To the Graduate Council:

I am submitting herewith a thesis written by Randall G. Short entitled "Use of Commercial Electronic Components in Missile Systems." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

Robert Richards,
Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

USE OF COMMERCIAL ELECTRONIC COMPONENTS IN MISSILE SYSTEMS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Randall G. Short

May 1998

DEDICATION

This thesis is dedicated to my mother the late Winifred Waltmire Short who always emphasized the importance of education and continuous learning.

ACKNOWLEDGMENTS

I would like to thank the numerous dedicated professionals in government and industry who early on recognized the need to address the issue on the use of commercial parts in military systems. It is because of their countless hours investigating the issues surrounding this topic that have made it possible for missile systems program managers to move forward with confidence. Their names are too many to mention, however a large number of them are located in the bibliography.

I would like to thank Dr. Bob Richards of the US Navy Test Pilot School for making the University of Tennessee Space Institute program a reality at the Naval Air Warfare Center, Patuxent River, Md. His dedication to this endeavor has ensured that aviation professionals have the opportunity to further their education.

I would like to thank my bride Teri and my children: Caitlin, Breanna and Michael for their patience, understanding and love over the months of this effort.

DISCLAIMER

This thesis discusses views that are those of the authors and are not official government policy.

ABSTRACT

Plastic Encapsulated Devices (PEDs) have historically been banned from most military systems. This is due to their perceived lower reliability than their counterpart, the Hermetically Sealed Device (HSD). In 1965 the Department of Defense (DoD) accounted for over 95 percent of all US manufactured semiconductor purchases. Currently DoD accounts for about one percent of their purchases. Although the total demand for semiconductors in DoD has increased dramatically it has paled in comparison to the consumer electronics and automotive demand for semiconductors. The market has shifted from one where DoD had significant input to one that is virtually driven by the consumer electronics and automotive demand. Recent DoD mandated acquisition reform initiatives have given Program Managers flexibility to incorporate non-military grade parts into their systems. As budget constraints put pressure on Program Managers to make system cost reductions, the use of PEDs was seriously considered. Numerous military programs have evaluated the use of PEDs in their systems. Extensive research into the history and manufacture of PEDs, their advantages and disadvantages has been conducted.

Problems with PEDs in missile systems predominately result from moisture and temperature. Moisture has the potential to cause long term storage problems from corrosion and to cause cracking of the encapsulant material during

soldering processes. Temperature extremes can cause part failure from different coefficients of thermal expansion of the parts of the PED or thermal breakdown.

Through proper process controls the risks associated with PED use can be reduced to an acceptable level. The proper use of process controls will allow the use of PEDs and mitigate the risks associated with them. These process controls involve; reviewing the environment the part must be used in, part selection, analyzing the reliability of the part in the intended application and environment, understanding logistics impacts, establishing partnerships with part manufacturers, detailed review of the part manufacturing processes, and ensuring the part is properly qualified.

Prospects for future improvements in the application of PEDs in missile systems are discussed. These include the elimination of most government oversight and control of the detail process controls through the use of effective warranties. Another prospect is the use of common parts databases across multiple programs both within a given contractor and across multiple contractors. The impact of future microcircuit technology advancements is also addressed.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

AR	Acquisition Reform
BIT	Built In Test
BMP	Best Manufacturing Practices
CCA	Circuit Card Assembly
CERDIP	Ceramic Dual In-Line Package
CMOS	Complementary Metal Oxide Semiconductor
DARPA	Defense Advanced Research Project Agency
DoD	Department of Defense
ESD	Electro-Static Discharge
FIT	Failures In Time
GAO	Government Accounting Office
GPS	Global Positioning System
HALT	Highly Accelerated Life Testing
HAST	Highly Accelerated Stress Testing
HSD	Hermetically Sealed Device
HSM	Hermetically Sealed Microcircuit
IC	Integrated Circuit
JDAM	Joint Direct Attack Munition
PLGR	Precision Lightweight Global Positioning System Receiver
MIL	Military
MIL-HDBK	Military Handbook
MIL-SPEC	Military Specification
MIL-STD	Military Standard
PDIP	Plastic Dual In-Line Package

PED	Plastic Encapsulated Device
PEM	Plastic Encapsulated Microcircuit
PEN	Plasma Enhanced Nitride
PQFP	Plastic Quad Flat Pack
PSG	Phosphosilicate Glass
PWB	Printed Wiring Board
QML	Qualified Manufacturers List
QPL	Qualified Parts List
SLAM ER	Standoff Land Attack Missile Expanded Response
SMD	Surface Mount Device
SOP	Small Outline Package
SPC	Statistical Process Control
SPEC	Specification
STD	Standard
TCE	Thermal Coefficient of Expansion
THB	Temperature Humidity Bias
TI	Texas Instruments
TQM	Total Quality Management
WRA	Weapon Replaceable Assembly

PED	Plastic Encapsulated Device
PEM	Plastic Encapsulated Microcircuit
PEN	Plasma Enhanced Nitride
PQFP	Plastic Quad Flat Pack
PSG	Phosphosilicate Glass
PWB	Printed Wiring Board
QML	Qualified Manufacturers List
QPL	Qualified Parts List
SLAM ER	Standoff Land Attack Missile Expanded Response
SMD	Surface Mount Device
SOP	Small Outline Package
SPC	Statistical Process Control
SPEC	Specification
STD	Standard
TCE	Thermal Coefficient of Expansion
THB	Temperature Humidity Bias
TI	Texas Instruments
TQM	Total Quality Management
WRA	Weapon Replaceable Assembly

CHAPTER I

INTRODUCTION

BACKGROUND

In 1994, the Honorable Dr. John Perry, then Secretary of Defense initiated what is commonly referred to as "acquisition reform". Dr. Perry released a Policy Memorandum on 29 June 1994 that directed all acquisition executives to implement several major policy changes. Although the thrust of the memorandum was military specifications (MIL-SPEC) and military standards (MIL-STD) reform, it was a turning point in the way DoD did business (Perry, 1994). Prior to this memorandum several studies were completed on what could be done within DoD to reform the acquisition process. These studies were the basis of Dr. Perry's initiative. Several key factors were instrumental in driving DoD to acquisition reform. The first was DOD receiving constant criticism for overpaying for just about everything it bought. There were "$400.00 hammers" and "$600.00 toilet seats" popping up everywhere. The taxpayers were questioning the judgment in DOD making these purchases and DOD was being ridiculed. Congress was demanding investigations and as stewards of the taxpayers dollars, Congress and DOD were obliged to respond. The second key factor was a change in the world order. The United States had perceived a very real threat from the

Soviet Union. Defense systems were critical to the survival of the United States as a nation and taxpayers were willing to pay any price to maintain independence. As the Soviet Union dissolved and the Berlin Wall crumbled, the nation no longer perceived a significant threat existed. All the time these first two events were transpiring, industry itself was undergoing some major transformations. In 1965 DOD accounted for over 95 percent of all U. S. manufactured semiconductor purchases; currently their use has dropped to about one percent (Tam, 1995). Furthermore, a new fabrication plant can cost well over $1 billion. The fabs become obsolete in three to five years. In order to recoup that investment a firm must run its plant at near capacity (The Economist, March 1996). The small volume of DOD does not offset the cost of these fabs. At current chip prices it takes the high volume of the commercial market with the production of hundreds of millions of chips to recoup these investments. This has resulted in numerous semiconductor manufacturers, such as Motorola, discontinuing their military semiconductor operations (Motorola News Release, 1995). With the change in world order DOD budgets plummeted. With all of these influences pressuring DOD, the time for acquisition reform was ripe.

THESIS OBJECTIVE

Although acquisition reform entails many improvements, the use of commercial parts is a major tenet. This paper will focus on the use of commercial electronic parts in missile systems. These differences are examined for their impact on meeting the requirements for these systems. Characteristic differences between commercial electronic parts and what has historically been available in the military market will be addressed. This thesis draws on the authors research for the Standoff Land Attack Missile Expanded Response Program (SLAM ER). A plan is developed to transition from military parts to commercial electronic parts without compromising the required performance of the missile system. It includes areas for further growth in the electronics industry and in acquisition of missile systems. The plan defines key points that must be adhered to when using PEDs. Existing and new developments in testing will be examined. Finally, recommendations for use of these parts will be discussed as will the impact of future microcircuit technology advances.

CHAPTER II

PRE ACQUISITION REFORM

MILITARY SPECIFICATIONS AND STANDARDS

Prior to acquisition reform DOD relied heavily on the use of military specifications (MIL-SPECs) and military standards (MIL-STDs). The practice was if in doubt, add the MIL-SPEC or MIL-STD since there was usually something in the first tier or one of the sub tiers of those MIL-SPECs or MIL-STDs that would make the contractor do what was wanted. The contractor was then required to sort through all the MIL-SPECs and MIL-STDs to try and determine his requirements. Significant effort was made at the beginning of a program to define and scope the level of effort required to design, build and test a system to meet these specifications and standards. This was in addition to the effort the government had to put forth to translate the systems requirements into MIL-SPECs and MIL-STDs. Under acquisition reform the contractor translates the system requirements.

MIL-SPECs and MIL-STDs total over 35,000 documents. They add as much as 30 to 40 percent to DOD acquisition costs (Aviation Week and Space Technology, 28 April 1997). Specifications and standards have not been as bad as people have made them out to be lately. They were established as a result of problems during the Spanish-American War and the requirement to ensure good procedures for preserving and packaging material and supplies. A compilation of lessons learned, they have made significant contributions to the economy promoting international commerce and allowing the interchange of competitive products. They have allowed interface of systems to exist such as railroads, electrical interfaces, radios and television.

Prior to acquisition reform it was safe to go with an approved MIL-SPEC or MIL-STD. The costs associated with those decisions were not an issue. Performance was the only concern. The Cold War was on and the survival as a nation was at stake. The onus was on the program manager to justify the use of anything other than an approved MIL-SPEC or MIL-STD. If he advocated a performance-based specification or used a commercial standard, and if something went wrong, then his decision was subjected to intense scrutiny. He put his career on the line for taking a risk that saved money.

COMMERCIAL MARKET DEMANDS

More than thirty years ago trends were underway that set the stage for toady's acquisition reform initiatives. In 1965, the commercial sector's investment in R&D surpassed that of DoD and the disparity has continued to grow. This has established the commercial sector as the driving force behind the pace of technological innovation in the country today. The demand for commercial products was insatiable. New electronic "gadgets" were brought to market quickly. At the same time the number of MIL-SPECs and MIL-STDs continued to grow to the over 35,000 in existence prior to acquisition reform. While business with the DoD became more difficult, the demand for commercial products increased.

This demand for commercial products had significant impact on the demand for semiconductors. In 1965 DoD accounted for more than 75% of all US semiconductor purchases. Although the use of semiconductors in military systems increased dramatically, in 1995 DoD only accounted for about 1% of all US semiconductor purchases.

This dramatic shift in purchasing power had significant impact on the ability of DoD to direct the market. Commercial markets became the driving force and could dictate requirements to semiconductor manufacturers.

STATISTICAL PROCESS CONTROL

During the same time period, the Japanese automotive industry was employing the tenets of Total Quality Management (TQM). Consistently trying to improve quality and reduce costs they were able to just about eliminate defects in their semiconductor manufacturing. The increasing use of semiconductors in the automotive industry and the competitive pressures put on the US automotive companies caused them to demand quality from their semiconductor suppliers. These suppliers embraced Statistical Process Control (SPC) and zero defects as their ultimate goal.

CHAPTER III

POLICY CHANGES

Almost everything in acquisition reform has been recommended by the Defense Science Board, Packard Commission, Center for Strategic and International Studies, Carnegie Commission on Science, Technology and Government, and other committees. These committees suggested areas for DoD to improve the acquisition process. Preceding what is now known as acquisition reform, their recommendations have had a major impact on the changes being implementing today.

Existing acquisition methods were a deeply imbedded part of the nations culture. People had spent their entire careers using those methods. Implementation of acquisition reform required a cultural change. In order to have this cultural change a major emotional event was required. That event was the enormous change in the world status, with the collapse of the Berlin Wall and the demise of the Soviet Union, resulting in the dramatic reduction of the defense budget. These events allowed the cultural change of acquisition reform to occur. With the stage set from the suggestions of the various committees the change occurred dramatically and almost overnight. Because of the change in world order and the reduced emphasis on defense, affordability became the driving force behind acquisition reform. A key method of obtaining affordable systems has been the use of realistic design to cost goals and making trades in performance for costs.

The most commonly referenced acquisition reform document, and probably the one document that really got things moving, was the Policy Memo from Secretary Perry "Specification and Standards- A New Way of Doing Business" of June 1994. In reality acquisition reform is much more encompassing than just what is in that memo. The thrust is to let the customer define the requirements and the contractor to determine the "how-to", enabling them to define and implement cost effective requirements solutions. Secretary Perry's Policy Memo centered on the reduction in relying on MIL-SPECs and MIL-STDs. A key point that must be remembered is that the memo was not about just doing away with MIL-SPECs and MIL-STDs, but finding suitable substitutes when available. MIL-SPECs and MIL-STDs are authorized as a last resort with a waiver, when a performance specification or suitable non-government standard is not available (Program Manager, July- August 1994). Sometimes contractors take portions of the memo out of context and think that all specifications and standards can be eliminated.

Following Secretary Perry's memo, another critical element on the path to acquisition reform was to make changes in the Federal Regulations. That was done by the Federal Acquisition Streamlining Act of 1994 which became public law after Secretary Perry's Policy Memo in October 1994. This eliminated some of the restrictive legal and regulatory requirements and led to more contractor self oversight. This also allowed the program managers wide latitude to tailor their programs to improve costs, schedule and performance.

The impact of these changes was immense. It meant that with the commercial sector leading R&D investment and demand for products, programs could no longer afford to support a separate infrastructure for a military industrial base across all programs. Programs must, where feasible integrate to a common military- commercial industrial base. This fits well with a move towards commercial standards and parts.

CHAPTER IV

TECHNICAL CHALLENGES

BACKGROUND

In order to understand the technical challenges facing the use of PEDs, the environment they are subjected to must be understood. Missile applications require operation of microcircuits throughout a wide temperature and humidity range. The actual range of temperature and humidity the microcircuit is exposed to depends on a number of factors. These include the actual environment the system is exposed to in both its operating and non-operating environments, the length of time in these environments and the characteristics of the system and internal components where the microcircuit is located.

MISSILE SYSTEM ENVIRONMENTS

Missile system environments can be classified as either non-operating or operating.

Non-Operating Environment

The non-operating environment can include storage, transportation, loading and any post loading condition. Storage is the time when a missile is stored in a magazine or in a container. When removed from the magazine it is transported, either in the container or on an open ordnance cart. The missile is then loaded to the vehicle from which it is employed. This may include hand held launchers, ships, submarines or aircraft. The post- loaded conditions are specific to the environment and employment of the vehicle to which the missile is loaded. During the post-loaded condition the missile may sit in a launcher on the back of a jeep in the sun for hours prior to use. It may be subjected to the same conditions inside a canister on a ship in addition to being exposed to salt spray. It may also be exposed unprotected to the sun on the wing of an aircraft and then captive carried on the aircraft at supersonics speeds prior to use.

Operating Environment

The operating environment includes any time power is applied to the missile. This includes any time prior to launch and the post launch flyout phase of the missile enroute to the target. The operating environment can last for less than a minute or for several hours if the missile remains powered prior to launch and has a flight range typical of a long-range cruise missile.

Temperature Range

The environments described above can subject the missile to temperature extremes. MIL-STD-210 has been used as a reference for world wide temperatures since 1953. The low temperatures would include exposure of a missile under the wing of an aircraft in a polar region during a ready alert status. The missile could then be taken to altitude and maintained in a captive carry configuration during a long on-station loiter. The lowest recorded temperature on the earth's surface (excluding Antarctica) of -68°C, occurred twice in Siberia (MIL-STD-210C, 1987).

The high temperature extreme would include exposure of the storage container to the sun while sitting on the tarmac in a desert environment. The highest recorded temperature of +58°C occurred in Libya (MIL-STD-210C, 1987). After exposure to the sun while on the tarmac, the missile could then be loaded onto the wing of an aircraft and remain exposed to the sun during a ready alert status. After launch the aircraft would perform a high speed dash to an intercept point where the missile would be launched. The missile would then fly at supersonic speeds to its target, where aerodynamic heating of the missile body adds to ambient air and solar radiation heating.

TECHNICAL BACKGROUND

This thesis discusses the use of Plastic Encapsulated Devices (PEDs) and Hermetically Sealed Devices (HSDs) of which Plastic Encapsulated Microcircuits (PEMs) and Hermetically Sealed Microcircuits (HSMs) are subsets. The broader terms of PED and HSD include other electronic components such as diodes that experience some of the same technical challenges as PEMs but are not classified as microcircuits.

Microcircuit Types

Microcircuits for military use have historically been Hermetically Sealed Microcircuits (HSMs). Since these were manufactured to military specifications and standards and thoroughly tested with detailed test procedures, they were believed to be more reliable than those in use in the commercial marketplace. The HSMs consist of a die or "chip" encased in a sealed metal, ceramic or glass case. As seen in figure 1, a large number of components make up the actual

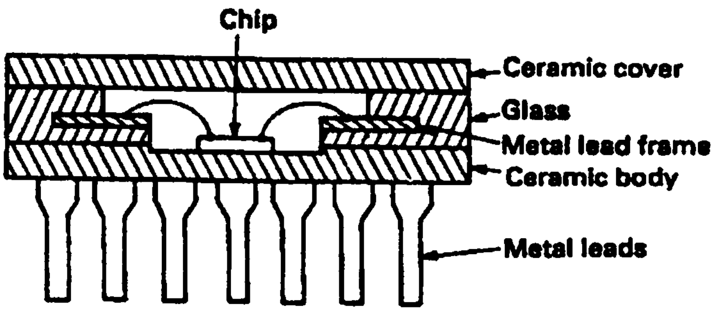

Figure 1

Hermetically Sealed Microcircuit
Ceramic Dual In Line Package

Source: Mazda, F. F. ELECTRONICS ENGINEER'S REFERENCE BOOK. Butterworths. London. 1989. pp. 25/19-20.

case, including a body, seals and a cover. The amount of processing to manufacture these components and assemble them is time consuming and expensive. Microcircuit manufacturers developed an alternative, the Plastic Encapsulated Microcircuit (PEM) in order to save cost and allow higher production rates. The PEM consist of the die (IC chip) and leads, as with the HSM, but uses a plastic encapsulant molded around the die and leads. As seen in figure 2, the number of components is reduced from that of the HSM.

PEDs are generally manufactured in continuous run, high volume fabrication plants using automatic machine

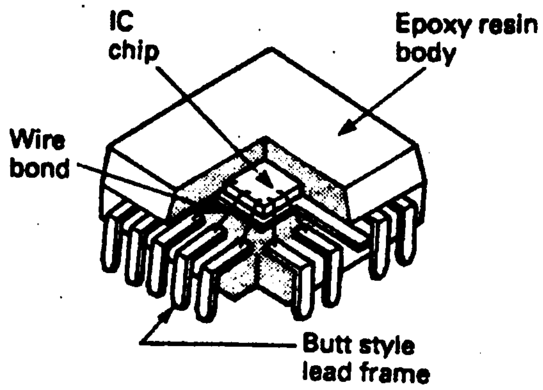

Figure 2

Plastic Encapsulated Microcircuit
Surface Mount Device

Source: Mazda, F. F. ELECTRONICS ENGINEER'S REFERENCE BOOK. Butterworths. London. 1989. pp. 25/19-20.

operations. Continuous, high volume production lends itself to using SPC to monitor and control process variation. HSDs on the other hand are generally produced in batches at lower volumes and require more hands-on operations. Batch production subjects each batch or lot to process variations from start up. This coupled with the lower volumes and variations from hands-on operations makes it harder to maintain Statistical Process Control (SPC)on HSDs. For this reason HSDs require a significant amount of costly post manufacturing inspection.

Various types of packaging options are listed in appendix A.

Reliability Theory

If the failure rate of a component is plotted against time a curve called the bathtub curve results. This curve, shown in figure 3, has three parts or periods. During the "infant mortality" period, weaker parts are being removed from the overall group of parts either through screening or early failure during equipment operation. During the second period, the "useful life" period the failure rate drops rapidly and remains fairly constant throughout the period. During this period, failures are random in nature. During the third period, the "wear-out" period, the components have become weaker and are more subject to failure. Failures are

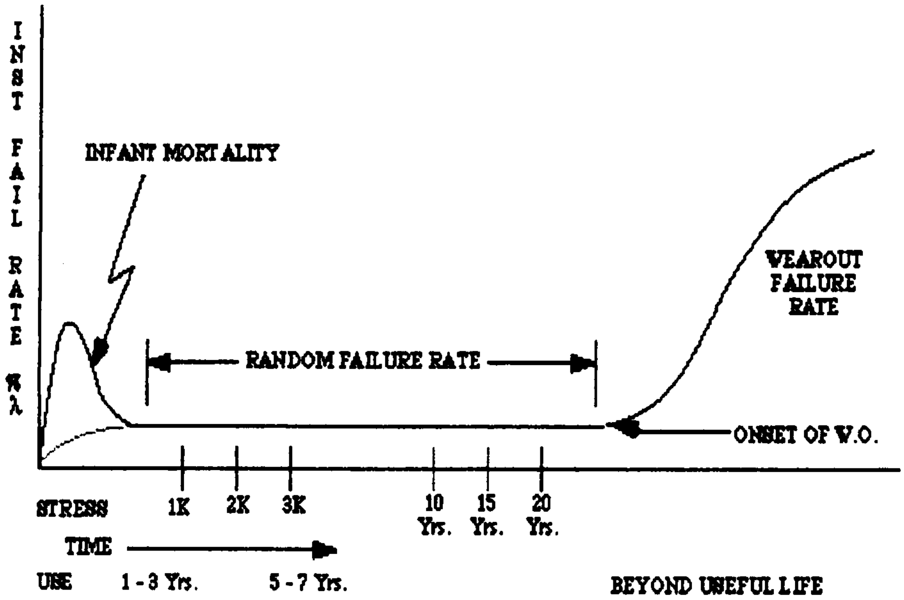

Figure 3

Bathtub Curve

Source: "Quality and Reliability Manual." Harris Semiconductor. Not Dated. p. 8.

grouped into four different classifications. Quality defects occur early in a components use. They are discovered through visual inspection or electrical screening. Reliability failures occur on components as a result of latent defects when they are subjected to normal stresses. Wear out failures occur when the part has exceeded its useful life. Design failures occur when parts are used outside their intended environment. As a result they are overstressed and fail earlier than they should. These failures increase the random failure rate during the useful life period. As will be discussed in this paper, these stresses may come from operating the part within its normal operating envelope or may result from storage in a specified environment.

CHALLENGES

Failure Mechanisms

Problems with PEDs center around two primary environmental factors, moisture and temperature.

Moisture and Contamination

The first problem is the introduction of moisture in the presence of contaminants within the package that come in direct contact with the die and or the lead bonds. These contaminants can be contained within the encapsulant material or may be introduced in the cleaning process during manufacturing. When cracking occurs around the lead frame or in the encapsulant itself, the introduction of moisture with contaminants may result in the contaminants reaching the metal surfaces inside the microcircuit. Contaminants include: Chloride, Bromide, Sodium and Potassium (Gottesfeld et al., 1994). Contaminants by themselves are not a problem. When these contaminants combine with moisture on bare metal interconnection surfaces, corrosion results. Moisture can be introduced in the manufacturing process or since plastics are not hermetic, may migrate through the encapsulant over time. The plastic encapsulant used on PEMs is pervious to moisture (Pecht, 1990). Additives may be used to slow the rate of moisture ingress, however some moisture will be able to get through to the die and lead bonds. The encapsulant material typically consist of the following: (Kovac, 1989)

a. An epoxy resin
b. A hardening component
c. A catalyst
d. An inorganic filler
e. Flame retardants
f. Coupling agents to bond the epoxy to the filler
g. Mold release agent
h. Anti fungus agent
i. Black coloring agent

Any one of these or the process to apply them can contain contaminants that will contribute to corrosion.
Figure 4 shows the hermeticity of various plastic encapsulants as a function of time and temperature.

Corrosion

Corrosion rate is affected by several factors. These include: moisture, temperature, bias voltage and electrolyte conductivity (Gottesfeld et al., 1994). The most common ionic contaminant is chloride. Moisture without ionic contamination will not cause corrosion. The elimination of these contaminants requires attention to: the microcircuit manufacturing process, the proper application (both installation and selection) of passivation coatings, purity

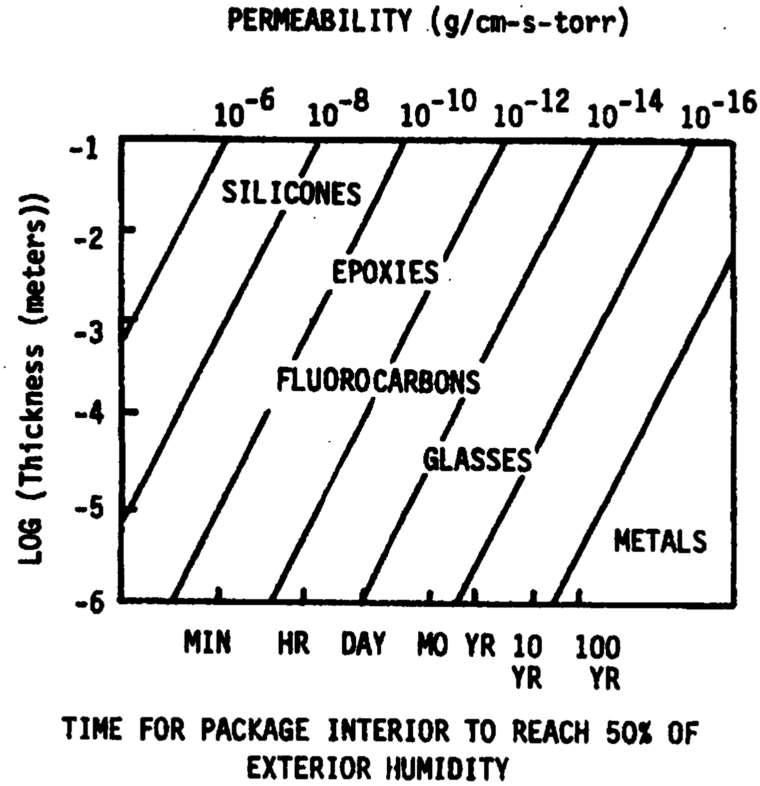

Figure 4

SEALANT MATERIAL EFFECTIVENESS

Source: "Proceedings of the 26th Annual Electronics Component Conference." INSTITUTE OF ELECTRICAL and ELECTRONIC ENGINEERS. 1976.

and adhesion of the mold compound, and lead frame integrity. The introduction of moisture and ionic contaminants must also be eliminated in the storage and manufacturing of the Printed Wiring Boards (PWBs) and the resulting Circuit Card Assemblies (CCAs).

Temperature affects the rate of corrosion. Its effect can be estimated using the Arrhenius Reaction Rate Model. Using this model, the rate of a reaction increases exponentially with an increase in absolute temperature. The model takes the form:

$$\lambda = (A)\ \exp -[(E_a/k)][(1/T)-(1/T_o)]$$

where: λ = temperature-related failure rate

A = a normalizing rate constant

E_a = activation energy (eV)

k = Boltzman's constant (8.63×10^{-5} eV/°K)

T = ambient temperature (°K)

T_o = reference temperature (°K)

As shown in table 1, mechanisms common to corrosion exhibit activation energies of about 0.7 eV. Activation energies of microcircuit failure mechanisms range from 0.06 eV to 1.4 eV. For a component in a typical storage environment of 20°C versus the same component operating near its junction temperature of 170°C, the failure rate increases more than 1000 times as shown in appendix B. As will be discussed later, this will be useful in component testing. It is important to note that since the activation energy is a constant for each specific reaction, it will vary dependent on the base material of the part and any contaminants that

Table 1

Activation Energies for Various
Failure Mechanisms of Silicon Devices

Sensitive Element	Failure Mechanism	Relevant Factors	Accelerating Stress	Typical Activation Energy
Dielectric and interfaces Si dielectric	Accumulation of surface charges	T, E/V	T, V	1.0- 1.05 eV (leakage type failures)
	Breakdown	T, E/V	E, T	0.3- 0.6 eV (0.36 eV for MOS gate structures)
	Oxide pinholes	T, E/V	E, T	1.0 eV (dielectric breakdown of bipolar devices)
	Ionic contamination	T	T	1.0 eV
	Hot carrier trapping in oxide	E/V, T	E, T	0.06 eV
	Charge loss	E, T	E, T	0.8 eV (MOS) EPROM
Metallization	Electro-migration	T, J	T, J	1.0 eV (large grain Al, glassivated)
	Contact Electro-migration	T, J Grain Size	T, J	
	Si in Al			0.9 eV
	Al at sidewalls			0.8- 1.4 eV
	Contact metal migration through barrier layer	T	T	1.8 eV
	Corrosion Chemical Galvanic Electrolytic	Contamination	H, E/V, T	0.3- 0.7 eV(Al) 0.6- 0.7 eV (electrolysis) 0.65 eV (corrosion) E/V may have thresholds
Metal Interfaces	Intermetallic compounds (Au, Al)	T, Impurities Bond Strength	T	1.0 eV (for open wires or high-resistance bonds at the pad bond due to Au-Al intermetallics)
Wafer fabrication and assembly related defects	Metal scratches	T, V	T, V	0.5- 0.7 eV 0.7 eV for assembly-related defects

Notes:
H-Humidity, V-Voltage, H-Electric Field,
T-Temperature, J-Current Density

Source: Pecht, Michael. Handbook of Electronic Package Design. Marcel Dekker. New York. 1991. p. 682.

come in contact with that base material. Since there may be several contaminants, there may be several rates of reaction occurring simultaneously.

Increased temperature not only speeds the rate of reaction, as defined by the Arrhenius Reaction Rate Model, but also raises the fraction of molecules with enough energy to react, thus compounding the problem (Eshbach et al., 1974).

Once the corrosion is initiated the presence of moisture is not required as the process becomes self sustaining. As die technology becomes smaller and smaller and bias voltages are reduced, the size of the leads are reduced. With smaller leads, the amount of corrosion required to cause a failure within the microcircuit becomes less and less. Die technology is currently in the 0.25 - 0.35 micron range. The Intel Merced chip, due on the market in 1999, will push die technology to 0.18 microns (Los Angeles Times, October 1997). New breakthroughs in etching techniques hold the promise of shrinking die technology to 0.1 micron (Holstein, 1997). Likewise, the thickness of the layers of the die is decreasing, causing even smaller electrical interconnects between layers (Heller, 1997). Bias voltage has experienced similar reductions. Ten years ago bias voltages were 5.0 volts. Now they are commonly 3.3 volts with 1.5 volts available.

Popcorning

A failure mechanism related to hermeticity that is primarily a legacy from the early manufacture of PEDs is an effect known as "Popcorning". This occurs when moisture is inside a Surface Mounted Device (SMD) type PED and the parts temperature is raised rapidly in reflow soldering. The moisture inside the PEM is vaporized and cannot escape the encapsulant fast enough. The pressure inside the PEM, between the die and the encapsulant, rises to the point where the encapsulant is fractured. The die and lead bonds are then open to contaminants and direct exposure to moisture. Popcorning is prevented by evaporating out the moisture by baking and then sealing the PEDs in dry-packs back-filled with dry nitrogen. The parts are maintained in these sealed bags until their use. Once the bags are opened the parts length of exposure to the atmospheric conditions of the CCA plant is monitored. Each part is given a predetermined amount of accumulated time it may be exposed prior to a rebake being required.

Thermal Shock

Other problems with PEDs result from different thermal coefficients of expansion of the die/lead material and the encapsulant material. Under rapid heating/ cooling the difference in the rate that the die and lead expands or contracts relative to the encapsulant results in shear stresses internal to the PED. The larger a microcircuit package is the larger the effect of these stresses, since the Thermal Coefficient of Expansion (TCE) is applied over a larger distance. Larger microcircuits result from a higher pin count than smaller microcircuits. The die is still in the center of the microcircuit, but the corners of the package are farther away. This results in fracture of the passivation layer, separation of the encapsulant from the die and cracks in the encapsulant around the leads (Gottesfeld et al., 1994). These failures in the packaging provide a path for direct migration of contaminants and moisture into the die and lead bonds. Under extreme stress the metallization layer may deform or shear causing an open or short between layers in the circuit. The passivation layer needs to be matched to help account for the differences in TCE between the encapsulant and the die. Attention must also be given to the layout of the microcircuit to reduce stresses at the corners.

Temperature Extremes

The temperature range the manufacturer is willing to guarantee the part will operate in is provided on data sheets for the parts. In order to capitalize on the latest technical advances in microcircuit technology, the use of parts outside the standard military temperature range must be considered. Parts may generally be used in more extreme temperature environments but must undergo a screening process to ensure their functionality throughout the wider temperature range. This involves evaluating the parts' electrical parameters in the extended temperature ranges. The system designer must ensure that each of those parts has adequate margin under the environmental and operational extremes it must operate at. Historically, the US Navy has used very explicit criteria for ensuring that non-military temperature range parts were acceptable for use (TE000-AB-GTP-010). Military grade parts are required to operate over the range shown in table 2.

Table 2

ELECTRONIC COMPONENT TEMPERATURE OPERATING RANGES

GRADE	LOW TEMPERATURE	MAXIMUM TEMPERATURE
Military	-55°C	+125°C
Commercial	0°C	+70°C
Industrial	-25°C	+85°C
Automotive	-40°C	+125°C

Source: Seles, Robert. "Proposed PEM Derating Guidelines." Unpublished Paper. 9 October 1997.

Thermal derating is done to limit the stress applied to the part to levels that are well within their specified or proven capabilities. This is critical to prevent overstressing the parts and causing failures during the "Useful Life" period of the Bathtub Curve.

Thermal screening is done when parts received from a vendor are only certified by the manufacturer or supplier to operate over a specified temperature range. When the part is not specified to operate over the required temperature range, thermal screening is performed to ensure the part will function properly in the required environment. This is becoming more common as military temperature range parts are no longer available and only automotive, industrial or commercial grade parts are. Most thermal screening is done by testing performance of the part over the required temperature range. Parts that are fully functional over the entire derated temperature range are selected for use. Concern exists about the fact that, having subjected a relatively small sample of the total production run of the parts to the extreme temperatures of the screening range, some portion of their useful life is expended. If the temperatures were at the point just prior to failure, a significant portion of their life may be used. Another approach to stress screening is to test a statistically significant quantity to failure. The temperatures at which the parts fail can be used to establish a margin above the derated requirements of the parts. This method does not have the same problem of overstressing the parts as the classic method of parts screening since the tested parts are disposed of. For this reason it is becoming a more accepted practice.

Fungus

Plastics are organic material and therefore are not fungus inert. Fungus will attack the plastic, causing it to deteriorate through decomposition (Alvino, 1995). The decomposition process may generate water and can expose the die and leads to moisture. Table 3 shows fungus nutrient materials. These materials can be used if properly treated for fungus resistance. If used in a hermetically sealed enclosure, treatment for fungus resistance is not required. They must be tested for the effectiveness of the fungicide and the effect of it on the electrical properties of the encapsulant or coating. Preferred materials to use from a fungus resistance standpoint are listed in table 4. Other characteristics of the material must be considered for its use as an encapsulant or coating. The materials in table 4 do not require testing for fungus resistance.

Table 3

FUNGUS NUTRIENT MATERIALS

ABS (acrylonitrile-butadiene-styrene)	Polyethylene, low and medium density (0.940 and below)
Acetal resins	
Cellulose acetate	Polymethyl methacrylate
Cellulose acetate butyrate	Polyurethane (the ester types are particularly susceptible)
Epoxy-glass fiber laminates	
Epoxy-resin	Polyicinoleates
Lubricants	Polyvinyl chloride
Melamine-formaldehyde	Polyvinyl chloride-acetate
Organic polysulphides	Polyvinyl fluoride
Phenol-formaldehyde	Rubbers, natural and synthetic
Polydichlorostyrene	Urea-formaldehyde

Source: "MIL-STD-454M." Department of Defense: Standard General Requirements for Electronic Equipment. Washington, D.C. 15 August 1990. pp. 4-1 through 4-3.

Table 4

FUNGUS INERT MATERIALS

Acrylonitrile-styrene	Polyamide
Acrylics	Polcarbonate
Asbestos	Polyester-glass fiber laminates
Ceramics	Polyethylene, high density (above 0.940)
Chlorinated polyester	Polyethylene terephthalate
Flourinated ethylenepropylene copolymer (FEP)	Polyimide
Glass	Polymonochlorotriflouoethylene Polypropylene
Metals	Polystyrene
Mica	Polysulfone
Plastic laminates:	Polytertafluoroethylene
Silicone-glass fiber	Polyvinylidene chloride
Phenolic-nylon fiber	Silicone resin
Diallyl phthalate	Siloxane-polyolefin polymer
Polyacrylonitrile	Siloxane polystyrene

Source: "MIL-STD-454M." Department of Defense: Standard General Requirements for Electronic Equipment. Washington, D.C. 15 August 1990. pp. 4-1 through 4-3.

Electro-Static Discharge

The plastic package does not protect the sensitive die from Electro-Static Discharge (ESD) and in fact the plastic package itself may contribute to the generation of a static charge. Plastics can easily build up static potential in excess of 20,000 volts. Damage to PEDs occurs at less than 4000 volts. Some ESD damage can weaken parts so they fail sometime during their use. For this reason special handling of PEDs must be observed to prevent damage from ESD. Military part sensitivity to ESD is classified according to either DoD-STD-1686, DoD-HDBK-263 or MIL-STD-883, based on the level of charge a part may be subjected to without damage. Commercial parts are not classified, however their sensitivity should still be quantified to determine if any special handling precautions are required.

PERFORMANCE OF PEDs

Available Data

Data on both HSD and PED performance in simulated aging and real world (actual) conditions exits in limited quantity and quality. Comparison data on the same die in both HSDs and PEDs is only available in simulated aging conditions. Real world performance of PEDs is available for many environments. The amount of that data available for PEDs subjected to the rigors of the military operating environment is limited. Simulated aging has been performed using the same die in both plastic and hermetic packages.

Aging conditions are simulated by subjecting the microcircuit to environmental extremes that exceed those of the normal use environment. Accelerated stress testing is used to determine the useful life of a component which may be required to last tens of years. These methods are required to obtain confidence in the component's life in a relatively short period of time. Accelerated stress testing is performed using several methods with variations of each. All methods rely on the fact that as temperature is increased, the rate of a reaction such as corrosion is increased according to the Arrhenius Reaction Rate Model. When running these tests for long-term storage reliability, if the part is left for a long enough period of time under bias, the heat generated from the bias current will tend to bake out any moisture. For this reason, to get realistic results, it is important to cycle bias voltage between on and off at regular intervals throughout the test. The more common methods are:

Temperature Humidity Bias (THB)- This test method involves applying a bias voltage to the microcircuit while it is subjected to 85 °C at 85% Relative Humidity (RH). As PED reliability has increased dramatically, THB conditions resulted in tests running several thousand hours.

Highly Accelerated Stress Test (HAST)- In order to reduce the test time THB was taking, HAST was developed. Accelerated stress was achieved by raising the temperature of the THB test to the 110 °C to 140 °C range.

Autoclave or Pressure Cooker- This test adds pressure to a 100% RH environment to force moisture into the die and lead frame area.

All of these tests are designed to accelerate the failure of PEDs due to moisture induced corrosion by applying the primary factors that affect corrosion: bias voltage, temperature and moisture. They assume package or passivation layer cracking does not occur and therefore contaminants would not enter the lead frame die area. The only contaminants present are those in the PED at the time of manufacture. For this reason it is imperative that even though a PED passes one of these tests, that cracking of the package and lead areas is prevented.

Since simulated test conditions can be performed for both PEDs and HSDs, the effects on each device type can be directly compared. A change in a stressed condition changes only the average life of each device type's reliability distribution (Pecht et al., 1991). The relative change of the distribution is the same for both the HSD and the PED.

CERDIP vs PDIP THB Result

In one test case, actual CCAs were built up using both PED and HSD versions of the same microcircuit (Condra et al., 1992). These tests were done on a CCA redesigned for parts obsolescence from one with a field history of over 20 years. The CCA, a single channel of a proximity sensor, used a microcircuit available in both 18-lead PDIP and Ceramic Dual In Line Package (CERDIP) versions from a variety of manufactures. The packaging for these tests were done at an offshore facility that did not employ extensive Statistical Process Control (SPC) methods. A total of forty eight circuit cards were tested in four different configurations. The first was the original fielded version of the card, the second was the new design card with CERDIP and Humiseal (urethane) conformal coat on the CCA, the third was Plastic Dual In Line Package (PDIP) and Humiseal on the CCA. The forth was PDIP and paralyne conformal coat on the CCA. Appendix C contains a table of conformal coat types and their key characteristics. The PDIPs were dry baked prior to soldering. An additional 16 of each PDIP and CERDIP were evaluated in a non CCA installed condition. These parts were subjected to up to 1000 hours of 85 °C at 85% relative humidity under electrical bias. The bias cycle was set to 30 minutes on followed by 30 minutes off. The on period allowed for electromigration, yet was not long enough for the microcircuits to bake out the moisture. The bare micro circuits were tested without bias at 85 °C/ 85% relative humidity. The functionality of the bare microcircuits was tested by measuring their performance with 26 electrical characteristics. There was virtually no change in any of the characteristics from beginning to end of test for any of the CERDIP or PDIP configurations. The CCAs were subjected to test of four characteristics. No failures of either PDIP or CERDIP microcircuits were observed, although there were two card failures. Projected life for moisture induced failures was in excess of 20 years for all CCA configurations.

Harris CERDIP vs PDIP and Small Outline Package Test Results

Harris Semiconductor compared reliability data on commercial grade CMOS metal gate, CMOS Silicon Gate and BiPolar ICs in CERDIP, PDIP and Small Outline Packages (SOP) (Gottesfeld et al., 1994). The data was collected for the period of January 1987 through July 1994 on over 480,000 parts. Failures In Time (FITs) for the PDIPs were about 50% of their ceramic counterpart CERDIP. Moisture testing was performed on the plastic packages only, using THB (85°C, 85% RH, 6-18 volt bias for 1000 hrs), HAST (145°C, 85% RH, 6-18 volt bias) and Autoclave (121°C, 100% RH, 15 psig, 192 hrs). The Defects Per Million (DPM) for the PDIP under all test conditions were 900, 300 and 400 for each test type respectively. Failures due to corrosion were 100, 60 and 200 DPM respectively.

Magnavox Real Use Results

Some of the most compelling data supporting the use of commercial and industrial grade components in long-term dormant storage conditions comes from Magnavox Corp. Magnavox has been using commercial and industrial components in military applications for over 20 years. Products include 2.5 million sonobuoys, 50,000 airborne radios and thousands of handheld radios. For the long-term dormant storage case, the sonobuoy data is some of the most realistic available in that the storage conditions are similar those of a missile.

Sonobuoy Reliability Data (Ricci, 1994)

Magnavox subjected 25,982 sonobuoys to lot acceptance and field testing. Of those there were 108 failures of commercial components resulting in sonobuoy reliability of 0.99584. The sonobuoys used a total of 10,313,150 parts. This resulted in a part reliability of 0.999989. The 108 failures include all types of part failures, not just those associated with corrosion due to storage or others that are unique to PEDs.

Handheld Radio Production Reliability Acceptance Testing (Ricci, 1994)

During a four year period Magnavox performed production reliability acceptance testing of their handheld radio production. PEDs were subjected to a total of 6,918,575 PED hours. Only 2 failures occurred resulting in a PED reliability of 0.2891 failures per million hours. The PEDs were subjected to 8 hour temperature cycles of -40°C to +55°C and 15 minute vibration cycles using sine sweeps of 5-500 Hz @ 2g. Using MIL-HDBK-217D, predicted failure rate for these conditions is 1.306 failures per million hours.

The data from these tests support the common industry held belief that MIL-HDBK-217 predictions from historical databases have become outdated as PEM manufacturing processes have improved. These predictions are based on the Arrhenius Reaction Rate Model. MIL-HDBK-217 reliability predictions of PEDs has been one of the driving forces behind the resistance to use PEDs in military systems.

Precision Lightweight Global Positioning System Receivers

Rockwell International, Collins Avionics and Communications Division performed accelerated storage reliability test on ten of its Precision Lightweight Global Positioning System (GPS) Receivers (PLGRs) (Emerson, 1995). These receivers used PEDs extensively.

The ten PLGRs were normal production units except for the addition of a Humiseal conformal coat to the CCAs. Performance of each PLGR was verified at the start of test and at intervals of 96, 193, 583 and 1026 hours. Each unit was subjected to 85°C/ 85% RH THB with no failures of PEDs. The equivalent storage life for 30°C at 40% RH was calculated to 224 years.

<u>Passivation Type Comparison</u>

HAST data on 16 lead PDIPs using three methods of passivation revealed a significant difference in the ability of a passivation layer to prevent corrosion (Gottesfeld et al., 1994). As shown in figure 5, silicon nitride/ Phoshosilicate Glass (PSG) sandwich passivation versus PSG and Plasma Enhanced Nitride (PEN), yielded variation of a full order of magnitude in life.

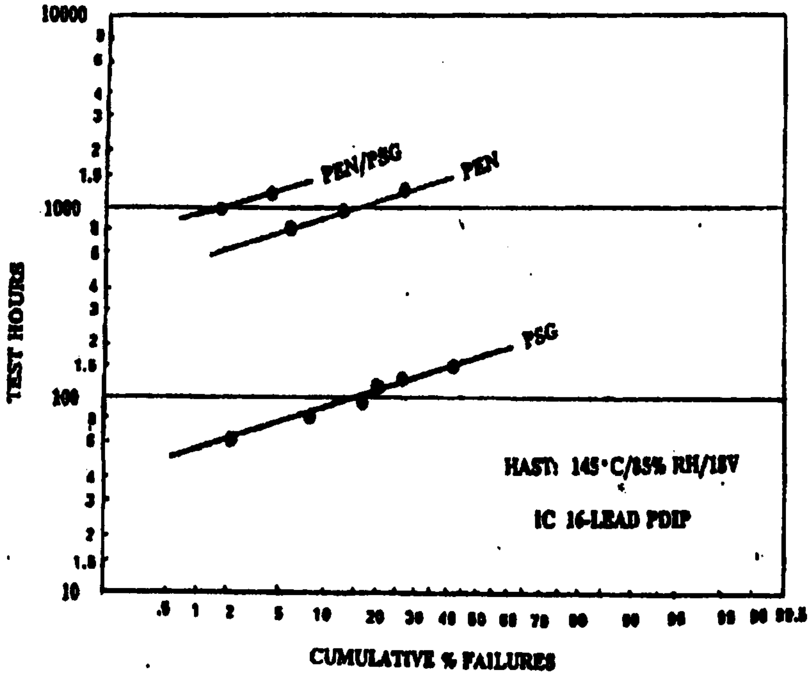

Figure 5

Comparison of Plasma Enhanced Nitride (PEN) and Phosphosilicate Glass (PSG) Passivation For Aluminum Corrosion

Source: Gottesfeld, Sheldon, William L. Shultz. "Reliability Considerations for Using Plastic-Encapsulated Microcircuits in Military Applications." Harris Semiconductor: Melborne Florida. August 22, 1994.

Manufacturer to Manufacturer Variation

Rome Laboratory performed C Mode- Scanning Acoustic Microscope (C-SAM) inspections of the same PED type manufactured by two different sources. The PED was a CD4011. Both manufacturers were using "Best Commercial Practices" at the time of manufacturer. Figure 6 shows the C-SAM image of a PED from manufacturer "A". All devices from manufacturer "A" were clear of voids.

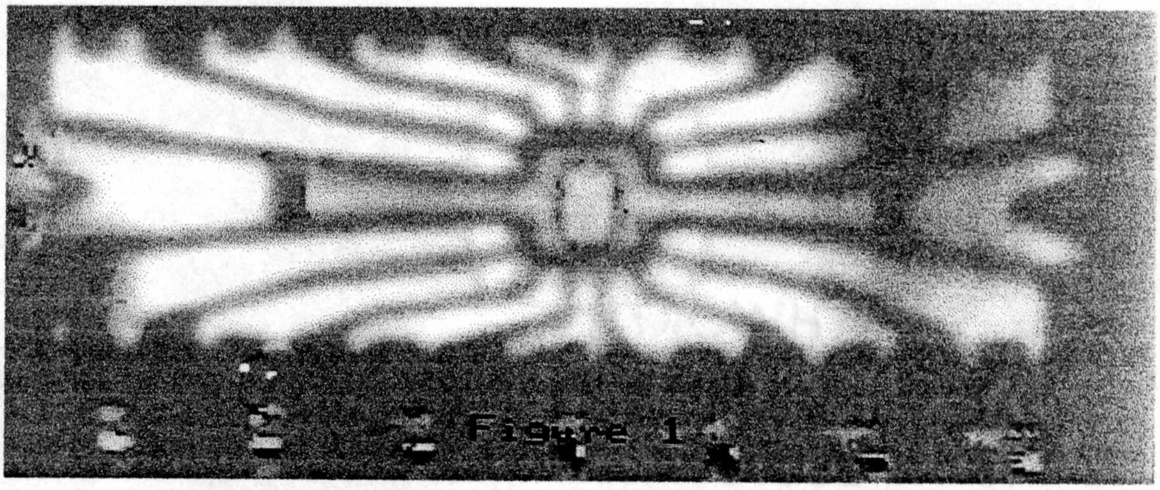

Figure 6

C-SAM Image of CD4011 PED Without Voids

Source: Reilly, Jim. "Plastic Encapsulated Microcircuit Evaluation Programs at Rome Laboratory." Reliability Analysis Center (RAC). Rome, New York. Not Dated.

Figure 7 shows the C-SAM image of a PED from manufacturer "B. All ten parts inspected showed voids due to delamination above and below the lead frame. These voids can cause several significant problems. The first of these is popcorning if moisture is trapped in them prior to soldering. The other major problem is corrosion due to a path being opened for moisture and contaminants to enter the lead frame area. These images show why it is critical that manufacturing processes for the PED be closely monitored.

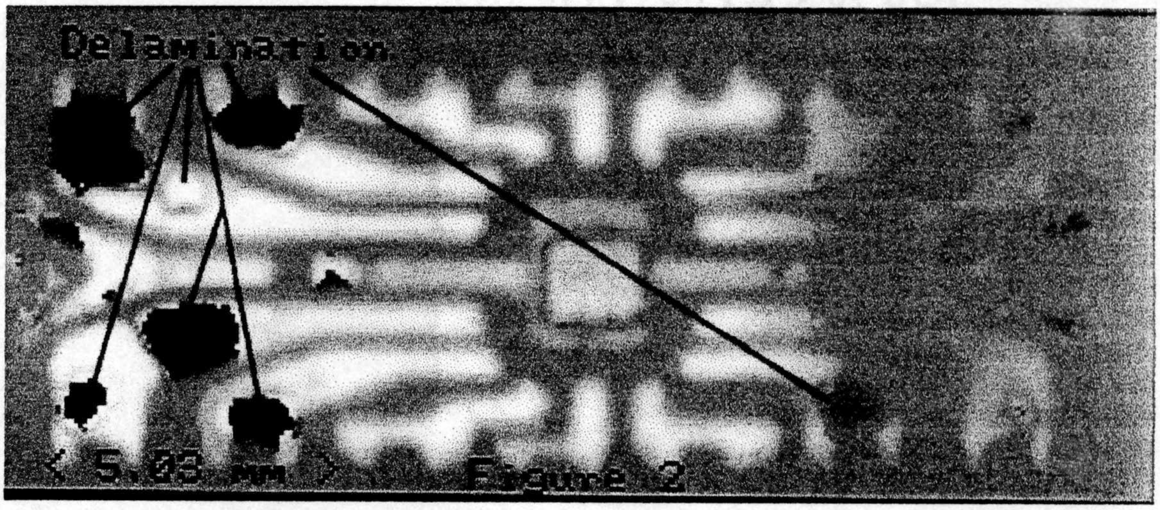

Figure 7

C-SAM Image of CD4011 PED Showing Voids

Source: Reilly, Jim. "Plastic Encapsulated Microcircuit Evaluation Programs at Rome Laboratory." Reliability Analysis Center (RAC). Rome, New York. Not Dated.

RELIABILITY IMPROVEMENTS TO PEDs

Reliability improvements to PEDs to counter the above issues have been made over the last 20 years. These include:

Improved encapsulant materials: Provide lower ionic impurities to prevent corrosion in the presence of moisture. Better adhesion to other packaging materials to prevent cracking and delamination of the package, die, leadframe and substrate. Higher glass-transition temperature to prevent breakdown at military temperature ranges. Coefficients of thermal expansion matched to the leadframe to reduce shear stresses internal to the die.

Advances in die passivation: Provide better die adhesion to prevent separation from the package while under stress. Fewer pinholes and lower moisture absorption to reduce the ability of moisture and contaminants to contact the leadframe and bonds. Lower ionic impurity to prevent corrosion in the presence of moisture.

Manufacturing processes using automatic assembly: Eliminate manual handling which eliminates operator error. The elimination of operator error coupled with high volume production have led to implementation of SPC.

Figure 8 is an example of the dramatic improvements in and the associated contributors to PED reliability over the 20 year period starting in 1974. The use of PEDs in missile

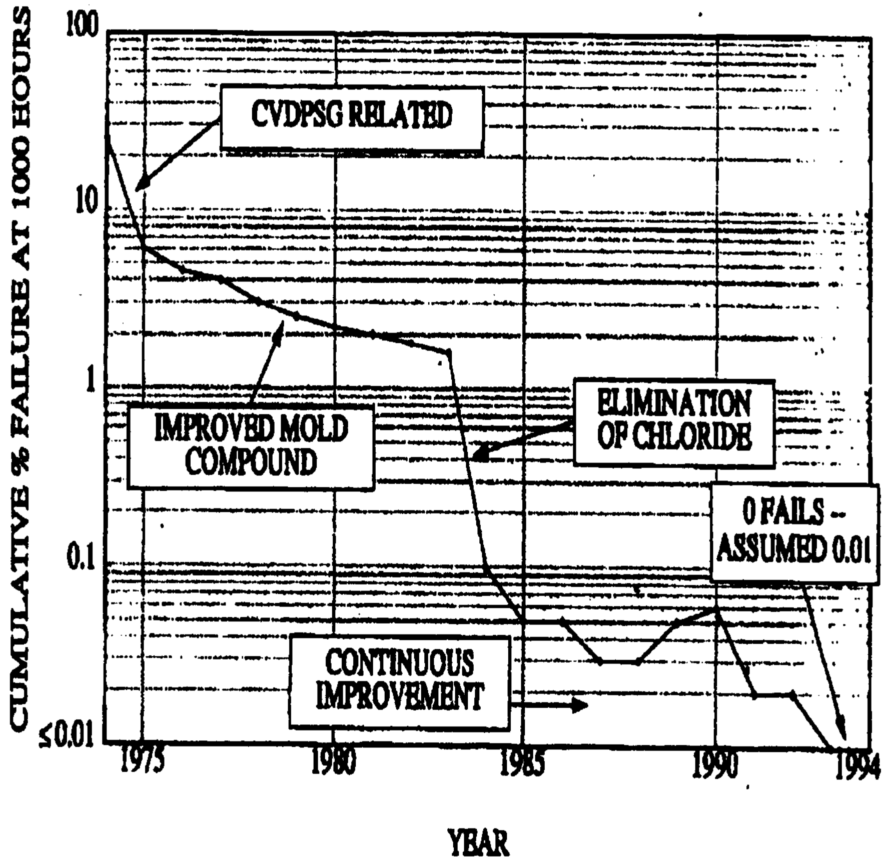

Figure 8

IMPROVEMENTS IN THB 85°C/ 85% RH PERFORMANCE IN PLASTIC-PACKAGED (PDIPs) CMOS LOGIC ICs

Source: Gottesfeld, Sheldon, William L. Shultz. "Reliability Considerations for Using Plastic-Encapsulated Microcircuits in Military Applications." Harris Semiconductor: Melborne Florida. August 22, 1994.

systems require these processes to be tightly controlled to prevent the problems addressed throughout this chapter.

PED ADVANTAGES

The advantages of PEDs compared to HSDs are: cost, size, weight, availability, shock resistance, and selection. Each item is discussed below.

Cost- The higher volume and more automated processes used in PED manufacturing result in cost savings of 50% or greater. This higher volume also allows tighter control of the processes through the use of SPC and elimination of post manufacturing tests.

Size- Surface mount technology is only available in PEDs. The smaller size of the microcircuits result in significant size reductions.

Weight- PEDs generally weigh one-half that of their ceramic counterparts. This coupled with the reduced CCA sizes results in significant weight savings.

Availability- PEDs are generally bought off an ongoing production line. The microcircuit does not have to be laid out prior to manufacture as in a limited production run for HSDs. Continuous high volume production is conducive to effectively employing Statistical Process Control (SPC).

Shock Resistance- Because the plastic molding compound is formed about the die there is no room for the die and/ or leads to move about when the part is subjected to a mechanical shock. This is unlike the ceramic devices in which the die is placed in a cavity and bonded in place with an adhesive. Shock places loads on the adhesive bonding since the die is free to move. Failures also occur in the lid "decanning" the PED and in the formation of cracks around the hermetic seals of the leads. If undetected during the manufacturing process or if a failure of this type occurs during the service life of the missile, the die is exposed to contaminants and moisture.

Selection- Due to the demand for PEDs in the commercial market place, development and manufacturing efforts are initially directed towards them. Military grade PEDs come two to three years later if ever. This results in high production volumes to meet the commercial market demands. The relatively small number of parts required for military systems is available from these large production volumes.

Manufacturing- Cost savings from PEDs result not only from the cost of the individual part but also from the assembly process. PEDs are better suited for automatic assembly procedures, using part reels and pick- place type machines (Priore et al., 1992). Automation results in better end product quality control and use of SPC for the CCA assembly process. The brittle nature of the glass-epoxy seals on HSDs subjects those parts to damage when handled with pick-place machines.

Thermal Coefficients of Expansion (TCE)- The TCE of PEDs more closely matches that of most Printed Circuit Boards (PCBs). This results in less thermal shock on the terminations and bonds between the microcircuits and the PCB than with HSDs.

Performance- Certain PED packages such as Plastic Quad Flat Pack (PQFP) and ball-grid arrays are more conducive to minimizing propagation delays within the microcircuit (Quearry et al., 1993). This results in faster performing microcircuits.

QUALITY STANDARDS

Unlike their military counterparts, commercial microcircuits do not have a universal quality standard. For this reason it is essential that each part is evaluated on a case by case basis using established and well documented procedures. The next chapter will cover recommendations for those procedures.

TECHNICAL CHALLENGES SUMMARY

PEDs have technical challenges that must be overcome if they are to be successfully used in missile systems. They also have advantages from cost, manufacturing process control, availability and certain reliability parameters.

A combination of real world and accelerated aging test data is available that confirms PEDs have the ability to provide long-term reliability comparable to if not better than HSDs. The same part produced by different manufacturers can exhibit significant differences in characteristics that affect long-term reliability.

The impact PEDs have to the overall reliability of a particular missile system must be evaluated on a case by case basis. If the reliability at the system level meets the users requirements then the use of PEDs should be considered. The ability of PEDs to overcome these technical challenges for each system application will determine whether they are suitable for use. The next chapter discusses methods to overcome the transition to the use of PEDs and ensure their successful employment in missile systems.

CHAPTER V

TRANSITION ISSUES

BACKGROUND

There are two approaches that the missile manufacturer can take to ensure reliable application of PEDs.

1. Through the use of environmental controls, the exposure of the part to moisture and temperature extremes can be controlled. Placement of CCAs in hermetically sealed cases can be used to prevent exposure of the parts to moisture and contaminants. Heaters and cooling methods can be used to maintain the parts within the temperature range specified on the manufacturers data sheet, eliminating the requirement for screening outside this range.
2. Manufacturing processes can be controlled to limit or eliminate contaminants and ensure packaging integrity to prevent the ingress of contaminants into the microcircuit throughout the life of the product.

The cost of implementing the first approach can be prohibitive on existing and the more complex weapon systems adding unnecessary costs. System designers should do a cost analysis of this approach to see if it is feasible. The recommendations of this paper address the second approach as a means to achieve the required reliability of missile systems.

Several key factors have enabled military programs to consider the use of PEDs utilizing this second approach:

- PED reliability has increased dramatically with the use of Best Manufacturing Processes (BMP).

- Improved methods of deterministic reliability prediction were developed including the Highly Accelerated Stress Test (HAST) and Temperature Humidity Bias (THB).

- An accumulation of reliability data on PEDs was available for a variety of Military and Commercial systems that could be compared with programs under current development.

Traditionally the manufacturer of PEDs has relied heavily on the use of screens and burn-ins to ensure the reliability of their products. The automotive industry drove the commercial component manufacturers to change from using screening as a method of quality assurance to using Statistical Process Control (SPC). Implementation of SPC and continuous improvement dramatically increased quality and reliability of these components. These are some of the main tenants of BMP and Total Quality Management (TQM). The United States automotive industries survival depended on their adaptation of SPC. It is the third point of Dr. Demings 14 points (Deming, 1986).

> "Cease dependence on inspection to achieve quality. Eliminate the need for inspection on a mass basis by building quality into the product in the first place."

If the transition to the use of PEDs is made, the technical challenges of the previous chapter must be addressed. Resolution for each of these technical challenges is discussed in the following PED implementation considerations.

PED IMPLEMENTATION CONSIDERATIONS

Government Visibility

The use of PEDs requires the transition from a well defined system of military standards, to a contractor administered system with customer oversight. The customer and contractor must team to form the requirements for the use of PEDs. The contractor should be left with the flexibility to carry out the day to day implementation of those requirements. The government program office must maintain visibility of parts selection and the ability to audit the contractors process.

PED Parts Control

Given that the part can be manufactured reliably one must first be sure the correct part is chosen for the environment in which it must operate. Proper part selection requires knowledge of the application, the component and manufacturers processes. In order to address these issues, a PED parts transition plan must be developed. The elements of this program should include; reviews of the environment the part must be used in, part selection, analysis of the reliability of the part in the intended application and its environment, an analysis of the future availability of the part, establishment of partnerships with part manufacturers, detailed review of the part manufacturing processes, ensuring the part is properly qualified, screening parts if required, a detailed review of CCA production controls, and stress testing of the parts at the piece part or CCA level.

Establishment of the Parts Environment

Since the major impediments to using PEDs are the concerns for moisture and temperature effects on their reliability, the environment the part is to be used in has to be defined in these and other terms. The environment must include those the part will be exposed to in part manufacture, handling, shipping, storage, assembly onto circuit cards, and testing in addition to usage in the system. Each of these environments must be defined in terms of: minimum and maximum temperature, vibration, humidity, mechanical shock, temperature shock, and power application cycle. The frequency and duration of occurrence of each environment must be defined. The environment each part is subjected to must be flowed down from the environment of the highest level of assembly the part is in at the time it will see that environment. This means it is flowed down from the all up round of the missile to each of the weapon replaceable assemblies (WRAs). From the WRAs it is flowed down to the Circuit Card Assemblies (CCAs), then to individual parts. The process of defining the environment is iterative. As part selections are made, their contributions to the overall part environment must be factored in. These include heat generated within the part as well as model effects on the vibration characteristics of a CCA due to mass properties and part location differences. The use of some parts may require the use of special heating, additional cooling such as heat sinks, or part relocation on a CCA. These changes will affect other parts in the design. Several design iterations may be required to arrive at a final design.

Part Selection

After the environment of the part is thoroughly understood, the requirements of each piece part must be specified. Part selection is then made and each components suitability for the design must be verified by analysis. Manufacturer's data sheets may be used to determine the advertised part performance in the design. Performance includes temperature range of the part versus the application or derated temperature range. Contamination and moisture controls that the part are manufactured to must be evaluated. Evaluation of process controls in the manufacture of a part are key to the selection of a suitable part. Manufacturing processes to mitigate failure modes must be evaluated. These include: proper selection of encapsulant and passivation materials, cleaning processes and, use of automated assembly processes to eliminate handling damage. Discussions with potential manufacturers must be held to clarify characteristics of the part. It is essential that emphasis is placed on manufacturing processes that affect moisture and contamination. As shown previously for a given part number, the quality can vary dramatically from supplier to supplier. Part manufacturers must have documented processes for material selections, contamination and moisture controls, material handling, fabrication, and testing. They must implement SPC to provide consistency in quality, reliability, and performance.

Manufacturer selection is critical. Time spent on finding qualified manufacturers can be minimized by developing a common parts management database and sharing this data across participating manufacturers. Some of the data listed in this database should include: device types, manufacturer, technology, reliability data, destructive physical analysis status, screening qualification results, and future availability.

Corporations should strive to transition to a single corporate wide parts management process. The commonality of parts from the same manufacturer must not be overlooked at the corporate level. This will provide quicker, less costly and better evaluations of a particular parts applicability.

Taking this a step further, industry itself should develop a common parts management database. This effort should be led by a joint industry and government working group. The purpose of this working group should be to share information with other members while also gaining information from those members. From this common database, the development of a common part management database could be made. Like the corporation common part database, this database should include: the device type, its manufacturer, the type and maturity of technology used for the part, reliability data for the specific part and any parts of similar type manufactured using the same processes, results of destructive physical analysis and screening and qualification tests. Future part availability should also be stated.

The use of an industry common database would allow the move toward standardization of commercial parts and a better understanding of the quality and capability of parts for specific applications. The use of electronic exchange of data would allow timely updates and rapid dissemination of test results or reliability.

A fractorial array may be used to reduce the amount of testing required to collect part reliability data (Kromholtz et al., 1994). When establishing a common parts management database, the minimum number of test conditions should be used to qualify a specific part for a variety of applications. Parts may be grouped according to common characteristics such as same technology, die size and manufacturer production processes. The fractorial array would allow the common parts management database working groups to ensure all aspects of a part are tested in the most cost effective manner.

The parts selection process must be ongoing. Even though a selection is made, the manufacturers processes are subject to variation and can become out of control. The missile manufacturer must continue to monitor the parts manufacturer performance with reviews of yield and test data.

PED Derating Guidelines

Existing derating requirements are covered in TE000-AB-GTP-010, revision 1 (TE000-AB-GTP-010). These requirements were developed for HSDs operating in the full military temperature range. Following TE000-AB-GTP-010 precludes the use of PEDs in many cases. Revised derating guidelines are required to allow use of PEDs in other than the full military temperature range. Recommended levels are to verify part performance to at least 25°C below the minimum operating temperature and 35°C above the maximum operating temperature (Seles, 1997). These tests must be done using a statistically significant sample size of parts after exposing them to the required temperature shock environment. Use of Step Stress Tests or Highly Accelerated Life Tests (HALT) at the CCA level is a valid method to determine that all parts on the CCA meet the thermal requirements of the system.

Qualified Manufacturer and Part Lists

The Qualified Manufacturing List (QML) contains manufacturers that have undergone a one time, in-depth audit of their processes (Schultz et al., 1995). The audit is used to verify the manufacturer has processes under control and uses Best Manufacturing Processes (BMP). The audit also ensures that the manufacturer can manage change and incorporate continuous improvements to their processes. Manufacturers are given the flexibility to eliminate non-value added processes to reduce costs. Since the elimination of these non-value added processes does not require further review, it is essential that the contractor have established procedures to ensure critical processes are not eliminated. Each part must still be evaluated for the application it is to be used in.

Even though QML provides some assurances that the manufacturers processes are established the system designer must still ensure the application of each specific part fits the requirements of the system.

The Qualified Parts List (QPL) is a list of specific parts that are qualified to specific performance levels. There generally is more than one manufacturer per part. It does not give any guarantee of further performance of a part if a particular manufacturer changes its processes. The missile manufacturer must exercise caution when selecting parts off of QPL. The manufacturers processes should be monitored on an ongoing basis as they are the most critical factor to ensure quality parts are used. Being on the QPL does not guarantee a particular part will work in the required application and its environment.

Each selected part should be compared to a military/ceramic equivalent when available. The best suited part in terms of reliability and costs should then be made.

Reliability Analysis

After selection of candidate parts, a reliability assessment should be performed on the preliminary design. Worst case electrical stresses must be analyzed for the worst case environment for each part. Reliability predictions should be made to determine if the overall system will meet the reliability requirements of the specification. This is flowed up from the projected reliability of each candidate part using the specified operational and storage environments at the missile level. Effects from moisture must be evaluated for corrosion.

Thermal effects must be evaluated for, delaminations, package cracking, bond and wire damage, die cracking, passivation fractures and popcorning.

Future Part Availability Analysis

Commercial parts tend to have much shorter life-cycles compared to their military counterparts. In a given form factor they are generally on the market 3-5 years, although the family of parts may last much longer. For this reason, future availability of parts should be considered in the design for both reparability and future production. The availability of a part or a suitable replacement has to be considered to keep production going. As parts become unavailable, design changes must be made which will affect CCA layout and necessitate retest and possibly requalification of the design. Part changes and CCA relayouts can have significant impacts on a variety of performance issues. These include software timing and Electromagnetic Interference (EMI) in addition to the areas discussed above. The effect on each of these areas has to be analyzed and may have to be retested. If the change or accumulation of changes is significant it may require retest at the WRA or even system level.

Part availability can drive cost of repairs in the future. As failures occur and are traced down to the CCA and piece part level, the availability of the part will determine whether the part itself can be replaced or the entire CCA will require replacement with a newer design CCA that uses currently available parts. Interchangeability and intermixability of CCAs within a WRA has to be maintained as obsolescence occurs and CCAs are redesigned. Technology maturity of the part and where it exists in its product life cycle should be evaluated. The preference is to design with parts that are in the beginning of their life cycle in order to leave as much remaining time as possible available for future production and repairs. The market base of the part should be considered in determining future availability. Parts that have a large market base tend to be available longer. As production of these parts is discontinued, suppliers will increase their inventories of stock. Ease of manufacture of the part is also considered. A part that is easy to manufacture may be able to be licensed to some of the smaller fabrication plants for small production runs if required.

Partnership Establishment With Part Manufacturers

Partnerships must be established to provide open communication between the manufacturers and the designers of the system using the parts. Designers must be notified early on of changes in the parts manufacturing process. This will enable an evaluation to be made on whether the part will still be suitable in the application or if any additional screening or tests will be required. If the part is not suitable, then ample time must be allowed to select another suitable part which may require relocation of all components on a CCA.

Manufacturer Process Review

A detailed technical review of the manufacturing processes is absolutely essential for each part. Since the cost of testing 100% of parts is prohibitive and in and of itself can induce failures from handling, emphasis must be placed on defect prevention using processes under SPC, not detection of defects by post production testing. The implementation of established and well documented programs of SPC is required.

The actual manufacturing process must be reviewed to ensure that:

> The introduction of contaminants is eliminated or reduced to minimum amounts to prevent the catalyst for corrosion. Manufacturers review all processes and material selections to ensure parts are contaminant free.
>
> The effect of shrinking microcircuit technology on the impact of corrosion is evaluated as this trend continues.
>
> All parts are dry baked and shipped in dry packs ready for use at the CCA manufacturer.

The parts design characteristics are reviewed to ensure risk in thermal shock environment is minimized by attention to layout and, coefficients of thermal expansion of materials used.

The supplier's quality system including change control process must be reviewed to ensure proper notification is given when changes to the manufacture of a part are implemented. These changes must be evaluated to determine their effect on the part reliability and the requirement for any further characterization testing.

Part Qualification

PEDs must be qualified to at least the level for their specific application in the system. A review of the suppliers performance on other programs must be completed. If existing data is adequate, qualification of the part may be done by similarity to other programs. If data is not available, the cost to perform qualification testing on the part should be compared to selection of an alternate part. If part qualification is selected then both HAST and temperature shock tests must be performed.

Part Screening

Part manufacturer screening programs must be reviewed to determine if any additional testing is required.

Additional tests if required, should be identified and performed at the part supplier or a third party tester. From these test results a deterministic assessment can be made regarding the particular parts suitability for use.

CCA Production

Like the piece part manufacturer, the CCA manufacturer must place emphasis on defect prevention not detection. Processes must be controlled with SPC to replace variability with predictability. The effect of each operation at the CCA manufacturer of the PEDs must be thoroughly understood. These operations start from receipt of piece parts in receiving through assembly of the CCA, to shipping of the final CCA.

In receiving, the integrity of dry seal packs should be verified. If these packs are to be opened for verifying part counts and qualities, they must be resealed in dry packs and the total time of exposure accounted for. A better approach would be to have the supplier of the piece parts certified to provide the correct type and quantity of parts requested. This omits one handling step that may introduce failures to the parts.

All handling must exercise proper ESD procedures to prevent damage to the parts. These procedures must be well established with equipment whose functionality is verified on a periodic schedule.

The handling and part preparation procedures and their effects on the piece parts reliability must be thoroughly understood. These include operations such as rebakes, lead dressing and placement into pick-place machines. Solder operations such as reflow soldering and wave soldering can have a significant impact on the future performance of a part with regards to reliability. If parts are subjected to too high a temperature, they may be stressed excessively and fail during their "useful life" period.

In cases where rework or repairs are required, the effect of those operations on the piece parts must also be considered. Desoldering operations can place excessive stress on the parts that can also degrade their "useful life". Determinations must be made on which parts can be subject to rework and reuse, and which parts will require replacement after removal during board rework.

Manufacturers should use the moisture induced stress sensitivity guidelines of IPC-SM-786A to determine out of bag times for PEDs. Level 1 classified PEDs should be used when possible to eliminate the requirement for a rebake under manufacturing conditions. Classifications of PEDs are contained in table 5.

Table 5

PED MOISTURE INDUCED STRESS SENSITIVITY CLASSIFICATIONS

Level	Floor Life (out-of-bag)
1	Unlimited at <= 85% RH
2	1 year at <= 30/60
3	1 week at <= 30/60
4	72 hours at <= 30/60
5	24 to 71 hours at <= 30/60 (as specified on label)
6	Mandatory bake

Source: "Response to Texas Instruments' Concern on the Use of PEMs." CALCE EPRC: University of Maryland. College Park, Md. Not dated.

Manufacturers should study the use of temperature ramping during reflow soldering processes. By ramping the temperature the requirement for rebakes may be able to be eliminated in certain cases. Any decision to do this should be thoroughly tested and reviewed by all industry and government participants.

Advanced Stress Tests

Once the first pre-production unit CCAs are assembled, they should undergo Step Stress Test to ensure sufficient margin exists for the parts to operate in the required environments over the required life of the product. HALT is preferred since it adds vibration which has been shown to increase corrosion rates. Interactions among stresses must be considered by evaluating the CCAs under combined stress conditions. The failure modes may be different than if stresses are applied independently (Kromholtz et al., 1994). HALT testing meets this requirement. In either method, environmental and application stresses are increased in steps until failure occurs or until the stress levels far exceed those required of the system. Table 6 shows an example of a step stress test for a power supply card. If this card was also to operate in a vibration environment, such as a missile, then HALT should be performed in place of Step Stress Testing.

BIT Detectability

The percentage of a parts functionality that can be tested through BIT should be considered. A design to cost trade of BIT functionality for all PEDs can be performed for the ability to use potentially less reliable parts.. As long as the overall system reliability requirements are met then limited failures may be acceptable if the user knows prior

Table 6

Sample Step Stress Test

Step	ΔT, °C/min.	ΔT, °C	Line voltage,%	No. of cycles	Duty cycle % on time	Output load, %
1	3	0 to +45	115	20	25	80
2	5	-10 to +55	100	20	50	100
3	7	-20 to +65	90	20	75	120
4	10	-30 to +71	80	20	100	140

Note: Step 2 is the normal operating condition.

Source: Kromholtz, G.A., L.W. Condra, M.G. Pecht, E.B. Haking. "Using Plastic Encapsulated Microcircuits in High Reliability Applications." 1994 PROCEEDINGS Annual RELIABILITY and MAINTAINABILITY Symposium.

to launch or loadout of the missile that it has failed. This must be evaluated in terms of the total life-cycle costs of the system and the availability of the required number of missiles for the user to place the required ordnance on target.

Military Temperature Range Parts Availability

After announcing discontinuation of military product lines shortly after initiation of "acquisition reform", some manufacturers have made a limited number of their products available in military temperature ranges (Motorola News

Release, June 1997). While these packages are not hermetic, they offer some design flexibility for critical applications requiring the temperature ranges they offer. The cost of these components can be two to three times their commercial counterparts (Intel News Release, April 1996). Another consideration, discussed earlier, is the fact that the Pentium Chip was available in a commercial temperature range for six years prior to the release of the military temperature range parts. As Intel is about to release its newest microprocessor, the Merced Chip, the Pentium has just become available in these higher temperature ranges. If programs wait until some of these higher temperature range parts become available they will always be behind the leading technology.

WARRANTIES

The use of warranties has received much attention for missile systems in the last several years. Some programs are offered full repair replacement warranties for missiles maintained in a stored condition for up to 20 years. There is on going debate between DOD and the Government Accounting Office (GAO) on whether the warranties are cost effective. At a minimum, programs must obtain a warranty if government control of the manufacturing process is relinquished to the contractor. The government must have some recourse in the event that the missile manufacturer makes a bad choice by not applying the recommended procedures for part selection and problems are encountered across a large population of missiles. The minimum requirement is to obtain warranty protection for all failures above an expected failure rate. The warranty would cover the catastrophic failures of multiple occurrences of parts but not the occasional random failures of different parts. Warranties should cover material and workmanship, design and manufacturing, failure free above a predetermined rate, and essential performance. The period of the warranty should extend to cover the time period when problems from the selection of a bad part could be expected to appear and the time when the next maintenance cycle or BIT of the missile will be performed. This is important to ensure that once the failure occurs, it can be detected to the levels of BIT detectability.

ADVANCED TECHNOLOGIES

Advanced Packaging

Advanced packaging used for Multichip Modules (MCMs) has been evaluated by Rome Laboratory (Fayette, Not Dated). Technologies from several major manufacturers were evaluated including General Electric, Texas Instruments, Hughes Aircraft, and International Business Machines. All manufacturers had problems, each of which included a subset of: sealing, voiding, delamination of die attach- substrate attach, excessive moisture internal to the package after sealing, and bubbles in the interlayers of the substrate.

The fact that so many high quality manufacturers have had problems making defect free parts using new technology is cause for concern. For this reason, if new technologies are to be used in missile systems they must be thoroughly tested to ensure they can be reliably manufactured. A number of different techniques are currently available as well as new techniques are being developed to deal with inspection of smaller technology dies.

Plastic Semiconductors

Opticom ASA and Lucent Technologies have entered a joint development agreement for plastic memory using organic integrated circuits (Opticom ASA and Bell Labs, 1997). These integrated circuits are made out of organic polymers that conduct electricity. As this technology is developed, it must be evaluated for use in missile systems. The same types of concerns exist as for today's technology microcircuits. The effect of moisture and temperature on the performance of the circuit must be evaluated. If this and other technologies are found suitable for use, then manufacturing should come under the same scrutiny of process control as current technology chips.

Improved Corrosion Inhibitors

PED manufacturers should continue to evaluate methods to improve corrosion resistance in PEDs. Some research that has been completed in this area is that done by Jain using barriers at the metal surface of the leads to create a built-in electric field (Jain, 1985). This built-in electric field impedes the transfer of electrons from the metal surface during the corrosion process. Research in improved corrosion inhibitors should be continued to give additional layers of protection to the parts in the event contaminants do come into contact with the metal interconnects of PEDs. Their use may allow relaxation of other manufacturing restrictions on the selection of mold compounds and other processes. The change of these processes may improve other characteristics of the parts.

CHAPTER VI

CONCLUSIONS

The technical risks associated with the use of PEDs can be mitigated with the implementation of an effective and well thought out transition strategy. The following transition strategy addresses each of the technical challenges and transition issues presented in previous chapters. It provides a generalized framework based on lessons learned in implementing the use of PEDs in the SLAM ER program and information gathered during further research of this topic. Individual programs should tailor this transition plan to their specific program requirements in terms of environmental and reliability requirements, specifics of system complexity, and program stage at which the transition is implemented.

PED TRANSITION PLAN

MAINTAIN GOVERNMENT VISIBILITY
- Transition to contractor administered system with government oversight
- Government and contractor team form requirements for the use of PEDs
- Contractor carries out day to day implementation
- Government program office maintain visibility of part selection and ability to audit contractors process

ESTABLISH THE PARTS ENVIRONMENT
- Environment part will be exposed to during:
  - part manufacture
  - handling
  - shipping
  - storage

    - assembly onto circuit cards
    - testing
    - usage in the system
- Environments defined in terms of:
    - minimum and maximum temperature
    - vibration
    - humidity
    - mechanical shock
    - temperature shock
    - power application cycle
    - frequency and duration of occurrence of each environment
- As part selections are made, factor in their contributions to the overall part environment
- Determine requirements for the use of special heating, additional cooling, or part relocation on a CCA

MAKE PART SELECTIONS
- Specify the requirement of each piece part
- Analyze each parts suitability for the design
- Evaluate process controls and documentation of these controls for the manufacture of each part:
    - moisture controls
    - contamination controls
    - material handling
    - fabrication
    - testing
- Review selection of:
    - encapsulant materials
    - passivation materials
    - cleaning processes
    - automated assembly processes
- Review SPC methods and results used for consistency in quality, reliability, and performance
- Transition to a single corporate parts management process
- Maintain an ongoing part selection process:
    - Review changes in manufacturing processes
    - Monitor the parts manufacturer yield and test data for variation
- Ensure processes are sufficiently documented
- Establish derating guidelines
    - Set upper and lower temperature verification levels
    - Sample statistically significant number of parts to verification levels
- Review Qualified Manufacturer and Part Lists
- Compare reliability to military ceramic equivalent

PERFORM A RELIABILITY ANALYSIS
- Assess reliability of the preliminary design
- Analyze worst case electrical stresses for the worst case environment of each part

- Make reliability predictions to determine if the overall system will meet the reliability requirements of the specification
- Evaluate corrosion effects from moisture
- Evaluate thermal effects for:
  - delaminations
  - package cracking
  - bond and wire damage
  - die cracking
  - passivation fractures
  - popcorning

ANALYZE FUTURE AVAILABILITY OF PARTS
- Availability of part or a suitable replacement
- The effect of CCA relayouts on software timing, EMI, shock, vibration and thermal coefficients of expansion and retest requirements
- Part availability and cost of repairs
- Interchangeability and intermixability of CCAs
- Technology maturity of the part and its product life cycle
- The market base of the part

ESTABLISH PARTNERSHIPS WITH PART MANUFACTURERS
- Provide open communication between manufacturers and designers
- Notify designers early on of changes in the parts manufacturing process
- Determine future part availability

REVIEW MANUFACTURER PROCESSES
- Perform a detailed technical review of the manufacturing processes for each part to:
  - Ensure emphasis is placed on defect prevention using processes under SPC
  - Eliminate introduction of contaminants to prevent the catalyst for corrosion
  - Ensure parts are dry baked and shipped in dry packs
- Review parts design characteristics to ensure thermal shock is minimized
- Review quality system including change control process to ensure proper notification is given when changes to the manufacture of a part are implemented

REVIEW EXISTING PART QUALIFICATION DATA
- Determine if qualified to at least the level for their specific application in the system
- Review suppliers performance on other programs

- If existing data is adequate, qualification of the part may be done by similarity to other programs
- If data is not available, the cost to perform qualification testing on the part should be compared to selection of an alternate part
- Both HAST and temperature shock tests must be performed for parts without adequate data

PERFORM PART SCREENING AS REQUIRED
- Part manufacturer screening programs must be reviewed to determine if any additional testing is required
- Identify additional tests required and perform at the part supplier or a third party tester

REVIEW CCA PRODUCTION PROCESSES
- Emphasize defect prevention not detection
- Evaluate use of process controls with SPC
- Verify dry pack seals at receipt
- Reseal dry packs after parts count
- Establish ESD Procedures
- Use of Rebakes
- Lead dressing processes
- Placement into pick-place machines
- Solder operations
- Rework/ repair procedures
- Evaluate potential use of temperature ramping during reflow soldering processes

PERFORM ADVANCED STRESS TESTS
- Step Stress Test
  - Perform on first pre-production CCAs
  - Ensure margin exists for required environments
- Highly Accelerated Life Test
  - Add vibration to temperature extremes of Step Stress to uncover different failure modes than temperature alone

REVIEW BIT DETECTABILITY
- Considered percentage of a parts functionality that can be tested through BIT
- Evaluate in terms of:
  - The total life-cycle costs of the system
  - When BIT failures are detected and the impact on the ability of the users to place required ordnance on target

ASSESS MILITARY TEMPERATURE RANGE PARTS AVAILABILITY

- Consider manufacturers with products available in military temperature ranges
- Consider total system cost using military temperature range parts compared to commercial counterparts
- Consider lag time behind commercial counterparts

DETERMINE REQUIRMENT FOR WARRANTY

- Must have if government control of the manufacturing process is relinquished to the contractor
- Warranties should structured such that they cover catastrophic failures of multiple parts
- Warranties should cover
  - Material and workmanship
  - Design and manufacturing
  - Failure free above a predetermined rate
  - Essential performance
- Period should cover the period
  - When problems from the selection of a bad part could be expected to appear
  - Time when the next maintenance cycle or BIT of the missile will be performed

CHAPTER VII

RECOMMENDATIONS

Acquisition reform has empowered program managers to make decisions about all aspects of their programs including the selection of commercial electronic components. There are several risks that PEDs present when used in missile environments. These risks include failure due to corrosion of the metallic interconnects within the package and thermal breakdown due to application outside the temperature range of the part. Missile system designers must be intimately familiar with reliability issues of PEDs and understand their risks and limitations. The program manager must understand the risks associated with selecting PEDs for use in missile systems and the requirement to ensure that proper process controls are used in the manufacture of PEDs and their circuitry. Program managers should implement the steps contained in the PED Transition Plan of the previous chapter.

The effect of future technological advances should be evaluated before implementation of these technologies into missile systems. These include new packaging methods and the use of organic semiconductors.

The processes recommended in the transition plan must be implemented on a continuous basis throughout the life of a program to prevent future changes in technology or degradation of the processes from causing a decrease in reliability of the system.

Through the use of effective warranties, the program manager can ensure the manufacturer of the missile system assumes his fair share of the risk for making proper parts selections when government oversight in the parts selection process is relinquished.

There are real benefits of PEDs in terms of cost and performance. However it is absolutely essential that program managers and missile manufacturers ensure the nation's inventory of weapons remains reliable and effective through proper parts selection.

BIBLIOGRAPHY

BIBLIOGRAPHY

Alvino, William M. Plastics for Electronics: Materials, Properties, and Design Applications. McGraw-Hill: New York. 1995. pp. 237-241.

Brindley, Keith. Newnes Electronics Assembly Handbook: Techniques, Standards and Quality Assurance. Butterworth- Heinemann Ltd. Oxford. 1993. pp.136.

"Buying Off-the-Shelf Challenges Military" Aviation Week and Space Technology. 28 April 1997. p. 57.

Condra, Lloyd, Steve O'Rear, Tim Freedman, Leo Flancia, Michael Pecht, and Donald Barker. "Comparison of Plastic and Hermetic Microcircuits Under Temperature Cycling and Temperature Humidity Bias." IEEE TRANSACTIONS ON COMPONENTS, HYBRIDS AND MANUFACTURING TECHNOLOGY. Vol. 15, No 5. October 1992.

Deming, W. Edwards. Out of the Crises. Cambridge, Mass: Massachusetts Institute of Technology, Center for Advanced Engineering Study. 1986. p. 23.

"DoD TO MOVE NOW; WILL NOT WAIT ON CONGRESS TO ACT ON REFORM." Program Manager. March- April 1994, pp. 12-17.

Emerson, D. A. "Storage Reliability Accelerated Life Test For Printed Circuit Boards For Joint Direct Attack Munitions (JDAM)." Rockwell International, Collins Avionics and Communications Division: Final Report. Cedar Rapids, Io. October 18, 1995.

Eshbach, Ovid W. and Mott Sanders, Handbook of Engineering Fundamentals , 3rd edition, John Wiley and Sons. 1974. pp. 1283 - 1286.

Fayette, Daniel. "Multichip Module (MCM) Reliability and Performance Assessment Program." Reliability Analysis Center (RAC). Rome, New York. Not Dated.

Fuqua, Norman B., Reliability Engineering for Electronic Design. Marcel Dekker. New York (1987).

Gottesfeld, Sheldon, William L. Shultz. "Reliability Considerations for Using Plastic-Encapsulated Microcircuits in Military Applications." Harris Semiconductor: Melborne Florida. August 22, 1994.

"Quality and Reliability Manual." Harris Semiconductor. Not Dated.

Heller, Arnie. "Compact, More Powerful Chips from Virtually Defect- Free, Thin- Film System." Science and Technology Review: Lawrence Livermore National Laboratory. Livermore, Ca. October 1997. pp. 8-9.

Holstein, William J. "What's good for Intel... Is it bailing out federal labs or selling out U.S. firms?", U.S. News and World Report. October 6, 1997. pp. 47-48.

"Intel Announces Availability of the Pentium Processor for Special Environments." Intel News Release. Chandler, Arizona. April 15, 1996.

"Intel Will Start Production of Its New Chip in 1999." Los Angeles Times. October 10, 1997. pp. D1.

Jain, F. C. "SEMICONDUCTOR/ INSULATOR FILMS FOR CORROSION PROTECTION." NAVAL AIR DEVELOPMENT CENTER: FINAL REPORT. October 1985.

Kaminski, Dr. Paul G., "Electronic Part Selection." MEMORANDUM FOR SERVICE ACQUISITION PROFESSIONALS. March 17, 1997.

Kovac, Caroline A. "Plastic Package Fabrication." Electronic Materials Handbook, ASM International. Vol. 1, pp. 470-482. November 1989.

Kromholtz, G.A., L.W. Condra, M.G. Pecht, E.B. Haking. "Using Plastic Encapsulated Microcircuits in High Reliability Applications." 1994 PROCEEDINGS Annual RELIABILITY and MAINTAINABILITY Symposium.

"LIFETIME BUY DATE EXTENDED FOR MILITARY CHIPS." Motorola News Release. Phoenix, Arizona. March 16, 1995.

Mazda, F. F. ELECTRONICS ENGINEER'S REFERENCE BOOK. Buttersworths. London. 1989. pp. 25/19-20.

"MIL-SPECs AND MIL-STDs NO MORE- DOD Changes Prioritizing Policy." Program Manager. July-August 1994. pp. 8-10.

"MIL-STD-210C." MILITARY STANDARD: CLIMATIC INFORMATION TO DETERMINE DESIGN AND TEST REQUIREMENTS FOR MILITARY SYSTEMS AND REQUIREMENTS. Department of Defense. 9 January 1987.

"MIL-HDBK-217F." MILITARY HANDBOOK: RELIABILITY PREDICTION OF ELECTRONIC EQUIPMENT. Department of Defense. 2 December 1991.

"MIL-STD-454M." Department of Defense: Standard General Requirements for Electronic Equipment. Washington, D.C. 15 August 1990. pp. 4-1 through 4-3.

"Opticom ASA and Bell Labs Joint Development Agreement Announced." BUSINESS WIRE. Murray Hill, N.J.: Oslo, Norway. October 7, 1997.

Pecht, Michael and Wing C. Ko. "A Corrosion Rate for Microelectronic Die Metallization." The International Journal for Hybrid Microelectronics. Vol. 13, No. 2. pp. 41-52. June 90.

Pecht, Michael. Handbook of Electronic Package Design. Marcel Dekker. New York. 1991. pp. 679-683.

Perry, Dr. William J. "Specifications & Standards - A New Way of Doing Business." Secretary of Defense Policy MEMORANDUM. 29 June 1994.

"PowerPC 603e MPUs Available for Industrial Temp Range." Motorola News Release. Austin, Texas. June 23, 1997.

Priore, M. G., and J. P. Farrell. "Plastic Microcircuit Packages: A Technology Review." Reliability Analysis Center (RAC) Report. Rome, New York. March 1992.

"Proceedings of the 26th Annual Electronics Component Conference." Institute of Electrical and Electronic Engineers. 1976.

"Quality and Reliability Manual." Harris Semiconductor. Not Dated. p. 8.

Quearry, Dan, Agarwal Rakesh, Michael G. Pecht. "Plastic Packaged Microcircuits: Quality, Reliability, and Cost Issues." IEEE TRANSACTIONS ON RELIABILITY. Vol. 42, No 4. December 1993.

Reilly, Jim. "Plastic Encapsulated Microcircuit Evaluation Programs at Rome Laboratory." Reliability Analysis Center (RAC). Rome, New York. Not Dated.

"Response to Texas Instruments' Concern on the use of PEMs." CALCE EPRC: University of Maryland. College Park, Md. Not dated.

Ricci, Bill. "Commercial and Industrial Components in Military Applications." Proceedings of the Case Studies Symposium on the Successful Use of Commercial Integrated Circuits (ICs) in Military Systems, Volume II. June 13- 15, 1994.

Schultz, William L., Sheldon Gottesfeld. "Reliability data supports PEMs in many military applications." Military & Aerospace Electronics. January 1995, p. 4.

Seles, Robert. "Proposed PEM Derating Guidelines." Unpublished Paper: Naval Air Warfare Center- Weapons Division. China Lake, Ca. 9 October 1997.

"Semiconductors, When the chips are down." The Economist. March 23rd - 29th, 1996. pp. 19- 21.

Tam, Sun Man. "Demonstrated Reliability of Plastic-Encapsulated Microcircuits For Missile Applications." IEEE Transactions on Reliability. Vol. 44, No 1. March 1995.

"TE000-AB-GTP-010, Revision 1, Parts Derating Requirements and Application Manual for Navy Electronic Equipment. March 1991.

APPENDICES

APPENDIX A

COMMON ELECTRONIC MICROCIRCUIT PACKAGE TYPES

Ceramic Dual In-line Package (CERDIP)

Ceramic Quad Flat Pack (CQFP)

Complementary Metal Oxide Semiconductor (CMOS)

Leadless Chip Carrier (LCC)

Pin Grid Array (PGA)

Plastic Dual In-line Package (PDIP)

Plastic Leadless Chip Carrier (PLCC)

Plastic Pin Grid Array (PPGA)

Plastic Quad Flat Pack (PQFP)

Small Outline Integrated Circuit (SOIC)

Small Outline Package (SOP)

Thin Small Outline Package (TSOP)

APPENDIX B

ARRHENIUS REACTION RATE MODEL COMPARISON SEMICONDUCTOR COOL STORAGE VS HOT OPERATION

$\lambda = (A) \exp -[(E_a/k)][(1/T)-(1/T_o)]$

where: λ = temperature-related failure rate

A = a normalizing rate constant

E_a = activation energy (0.7eV)

k = Boltzman's constant (8.63×10^{-5} eV/°K)

T = ambient temperature (273 + 170)°K

T_o = reference temperature (273 + 20)°K

$\lambda = (A) \exp -[(0.7eV/8.63 \times 10^{-5} eV/°K)][(1/443°K)-(1/293°K)]$

$\lambda = (A)e^{(9.3736)}$

$\lambda = (A)(1.1774 \times 10^{4})$ where "A" is a constant.

APPENDIX C

CONFORMAL COATING TYPES AND KEY PERFORMANCE CHARACTERISTICS

Material Characteristics[a]

Characteristic	Acrylic	Epoxy	Polyurethane	Silicone
Abrasion resistance	3	1	2	2
Acid resistance	1	1	3	2
Alkali resistance	1	1	3	2
Application ease	1	3	2	3
Cure Time	1	4[c]	3[b]	4
Humidity resistance				
Short-term	1	2	1	1
Long-term	2	3	1	2
Mechanical Strength	1	1	2	2
Pot-life	1	4	2	4
Removal				
Burn	1	3	2	-
Chemical	1	5	3	5
Solvent resistance	5	1	2	2
Temperature resistance	5	5	5	2

[a] Scored from 1 to 5, with 1 best and 5 worst
[b] Reduced to 3 if heat-cured
[c] Reduced to 2 if heat-cured

Source: Brindley, Keith. Newnes Electronics Assembly Handbook: Techniques, Standards and Quality Assurance. Butterworth-Heinemann Ltd. Oxford. 1993. pp.136.

VITA

Randall Short was born in Columbus, Mississippi. He received a BS in Aeronautical and Astronautical Engineering while attending Purdue University under the Navy Reserve Officer Training Corp Program. After receiving his commission, he attended flight school where he received his wings as a Naval Flight Officer. He then deployed with Patrol Squadron FOUR, flying the P-3C Orion throughout the Pacific and Indian Ocean operating areas. He attended the Naval Test Pilot School graduating with Class 91 and performed developmental and operational flight test in the P-3C through his next three assignments. He transferred to the Aeronautical Engineering Duty Officer profession dedicating the remainder of his Navy career to the acquisition of aeronautical systems. He has served his last four years as the Chief Engineer (Class Desk) of the Navy's Harpoon, Penguin and Standoff Land Attack Missile (SLAM) systems.