	
016			Incorrect Output	Reception	Incorrect Frequency From Local Oscillator	Mixer Produces Incorrect Output	System Disabled Loss of Comm. w/Tower	None	None	I	
017			Intermittent Output	Reception	Local Oscillator Intermittent Output Signal	Mixer Produces Intermit Signal	System Degraded Poor Reception	None	None	II	
018	Audio Amplifier Output	Amplifies Comm. Signal for Speaker Output	No Output	Reception	Loss of Comm. Signal	No Output From Speaker	System Disab. Loss of Comm. w/Tower	Bite Sounds Alarm	None	I	
019			Intermittent Output	Reception	Intermittent Comm. Signal	Intermittent Output From Speaker	System Degraded Poor Reception	None	None	II	
020			Limited Voltage Gain	Reception	Weak Amplificator of Comm. Signal	Weak Speaker Output	System Degraded Poor Reception Low Volume	None	None	III	
021	Speaker Output	Transduces Electrical Comm. Signal to Audible Signal	No Output	Reception	Loss of Output From Speaker	Loss of Reception	System Disabled Loss of Comm. w/Tower	None	None	I	

FIGURE 15: FMEA WORKSHEET (RECEIVER EXAMPLE) (CONT'D)

B) **Item/Functional Identification:** A term identifying either the item or functional block of the design under consideration. For the receiver example, Antenna Output, RF Amplifier Output, etc. are listed as functional components of the receiver.

C) **Function:** A concise statement regarding the item's function. For example, the function of the Antenna Output is to conduct the transmitted signal.

D) **Failure Mode and Causes:** A concise statement on the ways in which an item can fail. In the case of the Antenna Output function, the failure modes are No Reception, Signal Leakage, and Spurious Reception.

E) **Mission Phase/Operational Mode:** A statement identifying the objective or task of the item being analyzed. The mode of operation for the items within the communication system is reception.

The failure effects analysis is completed by propagating the effects of a single point failure throughout the various system levels. The columns labeled Local Effects, Next Higher Level and End Effects house this information.

F) **Local Effects:** An explanation of the immediate resultant effect from the occurrence of the identified failure mode. The first failure mode addressed in the example is the antenna failing to receive the incoming signal (No Reception). The "local level" is defined as the antenna. The failure effect at this level is listed as the "Antenna cannot receive the incoming transmissions".

G) **Next Higher Level:** An explanation of the effect of the local failure on the next higher system indenture level. In this case, the "next higher level" is defined as the Receiver. The effect of the antenna not receiving incoming transmissions causes an effect of "Loss of signal to the receiver".

H) **End Effects:** An explanation of the effects of the indicated failure mode on the system. A loss of signal to the receiver will have an effect on the entire communication system. This effect is presented in the "End effects" column. The "system" has been defined as the entire communication system. A loss of signal to the receiver will disable the communication system and cause a loss of communication between the control tower and the pilot.

I) **Failure Detection Method:** An explanation of the means by which a failure can be identified. The Built-In-Test-Equipment (BITE) is designed to detect a failure of the antenna. The BITE will sound an audible alarm upon the occurrence of this failure. The failure will be detected by the operator.

J) **Compensating Provisions:** An explanation of the provisions made, within the design, to negate the effects of this type of failure. This design does not provide compensating provisions for this type of failure (Antenna Failure). Therefore, the word "None" is placed in the Compensating Provisions Column of the worksheet.

K) **Severity Class:** A numerical representation of the degree of damage or injury that will be caused by the occurrence of the failure mode. The failure effect of the antenna would be classified as a Category I severity - A failure that causes the complete loss of communication between the aircraft and the control tower.

L) **Remarks:** A concise statement of related details concerning the evaluation of the given failure mode that could not be contained within the other Task 101 fields.

This analysis is performed on each functional block of the Receiver system for each potential failure mode of that block.

8.1.4 Criticality Analysis

Figure 16 shows a sample form of the Task 102 worksheets as referenced by MIL-STD-1629A. Each of the columns contains a letter referencing the fields defined in the following section. Fields that are carried over from the Task 101 forms are referenced with the same letter identified in the previous section. The explanations for these fields are not repeated in this section. Figure 17 shows the completed Task 102 forms for the communication receiver.

M) **Failure Probability/Failure Rate Data Source:** In a qualitative analysis, this column is used to indicate a ranking of the probability of occurrence of an item's failure (i.e., A, B, C, etc.) see Section 8.1.2 for actual probability of occurrence levels. In a quantitative analysis, this column is used to indicate the data source for item failure rate (i.e., MIL-HDBK-217).

N) **Failure Effect Probability (β):** A numeric value representing the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs. This factor is not applicable to a qualitative analysis.

SYSTEM_____ DATE_____

PART NAME_____ SHEET_____OF_____

REFERENCE DRAWING_____ COMPILED BY_____

MISSION _____ APPROVED BY_____

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda pt$	Item CRIT # $C_r = \Sigma(C_m)$	Remarks
(A)	(B)	(C)	(D)	(E)	(K)	(M)	(N)	(O)	(P)	(Q)	(R)	(S)	(T)

FIGURE 16: CA WORKSHEET (TASK 102)

SYSTEM Receiver
PART NAME Unit
REFERENCE DRAWING Example
MISSION Reception

DATE 3/25/92
SHEET 1 OF 2
COMPILED BY RJB
APPROVED BY AR

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda pt$	Item CRIT # $C_r = \Sigma(C_m)$	Remarks
001	Antenna Output	Conduct Transmitted Signals	No Reception	Reception	I	B							
002			Signal Leakage	Reception	II	C							
003			Spurious Reception	Reception	II	B							
004	RF Amplifier Output	Amplifies RF Signals from Antenna	No Output	Reception	I	D							
005			Limited Volt Gain	Reception	II	C							
006			Loss of RF Tuning Capability	Reception	I	E							
007	Mixer Output	Mixes Incoming & Local Oscillator Produces Provides IF	No Output	Reception	I	D							
008			Incorrect Output	Reception	I	D							
009	IF Amplifier Output	Amplifies Intermediate Frequencies	No Output	Reception	I	D							
010			Limited Voltage Gain	Reception	II	C							
011			Loss of Tuning IF Capability	Reception	I	D							
012	Detector Output	Detects Envelope of Incoming Signal	No Output	Reception	I	D							

FIGURE 17: CA WORKSHEET (RECEIVER EXAMPLE)

SYSTEM Receiver
PART NAME Unit
REFERENCE DRAWING Example
MISSION Reception

DATE 3/25/92
SHEET 2 OF 2
COMPILED BY RJB
APPROVED BY AR

Identification Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda pt$	Item CRIT # $C_r = \Sigma(C_m)$	Remarks
013			Intermittent Output	Reception	II	C							
004	Detector Output	Provides Feedback Signal for AGC	Loss of Feedback Signal	Reception	II	C							
005	Local Oscillator Output	Provides Constant Frequent to RF Amplifier Mixer	No Output	Reception	I	D							
006			Incorrect Output	Reception	I	C							
007			Intermittent Output	Reception	II	D							
008	Audio Amplifier Output	Amplifies Comm. Signal for Speaker Output	No Output	Reception	I	D							
009	Audio Amplifier Output	Amplifies Comm. Signal for Speaker Output	Intermittent Output	Reception	II	D							
010			Limited Voltage Gain	Reception	III	C							
011	Speaker Output	Transduces Electrical Comm. Signal to Audible Signal	No Output	Reception	I	E							

FIGURE 17: CA WORKSHEET (RECEIVER EXAMPLE) (CONT'D)

O) **Failure Mode Ratio (α):** This is the probability, expressed as a decimal fraction, that the given part or item will fail in the identified mode. This factor is not applicable to a qualitative analysis.

P) **Failure Rate (λ_p):** A numerical representation of the number of expected failures for a given item over a specified period of time. This may be a predicted or estimated value and is commonly expressed in failures per million hours. This factor is not applicable to a qualitative analysis.

Q) **Operating Time (t):** The total operating time that the indicated item is expected to function during the mission scenario. The value commonly used is the total life cycle time of the equipment. This factor is not applicable to a qualitative analysis.

R) **Failure Mode Criticality (C_m):** A relative measure of consequence of a failure mode and its frequency of occurrence. This factor is not applicable to a qualitative analysis.

S) **Item Criticality (C_r):** A relative measure of consequence of an item failure and its frequency of occurrence. This factor is not applicable to a qualitative analysis.

T) **Remarks:** A concise statement of related details concerning the evaluation of the given failure mode that could not be contained within the other Task 102 fields.

Figure 18 shows a sample form of the Task 103 worksheets as referenced by MIL-STD-1629A. Each of the columns contains a letter referencing the fields defined in the following section. Fields that are carried over from the Task 101 forms are referenced with the same letter identified in the previous section. The explanations for these fields are not repeated in this section. There are no completed Task 103 forms for the communication receiver since a maintainability analysis was not performed. An example of the Task 103 analysis is illustrated in the next example (quantitative analysis).

U) **Engineering Failure Mode:** Any failure causes from Task 101 Item (D) that relate to or result in the identified functional failure mode. There may be many engineering failure modes per functional failure.

V) **Minimum Equipment List:** If the system remains deployable with the analysis item inoperative, document any known limitations regarding system performance in this block.

SYSTEM/SUBSYSTEM NOMENCLATURE		SYSTEM IDENTIFICATION NUMBER		DATE:	PREPARED BY:
INDENTURE LEVEL	NEXT HIGHER LEVEL		MISSION	SHEET of	APPROVED BY:
SYSTEM/SUBSYSTEM DESCRIPTION: Task 103				COMPENSATING PROVISIONS	

Item I.D. No.	Item Nomenclature	Function		Functional Failure		Engineering Failure Mode		Mission Phase	Failure Effects			Failure Detection Method	Sev. Class	Min Equip List	Engineering Failure Mode MTBF & Remarks
		No.		LTR		No.			Local Effects	Next Higher Level	End Effects				
(A)	(B)		(C)		(D)		(U)	(E)	(F)	(G)	(H)	(I)	(K)	(V)	(W)

FIGURE 18: MAINTAINABILITY INFORMATION (TASK 103)

W) **Engineering Failure Mode MTBF & Remarks:** The mean/average time between occurrences of the indicated failure mode or failure causes. Also include a concise statement of related details concerning the evaluation of the given failure mode that could not be contained within the other Task 103 fields.

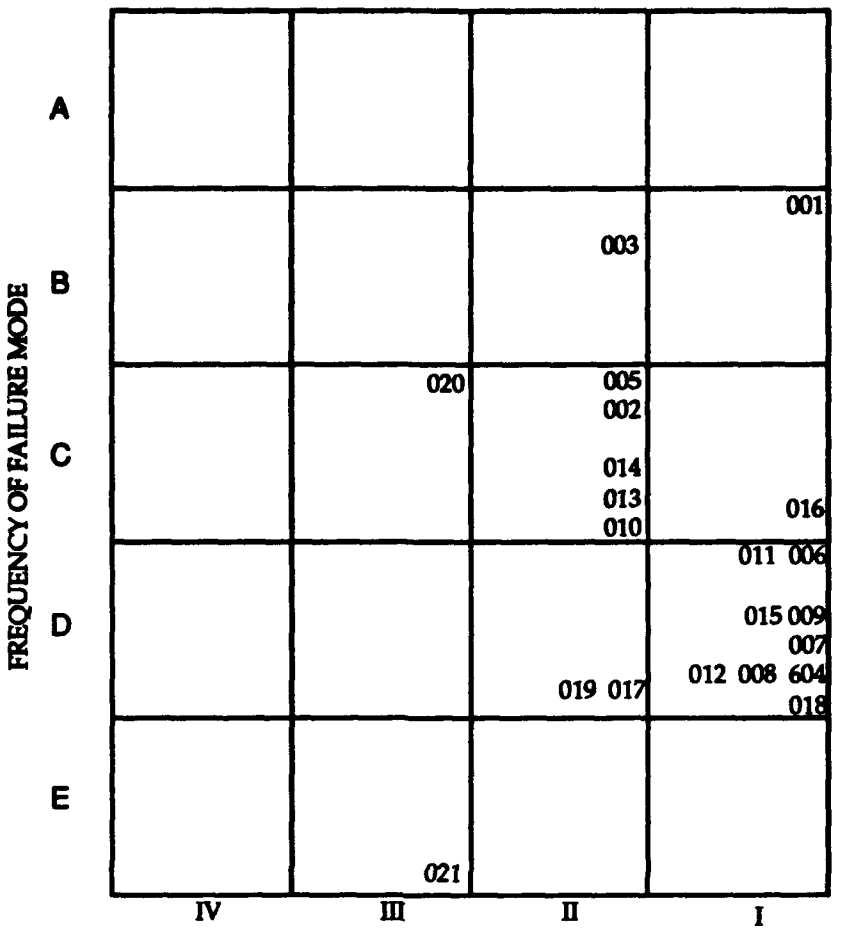
8.1.5 Criticality Matrix

A Criticality ranking of each functional item must be completed to determine the most critical failure modes and provide a basis for providing design improvement recommendations. A qualitative criticality matrix for the aircraft receiver is shown in Figure 19. Each failure mode is labeled in the matrix according to its identification number. From this matrix it is evident that certain failure modes are more critical than others. In Figure 19, the most mission critical failure mode is ID # 001. This ID number corresponds to loss of output signal from the antenna. A loss of the output signal from the antenna has a high probability of occurrence. This is based on the analyst's judgment. The end effect of this failure mode results in a loss of communication between the control tower and the pilot, which is a hazardous scenario. Therefore, the end effect has been classified a severity level of I.

8.1.6 Recommendations

Recommendations must be made to prevent or compensate for this possible failure mode. One recommendation that may be made is to provide a redundant antenna for signal reception. Should one antenna fail, the other antenna could be used to compensate for the loss of the first antenna. Furthermore, a backup means of radio communication should be provided to the pilot. This would compensate for this failure mode and other failure modes that cause severity II end effects.

Failure mode 016 is ranked as the second most critical failure mode. This failure mode corresponds to the local oscillator producing an incorrect output. A recommendation must be developed to compensate for or eliminate the possible occurrence of this failure mode. Since the stability of the local oscillator is critical to the mission, a recommendation should be made requiring the use of high quality parts in the design of the local oscillator. This may eliminate or reduce local oscillator drift. Another recommendation may be to perform a Worst Case Circuit



ID#	Item/Function	Failure Mode
001	Antenna Output	No Reception
002	Antenna Output	Signal Leakage
003	Antenna Output	Spurious Reception
004	RF Amp. Output	No Output
005	RF Amp. Output	Limited Voltage Gain
006	RF Amp. Output	Loss of RF Tuning Capability
007	Mixer Output	No Output
008	Mixer Output	Incorrect Output
009	IF Amplifier Output	No Output
010	IF Amplifier Output	Limited Voltage Gain
011	IF Amplifier Output	Loss of IF Tuning Capability
012	Detector Output	No Output
013	Detector Output	Intermittent Output
014	Detector Output	Loss of FB Signal
015	Local Oscillator Output	No Output
016	Local Oscillator Output	Incorrect Output
017	Local Oscillator Output	Intermittent Output
018	Audio Amplifier Output	No Output
019	Audio Amplifier Output	Intermittent Output
020	Audio Amplifier Output	Limited Voltage Gain
021	Speaker Output	No Output

FIGURE 19: CRITICALITY MATRIX (FAILURE MODES)

Analysis on the local oscillator circuitry. This analysis will determine effects of aging, temperature and other environmental conditions on the local oscillator circuitry over its operational lifetime.

8.2 FMECA Example - Quantitative Approach

The following is an example of a quantitative approach to FMECA. The example shown is a FMECA of the 5VDC Regulator displayed in Figure 20. This regulator serves as the regulated power supply for a security system. The structure of the security system will be kept simple for example purposes and only the 5VDC regulator sub-system will be detailed. The system structure is shown here for the purpose of defining next higher level and end effects of component failure within the 5VDC regulator. The steps followed in this example will adhere to the FMECA analysis process detailed in Section 5.1.

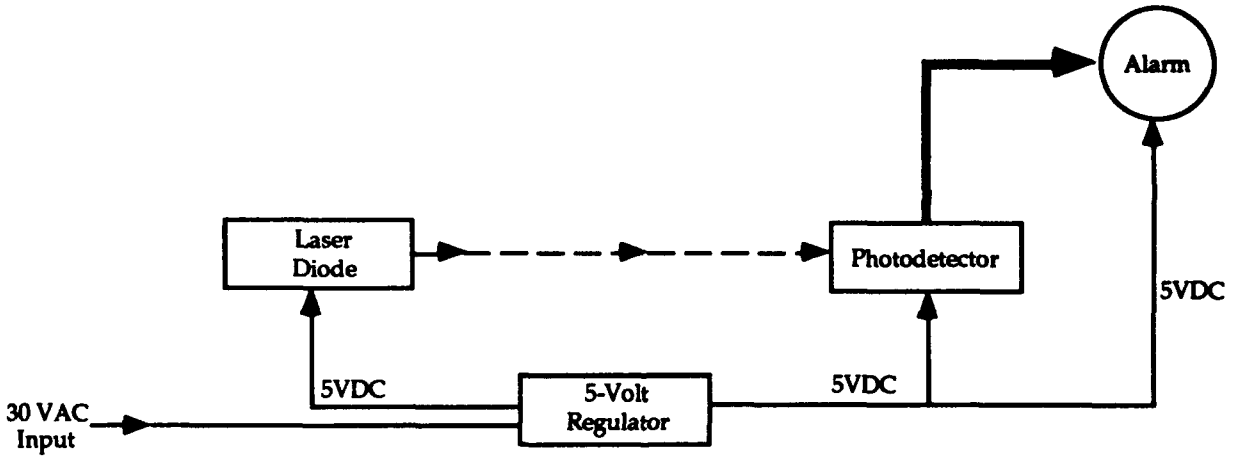


FIGURE 20: SECURITY SYSTEM BLOCK DIAGRAM

8.2.1 System/Item Indenture Level Definitions

The security system is designed as a simplified, single-purpose intrusion detection system. Its function is to set up an invisible beam of light across the entrance of any room, office, store, etc. When the light path is interrupted the alarm will sound.

Since the 5VDC regulator circuit is being studied in detail in this example, the schematic diagram for this unit is provided in Figure 21. The following describes the security system's major subassemblies.

Laser Diode Provides the signal received by the photodetector. The frequency is above the visible range and can be detected only by the photodetector circuitry.

Photodetector Receives the signal transmitted by the Laser Diode. When the photodetector is triggered by the incoming light signal it will deactivate the alarm. If the incoming signal is broken, it will cause the alarm to sound.

Alarm A 5VDC audio alarm used to give indication of an intrusion into the defined zone.

5VDC Regulator Provides the required source voltage to the security system. The regulator's power requirement is a 30VAC input. Diode CR3 provides half-wave rectification for the AC signal. R1 provides a means of current limiting for the source. Since half-wave rectification produces a large amount of ripple in the output signal, a 47μF capacitor (C11) is used for initial filtering. The series regulator circuit is constructed from R16, C9, R41, Q1, and CR10. CR10 is a 5.6VDC zener diode. It is used to set-up a fixed bias voltage input to the base of Q1. This will set the regulator output voltage to 5V since $V_{out} = V_{zener} - V_{be}$ (5.0VDC = 5.6VDC - 0.6VDC). Q1 is used as an emitter follower to pass the load current. R41 serves as protection for Q1 by limiting the maximum allowable load current so as not to exceed the maximum rating of Q1. R16 provides base current limiting and current limiting for CR10. Since the voltage at the cathode of CR10 may still have substantial ripple, C9 is used to filter high frequencies and smooth the biasing signal at the base of Q1. The final stage of the circuit has two capacitors used as output filters. C10 is a .01μF capacitor used to filter any high frequency noise from the line. C15 is a 3.3μF capacitor that will filter any remaining ripple voltage. The circuit output is a regulated 5VDC used to power the Laser Diode, Photodetector, and Alarm circuitry.

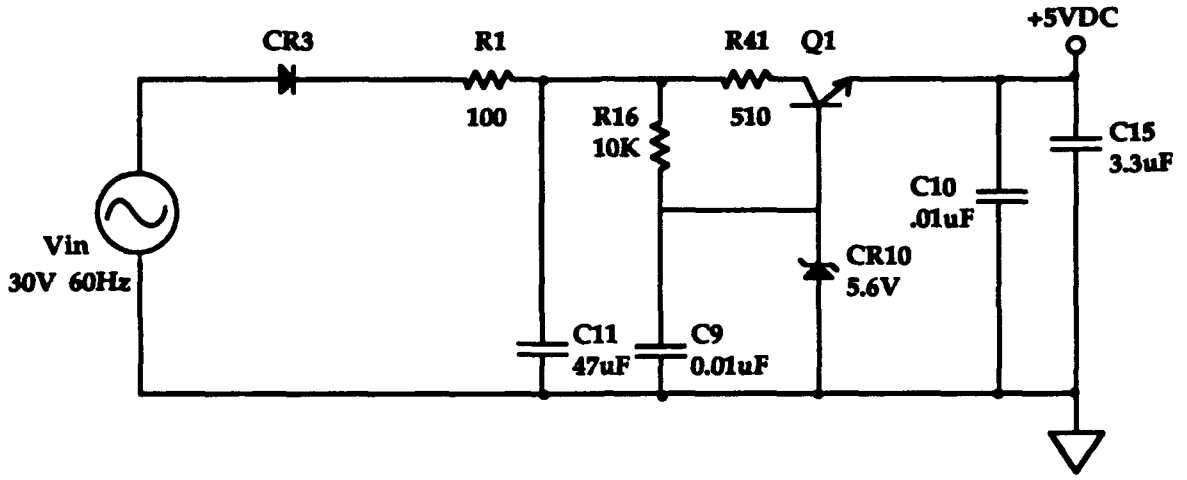


FIGURE 21: 5VDC REGULATOR

The mission phase is defined as being both the "scan" and "alert" modes of operation. The security system is being used in a retail store, operating 12 hours per day. The life expectancy for the system is 10 years or 43,800 operational hours. The primary mission objective is to sound the alarm as a result of intrusion. All end level failure effects will be classified according to their severity and are subject to customer approval. These classifications are given as follows:

Category I (Catastrophic) - (Loss of Alarm)	A failure that would cause the loss of alarm leaving an intrusion undetected.
Category II (Critical) - (False Alarm)	A failure what would cause a false alarm.
Category III (Marginal) - (Degraded Operation)	A failure that would cause degraded operation of the system, but system would currently remain functional.
Category IV (Minor) - (No Effect)	A failure that will alter system operation so slightly that it will cause no noticeable end effect.

8.2.2 System Block Diagram

The block diagram for the security system is shown in Figure 20.

8.2.3 Ground Rules and Assumptions

The FMECA has been completed by utilizing the available schematic diagrams, part data sheets, and flowcharts which depict the unit and its operation. It is assumed that all available system options are selected. The FMECA and corresponding report are presented in a bottom-up approach. It will be done in accordance with MIL-STD-1629A, Notice 2, Tasks 101, 102 and 103. This approach examines each component failure mode individually to determine its effect and criticality at the functional and system levels.

The system is assumed to be operating in a ground-fixed environment at an operating temperature of 20°C.

The (β) values are the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs. Since the design of the regulator is straightforward in terms of the function of each component, the failure of each component produces a distinct effect. Since there are no multiple effects associated with any failure mode, a β value of 1 is applicable for each Task 102 entry.

For the purpose of this example, it is assumed that a reliability part stress prediction was performed on all of the components within the 5VDC regulator circuitry according to MIL-HDBK-217E, Part Stress Method. The component failure rates from this analysis are as follows:

Component	Type	Style	Failure Rate (failures/million hours)
C9	Capacitor	Ceramic	.014
C10	Capacitor	Ceramic	.002
C11	Capacitor	Tantalum Elec.	.010
C15	Capacitor	Tantalum	.089
CR3	Diode	Rectifier	.123
CR10	Diode	Zener	.345
Q1	Transistor	Bipolar	.502
R1	Resistor	Fixed Film	.004
R16	Resistor	Fixed Film	.003
R41	Resistor	Fixed Film	.005

8.2.4 Failure Modes

Failure mode information for each component type is presented in Table 2. These values were derived from Failure Mode/Mechanism Distributions (FMD-91), a Reliability Analysis Center publication.

TABLE 2: PART FAILURE MODE DISTRIBUTIONS

Device Type	Failure Mode	Failure Mode Probability (α)
Capacitor, Ceramic	Short	.49
	Change in Value	.29
	Open	.22
Capacitor, Tantalum	Short	.57
	Open	.32
	Change in Value	.11
Capacitor, Tantalum, Electrolytic	Short	.69
	Open	.17
	Change in Value	.14
Diode, Rectifier	Short	.51
	Open	.29
	Parameter Change	.20
Diode, Zener, Voltage Regulator	Open	.45
	Parameter Change	.35
	Short	.20
Resistor, Fixed, Film	Open	.59
	Parameter Change	.36
	Short	.05
Transistor, Bipolar	Short	.73
	Open	.27

8.2.5 Failure Effects/Causes Analysis

The failure effects/causes analysis is completed in the Task 101 worksheets as referenced in MIL-STD-1629A. Figure 22 details the Task 101 worksheets for the 5VDC regulator circuit as part of the security system.

8.2.6 Failure Mode/Item Criticality Calculations

The failure mode/item criticality calculations are presented in the Task 102 worksheets as referenced in MIL-STD-1629A. Figure 23 details the Task 102 worksheets for the 5VDC regulator circuit as part of the security system.

SYSTEM Security System

ASSEMBLY NAME 5VDC Regulator

REFERENCE DRAWING A123

MISSION Intrusion Detection

SHEET 1

COMPILED BY SLP

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
001	CR3 Rectifier Diode	Half-Wave Rectifier	Short	Intrusion Detection	Loss of rectification of Vin	Loss of fixed 5VDC output	Loss of Alarm	None	None	I	
002			Open	Intrusion Detection	Loss of current to series regulator	Loss of output from 5VDC Regulator	Loss of Alarm	None	None	I	
003			Parameter Change	Intrusion Detection	Slight change in rectified voltage level	No change in output voltage	No effect	None	None	IV	
004	R1 Resistor Fixed Film 100 ohms	Current limit	Open	Intrusion Detection	Loss of current to series regulator	Loss of output from 5VDC Regulator	Loss of Alarm	None	None	I	
005			Parameter Change	Intrusion Detection	Slight change in input voltage level to Q1	No change in output voltage	No effect	None	None	IV	
006			Short	Intrusion Detection	Loss of current limiting protection	Possible overstress of circuit	Degraded operation	None	None	III	
007	C11 Capacitor Tantalum Elec 47µF	Filter	Short	Intrusion Detection	Loss of current supply to Q1	No output from 5VDC Regulator	Loss of Alarm	None	None	I	High current draw through CR3, R1, possible damage
008			Open	Intrusion Detection	Loss of filter for series regulator input	Possible instability in 5VDC output voltage	Degraded operation	None	None	III	

FIGURE 22: FAILURE MODE AND EFFECTS ANALYSIS (TASK 101)

SYSTEM Security System
ASSEMBLY NAME 5VDC Regulator
REFERENCE DRAWING A123
MISSION Intrusion Detection

DATE 3/31/92
SHEET 2 OF 4
COMPILED BY SLP
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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
009	C11 (continued)	Filter	Change in Value	Intrusion Detection	Slight change in filter performance	No change in output voltage	No effect	None	None	IV	
010	R16 Resistor Fixed Film 10,000 ohms	Base current source for Q1	Open	Intrusion Detection	Loss of bias current to Q1	No output from 5VDC Regulator	Loss of Alarm	None	None	I	
011			Parameter Change	Intrusion Detection	Slight variation in current through CR10	Possible slight drift in output voltage level	Degraded operation	None	None	III	
012			Short	Intrusion Detection	Excessive current through CR10	Q1 biased at 30VDC- output to 30VDC	Loss of alarm	None	None	I	Damage to CR10
013	C9 Capacitor Ceramic .01μF	Filter	Short	Intrusion Detection	Loss of bias current to Q1	No output from 5VDC Regulator	Loss of Alarm	None	None	I	
014			Change in Value	Intrusion Detection	Slight change in filter performance	No change in output voltage	No effect	None	None	IV	
015			Open	Intrusion Detection	Loss of filter for biasing circuit	Possible ripple in 5VDC output voltage	Degraded operation	None	None	III	
016	R41 Resistor Fixed Film 510 ohms	Current limit for series regulator	Open	Intrusion Detection	Loss of current to series regulator	No output from 5VDC Regulator	Loss of Alarm	None	None	I	

FIGURE 22: FAILURE MODE AND EFFECTS ANALYSIS (TASK 101) (CONT'D)

SYSTEM Security System

ASSEMBLY NAME 5VDC Regulator

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

SHEET 3 OF 4

COMPILED BY SLP

APPROVED BY RJB

I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
017	R41 (continued)	Current limiting for series regulator	Parameter Change	Intrusion Detection	Slight change in input current level to Q1	No effect	No effect	None	None	IV	
018			Short	Intrusion Detection	Loss of current limiting protection of Q1	Possible overstress of Q1	Degraded operation	None	None	III	
019	CR10 Zener Diode Voltage Regulator	Provides 5.6VDC bias voltage for Q1	Open	Intrusion Detection	Loss of regulated bias voltage to Q1	Output will rise to 30VDC. possible damage to system components	Degraded operation	None	None	III	
020			Parameter Change	Intrusion Detection	Slight variation in bias voltage to Q1	Drift in output voltage level	Degraded operation	None	None	III	
021			Short	Intrusion Detection	Loss of bias voltage to Q1	Loss of output	Loss of alarm	None	None	I	
022	Q1 NPN Transistor 2N6428	Provides output current at a regulated 5VDC	Short	Intrusion Detection	Loss of regulation	Output will rise to 30VDC. Probable damage to system components	Degraded operation	None	None	III	
023			Open	Intrusion Detection	Loss of current to output	Loss of output	Loss of alarm	None	None	IV	

FIGURE 22: FAILURE MODE AND EFFECTS ANALYSIS (TASK 101) (CONT'D)

SYSTEM Security System

ASSEMBLY NAME 5VDC Regulator

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

SHEET 4 OF 4

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Failure Effects			Failure Detection Method	Compensating Provisions	Severity Class	Remarks
					Local Effects	Next Higher Level	End Effects				
024	C10 Capacitor Ceramic .01μF	Filter	Short	Intrusion Detection	Q1 output shorted to ground	Loss of output from 5VDC Regulator	Loss of alarm	None	None	I	Over current damage to Q1
025			Change in Value	Intrusion Detection	Slight change in filter performance	No effect	No effect	None	None	IV	
026			Open	Intrusion Detection	Loss of high frequency filter on output	Possible high freq. noise in 5VDC output voltage	Degraded operation	None	None	III	
027	C15 Capacitor Tantalum 3.3μF	Filter	Short	Intrusion Detection	Q1 output shorted to ground	Loss of output from 5VDC Regulator	Loss of alarm	None	None	I	
028			Open	Intrusion Detection	Loss of ripple filter on output	Possible ripple in 5VDC output voltage	Degraded operation	None	None	III	
029			Change in Value	Intrusion Detection	Slight change in filter performance	No effect	No effect	None	None	IV	

FIGURE 22: FAILURE MODE AND EFFECTS ANALYSIS (TASK 101) (CONT'D)

SYSTEM Security System

ASSEMBLY NAME 5VDC Regulator

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

SHEET 1 OF 2

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda pt$	Item CRIT # $C_r = \Sigma(C_m)$	Remarks
001	CR3 Rectifier Diode	Half-Wave Rectifier	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.51	$.123 \times 10^{-6}$	43,800	2.747×10^{-3}	4.309×10^{-3}	
002			Open	Intrusion Detection	I	MIL-HDBK-217E	1	.29	$.123 \times 10^{-6}$	43,800	1.562×10^{-3}		
003			Parameter Change	Intrusion Detection	IV	MIL-HDBK-217E	1	.20	$.123 \times 10^{-6}$	43,800	1.077×10^{-3}	1.077×10^{-3}	
004	R1 Resistor Fixed Film 100 ohms	Current limit	Open	Intrusion Detection	I	MIL-HDBK-217E	1	.59	$.004 \times 10^{-6}$	43,800	$.103 \times 10^{-3}$	$.103 \times 10^{-3}$	
006			Short	Intrusion Detection	III	MIL-HDBK-217E	1	.05	$.004 \times 10^{-6}$	43,800	$.009 \times 10^{-3}$	$.009 \times 10^{-3}$	
005			Parameter Change	Intrusion Detection	IV	MIL-HDBK-217E	1	.36	$.004 \times 10^{-6}$	43,800	$.063 \times 10^{-3}$	$.063 \times 10^{-3}$	
007	C11 Capacitor Tantalum Elec. 47μF	Filter	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.59	$.010 \times 10^{-6}$	43,800	$.302 \times 10^{-3}$	$.302 \times 10^{-3}$	
008			Open	Intrusion Detection	III	MIL-HDBK-217E	1	.17	$.010 \times 10^{-6}$	43,800	$.074 \times 10^{-3}$	$.074 \times 10^{-3}$	
009			Change in Value	Intrusion Detection	IV	MIL-HDBK-217E	1	.14	$.010 \times 10^{-6}$	43,800	$.061 \times 10^{-3}$	$.061 \times 10^{-3}$	
010	R16 Resistor Fixed Film 10,000 ohms	Base current source for Q1	Open	Intrusion Detection	I	MIL-HDBK-217E	1	.59	$.003 \times 10^{-6}$	43,800	$.078 \times 10^{-3}$	$.085 \times 10^{-3}$	
012			Short	Intrusion Detection	I	MIL-HDBK-217E	1	.05	$.003 \times 10^{-6}$	43,800	$.007 \times 10^{-3}$		
011			Parameter Change	Intrusion Detection	III	MIL-HDBK-217E	1	.36	$.003 \times 10^{-6}$	43,800	$.047 \times 10^{-3}$	$.047 \times 10^{-3}$	
013	C9 Capacitor Ceramic .01μF	Filter	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.49	$.014 \times 10^{-6}$	43,800	$.300 \times 10^{-3}$	$.300 \times 10^{-3}$	
015			Open	Intrusion Detection	III	MIL-HDBK-217E	1	.22	$.014 \times 10^{-6}$	43,800	$.135 \times 10^{-3}$	$.135 \times 10^{-3}$	
014			Change in Value	Intrusion Detection	IV	MIL-HDBK-217E	1	.29	$.014 \times 10^{-6}$	43,800	$.178 \times 10^{-3}$	$.178 \times 10^{-3}$	

FIGURE 23: CRITICALITY ANALYSIS (TASK 102)

SYSTEM Security System

ASSEMBLY NAME 5VDC Regulator

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

SHEET 2 OF 2

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APPROVED BY RJB

LD. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Mission Phase/ Operational Mode	Severity Class	Failure Probability / Failure Rate Data Source	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha\lambda pt$	Item CRIT # $C_r = \Sigma(C_m)$	Remarks
016	R41 Resistor Fixed Film 510 ohms	Current limit for series regulator	Open	Intrusion Detection	I	MIL-HDBK-217E	1	.35	.005 x 10^{-6}	43,800	.129 x 10^{-3}	.129 x 10^{-3}	
018			Short	Intrusion Detection	III	MIL-HDBK-217E	1	.08	.005 x 10^{-6}	43,800	.011 x 10^{-3}	.011 x 10^{-3}	
017			Parameter Change	Intrusion Detection	IV	MIL-HDBK-217E	1	.57	.005 x 10^{-6}	43,800	.079 x 10^{-3}	.079 x 10^{-3}	
021	CR10 Zener Diode Voltage Regulator	Provides 5.6VDC bias voltage for Q1	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.25	.345 x 10^{-6}	43,800	3.022 x 10^{-3}	3.022 x 10^{-3}	
019			Open	Intrusion Detection	III	MIL-HDBK-217E	1	.45	.345 x 10^{-6}	43,800	6.500 x 10^{-3}	12.089 x 10^{-3}	
020			Parameter Change	Intrusion Detection	III	MIL-HDBK-217E	1	.33	.345 x 10^{-6}	43,800	5.289 x 10^{-3}		
022	Q1 NPN Transistor 2N6428	Provides output current at a regulated 5VDC	Short	Intrusion Detection	III	MIL-HDBK-217E	1	.73	.502 x 10^{-6}	43,800	16.051 x 10^{-3}	16.051 x 10^{-3}	
023			Open	Intrusion Detection	IV	MIL-HDBK-217E	1	.27	.502 x 10^{-6}	43,800	5.937 x 10^{-3}	5.937 x 10^{-3}	
024	C10 Capacitor Ceramic .01μF	Filter	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.49	.002 x 10^{-6}	43,800	.043 x 10^{-3}	.043 x 10^{-3}	
026			Open	Intrusion Detection	III	MIL-HDBK-217E	1	.22	.002 x 10^{-6}	43,500	.019 x 10^{-3}	.019 x 10^{-3}	
025			Change in Value	Intrusion Detection	IV	MIL-HDBK-217E	1	.29	.002 x 10^{-6}	43,800	.025 x 10^{-3}	.025 x 10^{-3}	
027	C15 Capacitor Tantalum 3.3μF	Filter	Short	Intrusion Detection	I	MIL-HDBK-217E	1	.57	.089 x 10^{-6}	43,800	2.222 x 10^{-3}	2.222 x 10^{-3}	
028			Open	Intrusion Detection	III	MIL-HDBK-217E	1	.32	.089 x 10^{-6}	43,800	1.247 x 10^{-3}	1.247 x 10^{-3}	
029			Change in Value	Intrusion Detection	IV	MIL-HDBK-217E	1	.11	.089 x 10^{-6}	43,800	.429 x 10^{-3}	.429 x 10^{-3}	

FIGURE 23: CRITICALITY ANALYSIS (TASK 102) (CONT'D)

8.2.7 Maintainability Information

Maintainability information is presented in the Task 103 worksheets as referenced in MIL-STD-1629A. Figure 24 details the Task 103 worksheets for the 5VDC regulator circuit as part of the security system.

8.2.8 Criticality Ranking

The criticality ranking for the items within the 5VDC regulator circuitry of the security system is presented in this section. The criticality ranking can be displayed in a number of ways. First, the criticality matrix is used to plot the Failure Mode Criticality vs. Severity of the Failure Effect as shown in Figure 25. Figure 26 displays an item criticality ranking which lists the unit's critical items in descending order, based on item criticality (Cr). Lastly, Figure 27 shows a failure mode criticality ranking which lists the unit's critical failure modes in descending order, based on failure mode criticality (Cm). The ranking worksheets are not required by MIL-STD-1629A but offer insight into critical design areas.

8.2.9 Results and Recommendations

The results of the criticality analysis indicate that the items requiring re-design attention are ID #s 021, 001, 027 and 002 which correspond to components CR10, C15 and CR3, since failure modes in each of these devices have high criticality rankings in the Level 1 severity class. Both the "open" and "short" modes of failure for CR3 will cause catastrophic failure effects, while only the "short" mode for CR10 and C15 will cause catastrophic effects. The largest contributing factor to the high criticality numbers of these devices is their high failure rates with respect to the other devices in the regulator circuit. The design should be modified to incorporate better quality diodes with higher forward current ratings in place of CR3 and CR10 in their respective circuit locations.

SYSTEM/SUBSYSTEM NOMENCLATURE Security System		SYSTEM IDENTIFICATION NUMBER ABC-1		DATE: 3/31/92	PREPARED BY: SLP
INDENTURE LEVEL A123	NEXT HIGHER LEVEL ABC-1	MISSION Intrusion Detection		SHEET 1 of 3	APPROVED BY: RJD
SYSTEM/SUBSYSTEM DESCRIPTION: Provides a regulated 5VDC supply to the Laser Diode, Photodetector, and Alarm circuitry of the security system				COMPENSATING PROVISIONS None	

Item I.D. No.	Item Nomenclature	Function No.	Function	Functional Failure LTR	Functional Failure	Engineering Failure Mode No.	Engineering Failure Mode	Mission Phase	Failure Effects: Local Effects	Failure Effects: Next Higher Level	Failure Effects: End Effects	Failure Detection Method	Sev. Class	Min Equip List	Engineering Failure Mode MTBF & Remarks
001	CR3 Rectifier Diode	1	Half-Wave	a	Short	1	Seal Failure	Intrusion Detection	Loss of rectification of Vin	Loss of fixed 5VDC output	Loss of Alarm	None	I	No	15.94 x 10^6 hrs.
002				b	Open	1	Poor Die Attachment	Intrusion Detection	Loss of current to series regulator	Loss of output from 5VDC Regulator	Loss of Alarm	None	I	No	28.03 x 10^6 hrs.
003				c	Para-meter Change	1	Contami-nated	Intrusion Detection	Small change in rectified voltage level	No change output voltage	No effect	None	IV	Yes	40.65 x 10^6 hrs.
004	R1 Resistor Fixed Film 100 ohms	1	Current limit	a	Open	1	Internal Connection Failure	Intrusion Detection	Loss of current to series regulator	Loss of output from 5VDC Regulator	Loss of alarm	None	I	No	423.73 x 10^6 hrs.
005				b	Para-meter Change	1	Contami-nated		Small change in input voltage level to Q1	No change in output voltage	No effect	None	IV	Yes	694.44 x 10^6 hrs.
006				c	Short	1	Substrate Defects	Intrusion Detection	Loss of current limiting protection	Possible overstress of circuit	Possible loss of alarm	None	III	Yes	5000 x 10^6 hrs.
007	C11 Capacitor Tantalum Elec 47µF	1	Filter	a	Short	1	Dielectric Breakdown	Intrusion Detection	Loss of current supply to Q1	No output from 5VDC Regulator	Loss of alarm	None	I	No	144.93 x 10^6 hrs. High current draw through CR3, R1, possible damage
008				b	Open	1	Contami-nated	Intrusion Detection	Loss of filter for series regulator input	Possible instability in 5VDC output voltage	Possible loss of alarm	None	III	Yes	588.24 x 10^6 hrs.
009				c	Change in Value	1	Contaimi-nated	Intrusion Detection	Slight change in filter performance	No change in output voltage	No effect	None	IV	No	714.29 x 10^6 hrs.
010	R16 Resistor Fixed Film 10,000 ohms	1	Base current source for Q1	a	Open	1	Internal Connection Failure	Intrusion Detection	Loss of bias current to Q1	No output from 5VDC Regulator	Loss of alarm	None	I	No	564.97 x 10^6 hrs.
011				b	Para-meter Change	1	Contami-nated	Intrusion Detection	Change in current through CR10	Drift in output voltage level	Possible loss of alarm	None	III	Yes	925.93 x 10^6 hrs.

FIGURE 24: MAINTAINABILITY INFORMATION (TASK 103)

SYSTEM/SUBSYSTEM NOMENCLATURE		SYSTEM IDENTIFICATION NUMBER	DATE: 3/31/92	PREPARED BY: SLP
Security System		ABC-1		
INDENTURE LEVEL	NEXT HIGHER LEVEL	MISSION	SHEET 2 of 3	APPROVED BY: RJB
A123	ABC-1	Intrusion Detection		
SYSTEM/SUBSYSTEM DESCRIPTION: Provides a regulated 5VDC supply to the Laser Diode, Photodetector, and Alarm circuitry of the security system			COMPENSATING PROVISIONS: None	

Item LD. No.	Item Nomenclature	Function No.	Function	Functional Failure LTR	Functional Failure	Engineering Failure Mode No.	Engineering Failure Mode	Mission Phase	Failure Effects: Local Effects	Failure Effects: Next Higher Level	Failure Effects: End Effects	Failure Detection Method	Sev. Class	Min Equip List	Engineering Failure Mode MTBF & Remarks
012				c	Short	1	Substrate Defects	Intrusion Detection	Excessive current through CR10	Q1 based at 30VDC output rises to 30VDC	Loss of alarm	None	I	No	6666.67 x 10^6 hrs. Damage to CR10
013	C9 Capacitor Ceramic .01μF	1	Filter	a	Short	1	Cracked Dielectric	Intrusion Detection	Loss of bias current to Q1	No output from 5VDC Regulator	Loss of alarm	None	I	No	145.77 x 10^6 hrs.
014				b	Change in value	1	Contaminated	Intrusion Detection	Slight change in filter performance	No change in output voltage	No effect	None	IV	Yes	246.31 x 10^6 hrs.
015				c	Open	1	Poor Solderability	Intrusion Detection	Loss of filter for biasing circuit	Possible ripple in 5VDC output voltage	Possible loss of alarm	None	III	Yes	324.68 x 10^6 hrs.
016	R41 Resistor Fixed Film 510 ohms	1	Current limit for series regulator	a	Open	1	Internal Connection Failure	Intrusion Detection	Loss of current to series regulator	No output from 5VDC Regulator	Loss of alarm	None	I	No	338.98 x 10^6 hrs.
017				b	Parameter Change	1	Contaminated	Intrusion Detection	Small change in input current level to Q1	No effect	No effect	None	IV	Yes	555.56 x 10^6 hrs.
018				c	Short	1	Substrate Defects	Intrusion Detection	Loss of current limiting protection of Q1	Possible overstress of Q1	Possible loss of alarm	None	III	Yes	4000 x 10^6 hrs.
019	CR10 Zener Diode Voltage Regulator	1	Provides 5.6V bias voltage for Q1	a	Open	1	Poor Die Attachment	Intrusion Detection	Loss of regulated bias voltage to Q1	Output will rise to 30VDC. Possible damage to system components	Possible loss of alarm	None	III	Yes	6.441 x 10^6 hrs.
020				b	Parameter Change	1	Leaking	Intrusion Detection	Slight variation in bias voltage to Q1	Drift in output voltage level	Possible loss of alarm	None	III	Yes	8.28 x 10^6 hrs.

FIGURE 24: MAINTAINABILITY INFORMATION (TASK 103) (CONT'D)

SYSTEM/SUBSYSTEM NOMENCLATURE	SYSTEM IDENTIFICATION NUMBER	DATE: 3/31/92	PREPARED BY: SLP
Security System	ABC-1	SHEET 3 of 3	APPROVED BY: RJB
INDENTURE LEVEL: A123	NEXT HIGHER LEVEL: ABC-1	MISSION: Intrusion Detection	
SYSTEM/SUBSYSTEM DESCRIPTION: Provides a regulated 5VDC supply to the Laser Diode, Photodetector, and Alarm circuitry of the security system		COMPENSATING PROVISIONS: None	

Item I.D. No.	Item Nomenclature	Function No.	Function	Functional Failure LTR	Functional Failure	Engineering Failure Mode No.	Engineering Failure Mode	Mission Phase	Failure Effects: Local Effects	Failure Effects: Next Higher Level	Failure Effects: End Effects	Failure Detection Method	Sev. Class	Min Equip List	Engineering Failure Mode MTBF & Remarks
021				c	Short	1	Reverse Current Breakdown	Intrusion Detection	Loss of bias voltage to Q1	Loss of output	Loss of alarm	None	I	No	14.49×10^6 hrs.
022	Q1 NPN Transistor 2N5428	1	Provides output current at a regulated 5VDC	a	Short	1	Contaminated	Intrusion Detection	Loss of regulation	Output will rise to 30VDC. Probable damage to system components	Possible loss of alarm	None	III	Yes	2.73×10^6 hrs.
023				b	Open	1	Poor Internal Bond	Intrusion Detection	Loss of current to output	Loss of output	Loss of alarm	None	IV	No	7.38×10^6 hrs.
024	C10 Capacitor Ceramic .01μF	1	Filter	a	Short	1	Cracked Dielectric	Intrusion Detection	Q1 output shorted to ground	Loss of output from 5VDC Regulator	Loss of alarm	None	I	No	1020.41×10^6 hrs. Over current damage to Q1
025				b	Change in Value	1	Contaminated	Intrusion Detection	Slight change in filter performance	No effect	No effect	None	IV	Yes	1724.14×10^6 hrs.
026				c	Open	1	Poor Solderability	Intrusion Detection	Loss of high frequency filter on output	Possible high freq. noise in 5VDC output voltage	Possible loss of alarm	None	III	Yes	2272.73×10^6 hrs.
027	C15 Capacitor Tantalum 3.3μF	1	Filter	a	Short	1	Dielectric Breakdown	Intrusion Detection	Q1 output shorted to ground	Loss of output from 5VDC Regulator	Loss of alarm	None	I	No	19.71×10^6 hrs.
028				b	Open	1	Contaminated	Intrusion Detection	Loss of ripple filter on output	Possible ripple in 5VDC output voltage	Possible loss of alarm	None	III	Yes	35.11×10^6 hrs.
029				c	Change in Value	1	Substrate Detect	Intrusion Detection	Slight change in filter performance	No effect	No effect	None	IV	Yes	102.15×10^6 hrs.

FIGURE 24: MAINTAINABILITY INFORMATION (TASK 103) (CONT'D)

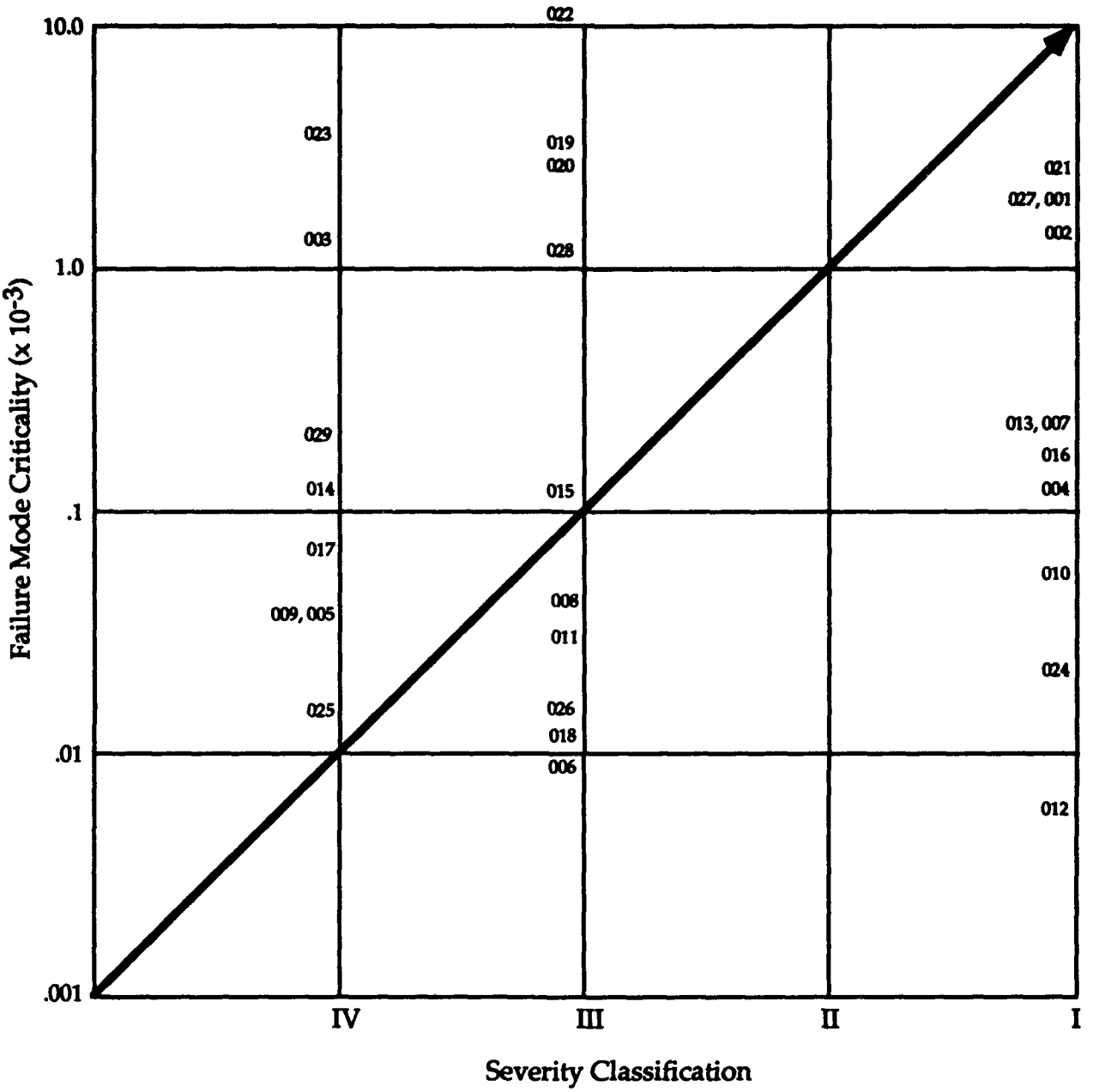

FIGURE 25: FAILURE MODE CRITICALITY MATRIX

SYSTEM Security System

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Severity Class	Failure Effect Probability (β)	Failure Rate (λ_p)	Operating Time (t)	Item CRIT # Cr = Σ(Cm)
022	Q1 NPN Transistor 2N6428	Provides output current at a regulated 5VDC	III	1	.5023 x 10^{-6}	43,800	16.051 x 10^{-3}
019	CR10 Zener Diode Voltage Regulator	Provides 5.6V bias voltage for Q1	III	1	.3451 x 10^{-6}	43,800	12.089 x 10^{-3}
023	Q1 NPN Transistor 2N6428	Provides output current at a regulated 5VDC	IV	1	.5023 x 10^{-6}	43,800	5.937 x 10^{-3}
001	CR3 Rectifier Diode D1N4004	Half-Wave Rectifier	I	1	.1234 x 10^{-6}	43,800	4.309 x 10^{-3}
021	CR10 Zener Diode Voltage Regulator	Provides 5.6V bias voltage for Q1	I	1	.3451 x 10^{-6}	43,800	3.022 x 10^{-3}
027	C15 Capacitor Tantalum 3.3μF	Filter	I	1	.0892 x 10^{-6}	43,800	2.222 x 10^{-3}
028	C15 Capacitor Tantalum 3.3 μF	Filter	III	1	.0892 x 10^{-6}	43,800	1.247 x 10^{-3}
003	CR3 Rectifier Diode D1N4004	Half-Wave Rectifier	IV	1	.1234 x 10^{-6}	43,800	1.077 x 10^{-3}

FIGURE 26: ITEM CRITICALITY RANKING

SYSTEM Security System

REFERENCE DRAWING A123

MISSION Intrusion Detection

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Modes and Causes	Severity Class	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha(Fp)t$
022	Q1 NPN Transistor 2N6423	Provides output current at a regulated 5VDC	Short	III	1	.73	$.5023 \times 10^{-6}$	43,800	16.051×10^{-3}
019	CR10 Zener Diode Voltage Regulator	Provides 5.5V bias voltage for Q1	Open	III	1	.45	$.3451 \times 10^{-6}$	43,800	6.800×10^{-3}
023	Q1 NPN Transistor 2N5423	Provides output current at a regulated 5VDC	Open	IV	1	.27	$.5023 \times 10^{-6}$	43,800	5.937×10^{-3}
020	CR10 Zener Diode Voltage Regulator	Provides 5.5V bias voltage for Q1	Parameter Change	III	1	.35	$.3451 \times 10^{-6}$	43,800	5.289×10^{-3}
021	CR10 Zener Diode Voltage Regulator	Provides 5.5V bias voltage for Q1	Short	I	1	.20	$.3451 \times 10^{-6}$	43,800	3.022×10^{-3}
001	CR3 Rectifier Diode, D1N4004	Half-Wave Rectifier	Short	I	1	.51	$.1234 \times 10^{-6}$	43,800	2.747×10^{-3}
027	C15 Capacitor Tantalum 3.3µF	Filter	Short	I	1	.57	$.0692 \times 10^{-6}$	43,800	2.222×10^{-3}
002	CR3 Rectifier Diode, D1N4004	Half-Wave Rectifier	Open	I	1	.29	$.1234 \times 10^{-6}$	43,800	1.562×10^{-3}
028	C15 Capacitor Tantalum 3.3µF	Filter	Open	III	1	.32	$.0692 \times 10^{-6}$	43,800	1.247×10^{-3}
003	CR3 Rectifier Diode, D1N4004	Half-Wave Rectifier	Parameter Change	IV	1	.20	$.1234 \times 10^{-6}$	43,800	1.077×10^{-3}
029	C15 Capacitor Tantalum 3.3µF	Filter	Change in Value	IV	1	.11	$.0692 \times 10^{-6}$	43,800	0.429×10^{-3}
007	C11 Capacitor Tantalum Elec. 47µF	Filter	Short	I	1	.59	$.0104 \times 10^{-6}$	43,800	0.302×10^{-3}
013	C9 Capacitor Ceramic .01µF	Filter	Short	I	1	.49	$.0140 \times 10^{-6}$	43,800	0.300×10^{-3}
014	C9 Capacitor Ceramic .01µF	Filter	Change in Value	IV	1	.29	$.0140 \times 10^{-6}$	43,800	0.178×10^{-3}
015	C9 Capacitor Ceramic .01µF	Filter	Open	III	1	.22	$.0140 \times 10^{-6}$	43,800	0.135×10^{-3}

FIGURE 27: FAILURE MODE CRITICALITY RANKING

SYSTEM Security System

REFERENCE DRAWING A123

MISSION Intrusion Detection

DATE 3/31/92

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I.D. Number	Item/Functional Identification (Nomenclature)	Function	Failure Mode	Severity Class	Failure Effect Probability (β)	Failure Mode Ratio (α)	Failure Rate (λ_p)	Operating Time (t)	Failure Mode CRIT # $C_m = \beta\alpha(Fp)t$
016	R41 Resistor Fixed Film 510 ohms	Current limit for series regulator	Open	I	1	.59	$.005 \times 10^{-6}$	43,800	$.129 \times 10^{-3}$
004	R1 Resistor Fixed Film 100 ohms	Current limit	Open	I	1	.59	$.004 \times 10^{-6}$	43,800	$.103 \times 10^{-3}$
017	R41 Resistor Fixed Film 510 ohms	Current limit for series regulator	Parameter Change	IV	1	.36	$.005 \times 10^{-6}$	43,800	$.079 \times 10^{-3}$
010	R16 Resistor Fixed Film 10,000 ohms	Base current source for Q1	Open	I	1	.59	$.003 \times 10^{-6}$	43,800	$.078 \times 10^{-3}$
008	C11 Capacitor Tantalum Elec. 47μF	Filter	Open	III	1	.17	$.0104 \times 10^{-6}$	43,800	$.074 \times 10^{-3}$
005	R1 Resistor Fixed Film 100 ohms	Current limit	Parameter Change	IV	1	.36	$.004 \times 10^{-6}$	43,800	$.063 \times 10^{-3}$
009	C11 Capacitor Tantalum Elec. 47μF	Filter	Change in Value	IV	1	.14	$.0104 \times 10^{-6}$	43,800	$.061 \times 10^{-3}$
011	R16 Resistor Fixed Film 10,000 ohms	Base current source for Q1	Parameter Change	III	1	.36	$.003 \times 10^{-6}$	43,800	$.047 \times 10^{-3}$
024	C10 Capacitor Ceramic .01μF	Filter	Short	I	1	.49	$.002 \times 10^{-6}$	43,800	$.043 \times 10^{-3}$
025	C10 Capacitor Ceramic .01μF	Filter	Change in Value	IV	1	.29	$.002 \times 10^{-6}$	43,800	$.025 \times 10^{-3}$
026	C10 Capacitor Ceramic .01μF	Filter	Open	III	1	.22	$.002 \times 10^{-6}$	43,800	$.019 \times 10^{-3}$
018	R41 Resistor Fixed Film 510 ohms	Current limit for series regulator	Short	III	1	.05	$.005 \times 10^{-6}$	43,800	$.011 \times 10^{-3}$
006	R1 Resistor Fixed Film 100 ohms	Current limit	Short	III	1	.05	$.004 \times 10^{-6}$	43,800	$.009 \times 10^{-3}$
012	R16 Resistor Fixed Film 10,000 ohms	Base current source for Q1	Short	IV	1	.05	$.003 \times 10^{-6}$	43,800	$.007 \times 10^{-3}$

FIGURE 27: FAILURE MODE CRITICALITY RANKING (CONT'D)

9.0 SOFTWARE TOOLS FOR FMECA

Computer software used to perform FMECA is commercially available from several companies. These software packages are designed to have simple user interfaces for data input routines including part information, failure modes, failure rates, failure effects, etc. These programs allow the user to build a database that represents the hierarchical structure according to the indenture level of the system or equipment being analyzed. The computer programs are used primarily for database functions such as sorting and reporting since a FMECA requires significant record keeping. In addition, these programs are useful in quantitative FMECA evaluations by performing model failure rate calculations for each part failure mode and criticality number computations. Output reports include worksheets from the traditional formats of MIL-STD-1629. A few programs also provide generation of criticality matrices and allow data interchange between programs such as reliability prediction, maintainability analysis and fault tree analysis software.

Documents are available which provide information on the various software tools available to perform a FMECA. The Reliability & Maintainability Software Tools (RMST) series, available from the Reliability Analysis Center, provides a listing of the available reliability, maintainability and related software packages including FMECA, which are commerically available to the R&M analyst. In most instances, these products are available to both government and industry. RMST also highlights relevant data such as cost, point of contact, access/limitations, hardware/software requirements, and capabilities.

Future FMECA software development activity must focus on integration between computer-aided-engineering tools and expert system shells. Schematic capture utilities capable of producing parts list could be interfaced to a knowledge-base of known component inter-relationship information to yield a logical first pass draft of the FMECA worksheets. This could save much of the worksheet prepartion time and allow engineers to concentrate additional time on investigating potential failure effects. The initial draft could then be updated with improved data and passed to the master knowledge-base of component inter-relationships for use in future FMECA activity. Knowledge bases could someday be shared or standardized to make the FMECA a less labor intense activity. This type of configuration would allow most any design engineer not familiar with FMECA construction and procedures to effectively and consistently perform the analysis.

10.0 ADDITIONAL SOURCES/METHODS

MIL-STD-1629 is not the only standard published which provides guidelines and procedures for performing a FMECA. Many industries have developed special methods for performing FMECA tailored to a particular type of system or process (see Section 10.1). The automobile, space and nuclear energy industries have developed specialized methods for performing FMECA on specific types of equipments and processes. Many papers, articles, methods and standards have been written on the subject of FMECA. Appendix B provides a list of additional reading on some of these specialized FMECA techniques.

10.1 Process FMEA

Process FMEA is a new method for identifying potential or known processing failure modes and providing problem follow-up and corrective action guidelines. The intent of the Process FMEA is to identify and correct known or potential failure modes that can occur during the product development process, prior to the first production run, particularly as a result of the system or product manufacturing and assembly processes. Once failure modes and causes have been determined, each failure mode is ranked similarly to the methods used and described in this report. The Process FMEA has the greatest impact in the early stages of process design, before any machines, tools or facilities are purchased. Each process variable msut be identified, analyzed for its potential modes of failure and recorded in the Process FMEA. Failure modes are determined by analysis of potential process flow problems that can occur during a production run.

The probability of each failure mode occurrence is ranked on a "1" to "10" scale and listed on the Process FMEA form. Each failure mode is ranked by its potential order of occurrence. The absolute number of failure occurrences assigned to a ranking is at the discretion of the analyst but must be consistent throughout the analysis.

The severity of each potential failure effect is also ranked on a scale of "1" to "10" and recorded on the Process FMEA form. This factor represents the seriousness of failure consequence to the end user after the failure has occurred.

A defect detection factor for each potential failure mode is recorded on the Process FMEA form. This factor also ranges from "1" to "10" and estimates the probability of detecting a defect before a part or component leaves the manufacturing or assembly location.

A risk priority number (RPN), may then be calculated for each potential failure mode. This number if calculated by multiplying together the occurrence, severity and detection ranking factors for all process failure modes. Each RPN is listed on the Process FMEA form.

Failure modes with the highest RPN's and occurrence rankings should be given priority consideration for corrective action or change implementation. Recommended corrective actions and the revised rankings of such actions or other actions taken, are listed on the Process FMEA form. Figure 28 presents a sample Process FMEA Worksheet. This worksheet and the description of its field contents were taken from the Quality Alert Institute's Failure Mode and Effects Analysis presentation given by Dr. D.H. Stamatis to the Texas Instruments Semi-conductor Group in Dallas, TX, September 23, 1991.

To provide a uniform development of potential failure mode and effects analysis for manufacturing and assembly processes, a common process FMEA form must be utilized. This section provides detailed instructions on the use of process FMEA worksheets. Circled numbers on the form correspond to the numbers and instructions that follow.

1. **Process**
   - Identify the process operation being studied.

2. **Primary Process Responsibility**
   - Enter the manufacturing division and plant that has prime responsibility for the machine, equipment or assembly process.

3. **Other Division or Product Engineering Office Involvement**
   - In cases where more than one Product Engineering Office is working on the design program, identify each office involved. Also, indicate other manufacturing divisions or plants involved.

Process (1)

Primary Process Responsibility (2)

Other Division/PEO Involved (3)

Outside Suppliers Affected (4)

Model Year/Product(s) (5)

Scheduled Production Release (6)

Engineer (7)

Section Supervisor (8)

FMEA Date Original _____ Revised (9)

Part Name Part Number	Process Function	Potential Failure Mode	Potential Effects of Failure	▼	Potential Causes of Failure	Existing Conditions: Current Controls	OCCUR	SEVER	DETECT	Risk Prior No.	Recommended Action(s) & Status	Resulting: Action(s) Taken	OCCUR	SEVER	DETECT	Risk Prior No.	Responsible Activity
(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)				(23)	(24)

FIGURE 28: PROCESS FMEA WORKSHEET

4. **Outside Suppliers Affected**
   - Identify outside suppliers involved as a design source or manufacturing source of a major component within the subsystem.

5. **Model Year/Product(s)**
   - Enter the model year and all products that will utilize the system, subsystem or component.

6. **Scheduled Production Release**
   - Indicate the date the component, subsystem or system is scheduled for release. If the subsystem or system includes several components with varied release dates, show the last date.

7. **Engineer**
   - Show the name and the phone number of the manfacturing/assembly process engineer.

8. **Section Supervisor**
   - Show the name and phone number of the section supervisor and intial when approved.

9. **FMEA Date**
   - Show the date of the first FMEA completed and the product and the date of the last revision.

10. **Part Name/Part Number**
    - Specify the name of items being analyzed. Show the design level by suffixes and change letters, if pertinent.

11. **Process Function**
    - Indicate, as concisely as possible, the function of the process or component being analyzed.

12. **Potential Failure Mode**
    - Describe each possible failure mode. The assumption is made that the failure could occur, but will not necessarily occur. The process engineer should be able to answer the questions "What could possibly go wrong with the process?" and "How can the part fail to meet specifications?"

13. **Potential Effect(s) of Failure**
    - Assuming the failure has occurred, describe what the customer might notice or experience: "What will result from the failure mode identified?" The description must be as specific as possible.

14. **Control Items (v)**
    - Indicate all Control Item Characteristics (v) with the appropriate symbol.

15. **Potential Cause(s) of Failure**
    - List all potential causes assignable to each failure mode. Answer the question, "What processing variables could result in the potential failure mode?" Be sure the list is inclusive so that remedial efforts will be aimed at all variables.

16. **Current Controls**
    - List all current process variable controls which are intended to prevent the cause(s) of failure from occurring, or are intended to detect the cause(s) of failrue or the resultant failure mode.

17. **Occurrence**
    - Estimate the probability of occurrence on a "1" to "10" scale as defined below. Only controls intended to prevent the cause of failure from occurring should be considered in this estimate. When estimating the Occurrence Ranking, consider the probability that the potential cause of failure will occur and thus result in the indicated potential failure mode. For this estimate, assume that the cause of failure and failure modes are not detected before the product reaches the customer.

18. **Severity**
    - Estimate the severity of the "effects of failure" to the customer on a "1" to "10" scale. Severity is the factor that represents the seriousness of the failure to the customer after it has occurred.

19. **Detection**
    - Using a "1" to "10" scale, estimate the probability of detecting a defect before the part or component leaves the manufacturing or assembly location. Assume the cause of failure has happened and assess the capabilities of all current controls to prevent shipment of the defect. Random quality control checks would unlikely detect an isolated defect and therefore would not result in a noticeable detection ranking change. However, sampling done on a statistical basis is a valid detection control.

20. **Risk Priority Number (RPN)**
    - Calculate the RPN by multiplying together the Occurrence (17), Severity (18), and Detection (19) for all causes of failure. The highest RPN's and Occurrence Rankings should be given the first consideration for corrective actions and statistical process control charting.

21. **Recommended Action(s) and Status**
    - The need for taking positive corrective actions with quantifiable benefits cannot be overemphasized. A well developed process FMEA will be of limited value without effective corrective actions and follow-up. Corrective actions are generally either design or process.

22. **Action(s) Taken**
    - Enter the status of the recommended corrective action - Product Change Request (PCR) numbers, transmittal numbers, promise dates or closed dates under the description of the corrective action. Once the corrective action has been completed, the data in the columns under Resulting Rankings (23) will be revised for the affected cause of failure. At that time, the Revision Level (9) will also be updated.

23. **Resulting Rankings**
    - Enter the Revised Rankings after corrective action is completed. Recalculate the RPN.

24. **Responsible Activity**
    - Enter the responsible activity and/or individual for the action recommended.

APPENDIX A:

TYPICAL COMPONENT FAILURE MODE DISTRIBUTIONS (α)

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91

Device Type	Failure Mode	Failure Mode Probability (α)
Accumulator	Leaking	.47
	Seized	.23
	Worn	.20
	Contaminated	.10
Actuator	Spurious Position Change	.36
	Binding	.27
	Leaking	.22
	Seized	.15
Adapter	Physical Damage	.33
	Out of Adjustment	.33
	Leaking	.33
Alarm	False Indication	.48
	Failure to Operate on Demand	.29
	Spurious Operation	.18
	Degraded Alarm	.05
Antenna	No Transmission	.54
	Signal Leakage	.21
	Spurious Transmission	.25
Battery, Lithium	Degraded Output	.78
	Startup Delay	.14
	Short	.06
	Open	.02
Battery, Lead Acid	Degraded Output	.70
	Short	.20
	Intermittent Output	.10
Battery, Rechargeable, Ni-Cd	Degraded Output	.72
	No Output	.28
Bearing	Binding/Sticking	.50
	Excessive Play	.43
	Contaminated	.07
Belt	Excessive Wear	.75
	Broken	.25
Blower Assembly	Bearing Failure	.45
	Sensor Failure	.16
	Blade Erosion	.15
	Out of Balance	.10
	Short Circuit	.07
	Switch Failure	.07
Brake	Excessive Wear	.56
	Leaking	.23
	Scored	.11
	Corroded	.05
	Loose	.05
Bushing	Excessive Wear	.85
	Loose	.11
	Cracked	.04

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Cable	Short	.45
	Excessive Wear	.36
	Open	.19
Capacitor, Aluminum, Electrolytic, Foil	Short	.53
	Open	.35
	Electrolyte Leak	.10
	Decrease in Capacitance	.02
Capacitor, Ceramic	Short	.49
	Change in Value	.29
	Open	.22
Capacitor, Mica/Glass	Short	.72
	Change in Value	.15
	Open	.13
Capacitor, Paper	Short	.63
	Open	.37
Capacitor, Plastic	Open	.42
	Short	.40
	Change in Value	.18
Capacitor, Tantalum	Short	.57
	Open	.32
	Change in Value	.11
Capacitor, Tantalum, Electrolytic	Short	.69
	Open	.17
	Change in Value	.14
Capacitor, Variable, Piston	Change in Value	.60
	Short	.30
	Open	.10
Chopper	Contact Failure	.48
	Short	.25
	Open	.25
	Coil Failure	.02
Circuit Breaker	Opens Without Stimuli	.51
	Does Not Open	.49
Clutch	Binding/Sticking	.56
	Slippage	.24
	No Movement	.20
Coil	Short	.42
	Open	.42
	Change in Value	.16
Computer System	Hardware Failure	.57
	Software Failure	.43
Connector/Connection	Open	.61
	Poor Contact/Intermittent	.23
	Short	.16
Controller, Electromechanical	Erroneous Output	.75
	Loss of Control	.25

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Counter Assembly	Inaccurate Count	.91
	Seized	.09
Crystal, Quartz	Open	.89
	No Oscillation	.11
Diode, General	Short	.49
	Open	.36
	Parameter Change	.15
Diode, Rectifier	Short	.51
	Open	.29
	Parameter Change	.20
Diode, SCR	Short	.98
	Open	.02
Diode, Small Signal	Parameter Change	.58
	Open	.24
	Short	.18
Diode, Thyristor	Failed Off	.45
	Short	.40
	Open	.10
	Failed On	.05
Diode, Triac	Failed Off	.90
	Failed On	.10
Diode, Zener, Voltage Reference	Parameter Change	.69
	Open	.18
	Short	.13
Diode, Zener, Voltage Regulator	Open	.45
	Parameter Change	.35
	Short	.20
Electric Motor, AC	Winding Failure	.31
	Bearing Failure	.28
	Fails to Run, After Start	.23
	Fails to Start	.18
Fitting	Leaking	.90
	Contaminated	.05
	Scored	.05
Fuse	Fails to Open	.49
	Slow to Open	.43
	Premature Open	.08
Gasket/Seal	Leaking	1.00
Gear	Excessive Wear	.54
	Binding/Sticking	.46
Generator	Degraded Output	.60
	No Output	.22
	Fails to Run, After Start	.09
	Loss of Control	.09

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Hybrid Device	Open Circuit	.51
	Degraded Output	.26
	Short Circuit	.17
	No Output	.06
Injector	Corroded	.87
	Deformed	.08
	Cracked/Fractured	.05
Inner Tube	Leaking	1.00
Keyboard Assembly	Spring Failure	.32
	Contact Failure	.30
	Connection Failure	.30
	Lock-up	.08
Lamp/Light	No Illumination	.67
	Loss of Illumination	.33
Liquid Crystal Display	Dim Rows	.39
	Blank Display	.22
	Flickering Rows	.20
	Missing Elements	.19
Mechanical Filter	Leaking	.67
	Clogged	.33
Meter	Faulty Indication	.51
	Unable to Adjust	.23
	Open	.14
	No Indication	.12
Microcircuit, Digital, Bipolar	Output Stuck High	.28
	Output Stuck Low	.28
	Input Open	.22
	Output Open	.22
Microcircuit, Digital, MOS	Input Open	.36
	Output Open	.36
	Supply Open	.12
	Output Stuck Low	.09
	Output Stuck High	.08
Microcircuit, Interface	Output Stuck Low	.58
	Output Open	.16
	Input Open	.16
	Supply Open	.10
Microcircuit, Linear	Improper Output	.77
	No Output	.23
Microcircuit, Memory, Bipolar	Slow Transfer of Data	.79
	Data Bit Loss	.21
Microcircuit, Memory, MOS	Data Bit Loss	.34
	Short	.26
	Open	.23
	Slow Transfer of Data	.17
Microwave Amplifier	No Output	.90
	Limited Voltage Gain	.10
Microwave Antenna	No Transmission	1.00

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Microwave Attenuator	Attenuation Increase	.90
	Insertion Loss	.10
Microwave Connector	High Insertion Loss	.80
	Open	.20
Microwave Detector	Power Loss	.90
	No Output	.10
Microwave, Diode	Open	.60
	Parameter Change	.28
	Short	.12
Microwave Filter	Center Frequency Drift	.80
	No Output	.20
Microwave Mixer	Power Decrease	.90
	Loss of Intermediate Frequency	.10
Microwave Modulator	Power Loss	.90
	No Output	.10
Microwave Oscillator	No Output	.80
	Untuned Frequency	.10
	Reduced Power	.10
Microwave VCO	No Output	.80
	Untuned Frequency	.15
	Reduced Power	.05
Microwave YIG	No Output	.80
	Untuned Frequency	.15
	Reduced Power	.05
Microwave Phase Shifter	Incorrect Output	.90
	No Output	.10
Microwave Polarizer	Change in Polarization	1.00
Optoelectronic LED	Open	.70
	Short	.30
Optoelectronic Sensor	Short	.50
	Open	.50
Pneumatic Actuator	Spurious Closing	.54
	Spurious Opening	.46
Power Supply	No Output	.52
	Incorrect Output	.48
Printed Wiring Assembly	Open	.76
	Short	.24
Pump, Centrifugal	No Output	.67
	Degraded Output	.33
Pump, Hydraulic	Leaking	.82
	Improper Flow	.12
	No Flow	.06
Regulator	Stuck Closed	.23
	Stuck Open	.23
	No Output	.22
	Leaking	.22
	Insufficient Output	.10

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Relay	Fails to Trip	.55
	Spurious Trip	.26
	Short	.19
Resistor, Composition	Parameter Change	.66
	Open	.31
	Short	.03
Resistor, Fixed	Open	.84
	Parameter Change	.11
	Short	.05
Resistor, Fixed, Film	Open	.59
	Parameter Change	.36
	Short	.05
Resistor, Fixed, Wirewound	Open	.65
	Parameter Change	.26
	Short	.09
Resistor, Network	Open	.92
	Short	.08
Resistor, Thermistor	Open	.63
	Parameter Change	.22
	Short	.15
Resistor, Variable	Open	.53
	Erratic Output	.40
	Short	.07
Rotary Switch	Improper Output	.53
	Contact Failure	.47
Screw	Loose	.67
	Excessive Wear	.33
Sensor	Erratic Output	.59
	Short	.20
	Open	.12
	No Output	.10
Software	Design Changes	.46
	Design Errors	.41
	User Error	.07
	Documentation Error	.06
Solenoid	Short	.52
	Slow Movement	.43
	Open	.05
Switch, Push-button	Open	.60
	Sticking	.33
	Short	.07
Switch, Thermal	Parameter Change	.63
	Open	.27
	No Control	.08
	Short	.02

NORMALIZED FAILURE MODE DISTRIBUTIONS FOR FMECA, FMD-91 (CONT'D)

Device Type	Failure Mode	Failure Mode Probability (α)
Switch, Toggle	Open	.65
	Sticking	.19
	Short	.16
Synchro	Winding Failure	.45
	Bearing Failure	.33
	Brush Failure	.22
Tire	Leaking	.76
	Excessive Wear	.24
Transducer, Sensor	Out of Tolerance	.68
	False Response	.15
	Open	.12
	Short	.05
Transformer	Open	.42
	Short	.42
	Parameter Change	.16
Transistor, Bipolar	Short	.73
	Open	.27
Transistor, FET	Short	.51
	Output Low	.22
	Parameter Change	.17
	Open	.05
	Output High	.05
Transistor, GaAs FET	Open	.61
	Short	.26
	Parameter Change	.13
Transistor, R.F.	Parameter Change	.50
	Short	.40
	Open	.10
Tube, Electron	Change in Parameter	.53
	Open	.25
	Unstable Output	.15
	Short	.07
Tube, Traveling Wave	Reduced Output Power	.71
	High Helix Current	.11
	Gun Failure	.09
	Open Helix	.09
Valve, Hydraulic	Leaking	.77
	Stuck Closed	.12
	Stuck Open	.11
Valve, Pneumatic	Leaking	.28
	Stuck Open	.20
	Stuck Closed	.20
	Spurious Opening	.16
	Spurious Closing	.16
Valve, Relief	Premature Open	.77
	Leaking	.23

APPENDIX B:

ADDITIONAL FMECA READING

Reprinted by permission from Pergamon Press Publication, Microelectronics and Reliability International Journal & World Abstracting Service, Volume 32, Number 5, May 1992, "Failure Modes and Effects Analysis Bibliography, pages 721-731.

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APPENDIX C:

RAC PRODUCTS

RAC Product Order Form

(DP92-2)

		U.S.	Non-U.S.	Qty	Item Total
217	MIL-HDBK-217F, Notice 1 (Microsoft Word Version 4.0)	75.00	85.00		
338	MIL-HDBK-338B (Draft) (Microsoft Word Version 4.0)	95.00	105.00		
ATH	Analog Testing Handbook	100.00	120.00		
CRTA-CE	Introduction to Concurrent Engineering	75.00	85.00		
CRTA-FMECA	Failure Mode, Effects and Criticality Analysis	75.00	85.00		
CRTA-GAAS	An Assessment of GaAs Device Quality and Reliability	50.00	60.00		
CRTA-PEM	Plastic Microcircuit Packages: A Technology Review	50.00	60.00		
CRTA-PSA	Parts Selections, Application and Control	50.00	60.00		
CRTA-QML	Qualified Manufacturer's List: New Device Manufacturing and Procurement Technique	50.00	60.00		
CRTA-TEST	Testability Design and Assessment Tools	50.00	60.00		
CRTA-WCCA	Worst Case Circuit Analysis Application Guidelines	75.00	85.00		
DSR-4	Discrete Semiconductor Device Reliability	100.00	120.00		
FMD-91	Failure Mode/Mechanism Distributions	100.00	120.00		
FTA	Fault Tree Analysis Application Guide	80.00	90.00		
MDR-21	Microcircuit Device Reliability Trend Analysis Databook	100.00	120.00		
MDR-22	Microcircuit Screening Analysis	125.00	145.00		
MFAT-1	Microelectronics Failure Analysis Techniques - A Procedural Guide	140.00	180.00		
MFAT-2	GaAs Microcircuit Characterization & Failure Analysis Techniques	100.00	120.00		
MFAT-1&2	Combined set of MFAT-1 and MFAT-2	200.00	260.00		
NONOP-1	Nonoperating Reliability Databook	150.00	170.00		
NPRD-91	Nonelectronic Parts Reliability Data 1991	150.00	170.00		
NPRD-91P	Nonelectronic Parts Reliability Data 1991 (IBM PC database)	400.00	440.00		
NPS-1	Analysis Techniques for Mechanical Reliability	60.00	70.00		
PRIM-92	A Primer for DoD Reliability, Maintainability, Safety and Logistics Stds	120.00	140.00		
QML-1	QML Workshop Proceedings	25.00	35.00		
QREF	RAC Quick Reference Guides	39.00	49.00		
RAC-NRPS	Nonoperating Reliability Prediction System (Includes NONOP-1)	1400.00	1450.00		
RMST-93	Reliability and Maintainability Software Tools 1993	50.00	60.00		
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SOAR-8	Process Action Team (PAT) Handbook	80.00	90.00		
VPRED	VHSIC Reliability Prediction Software	150.00	170.00		
VZAP-91	Electrostatic Discharge Susceptibility Data 1991	150.00	170.00		
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