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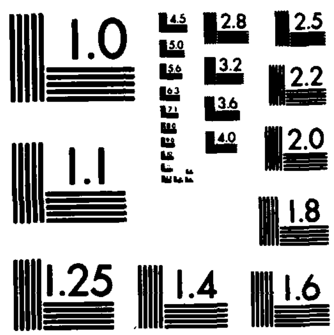

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POWER SUPPLY TECHNOLOGY WORKING GROUP REPORT

(IDA/OSD R&M STUDY)

Donald Hornbeck
EG&G Almond Instruments
Working Group Chairman

August 1983

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This document records the activities and presents the findings of the Power Supply Technology Working Group part of the IDA/OSD Reliability and Maintainability Study, conducted during the period from July 1982 through August 1983.

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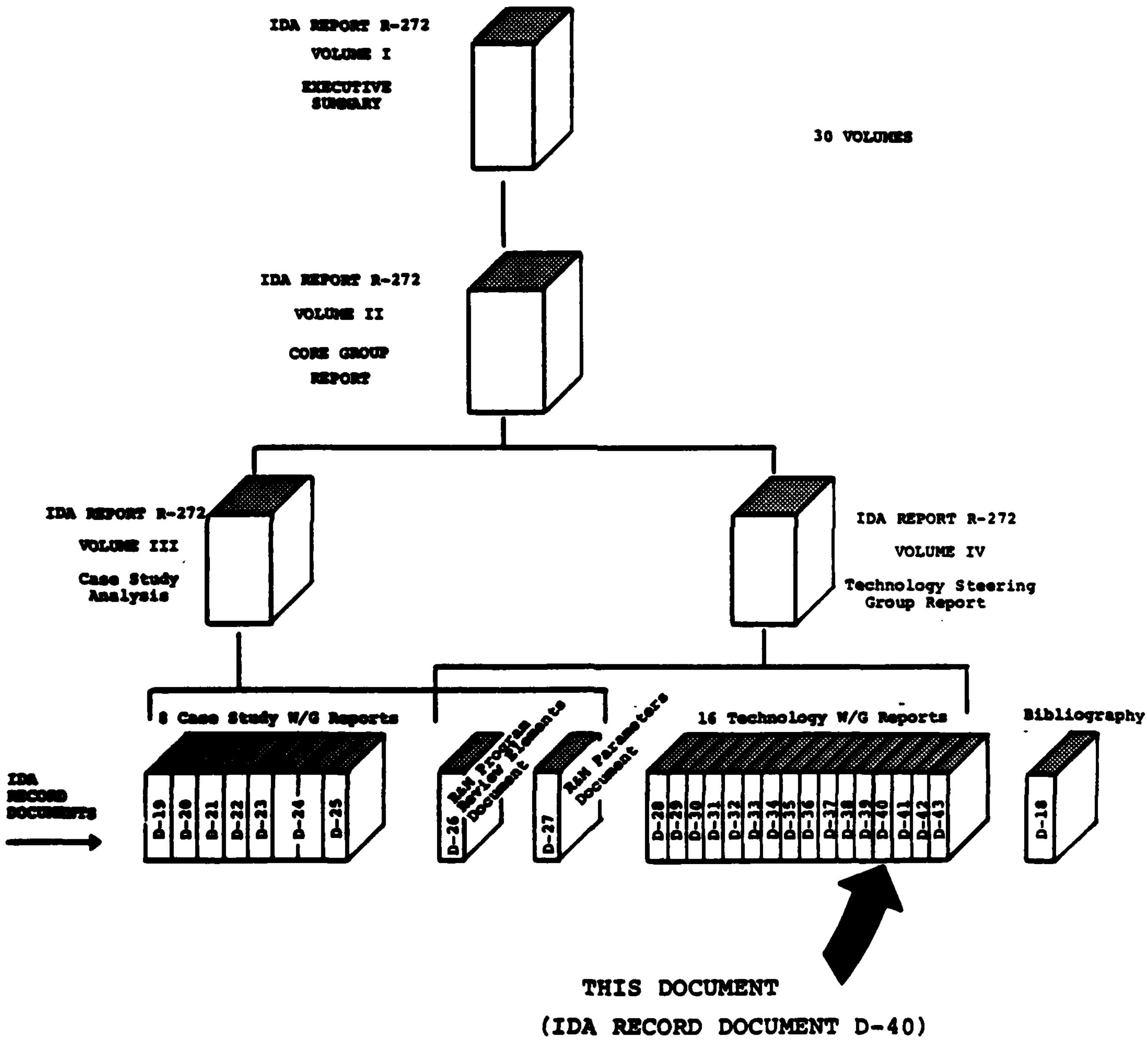
Task T-2-126

RELIABILITY AND MAINTAINABILITY STUDY

— REPORT STRUCTURE —



PREFACE

As a result of the 1981 Defense Science Board Summer Study on Operational Readiness, Task Order T-2-126 was generated to look at potential steps toward improving the Material Readiness Posture of DoD (Short Title: R&M Study). This task order was structured to address the improvement of R&M and readiness through innovative program structuring and applications of new and advancing technology. Volume I summarizes the total study activity. Volume II integrates analysis relative to Volume III, program structuring aspects, and Volume IV, new and advancing technology aspects.

The objective of this study as defined by the task order is:

> "Identify and provide support for high payoff actions which the DoD can take to improve the military system design, development and support process so as to provide quantum improvement in R&M and readiness through innovative uses of advancing technology and program structure."

The scope of this study as defined by the task order is:

> To (1) identify high-payoff areas where the DoD could improve current system design, development program structure and system support policies, with the objective of enhancing peacetime availability of major weapons systems and the potential to make a rapid transition to high wartime activity rates, to sustain such rates and to do so with the most economical use of scarce resources possible, (2) assess the impact of advancing technology on the recommended approaches and guidelines, and (3) evaluate the potential and recommend strategies that might result in quantum increases in R&M or readiness through innovative uses of advancing technology.

The approach taken for the study was focused on producing meaningful implementable recommendations substantiated by quantitative data with implementation plans and vehicles to be provided where practical. To accomplish this, emphasis was placed upon the elucidation and integration of the expert knowledge and experience of engineers, developers, managers, testers and users involved with the complete acquisition cycle of weapons systems programs as well as upon supporting analysis. A search was conducted through major industrial companies, a director was selected and the following general plan was adopted.

General Study Plan

Vol. III • Select, analyze and review existing successful program

Vol. IV • Analyze and review related new and advanced technology

Vol. II (• Analyze and integrate review results
(• Develop, coordinate and refine new concepts

Vol. I • Present new concepts to DoD with implementation plan and recommendations for application.

The approach to implementing the plan was based on an executive council core group for organization, analysis, integration and continuity, making extensive use of working groups, heavy military and industry involvement and participation, and coordination and refinement through joint industry/service analysis and review. Overall study organization is shown in Fig. P-1.

The basic technology study approach was to build a foundation for analysis and to analyze areas of technology to surface: technology available today which might be applied more broadly; technology which requires demonstration to finalize and reduce risk; and technology which requires action today to provide reliable and maintainable systems in the future. Program structuring implications were also considered. Tools used to accomplish

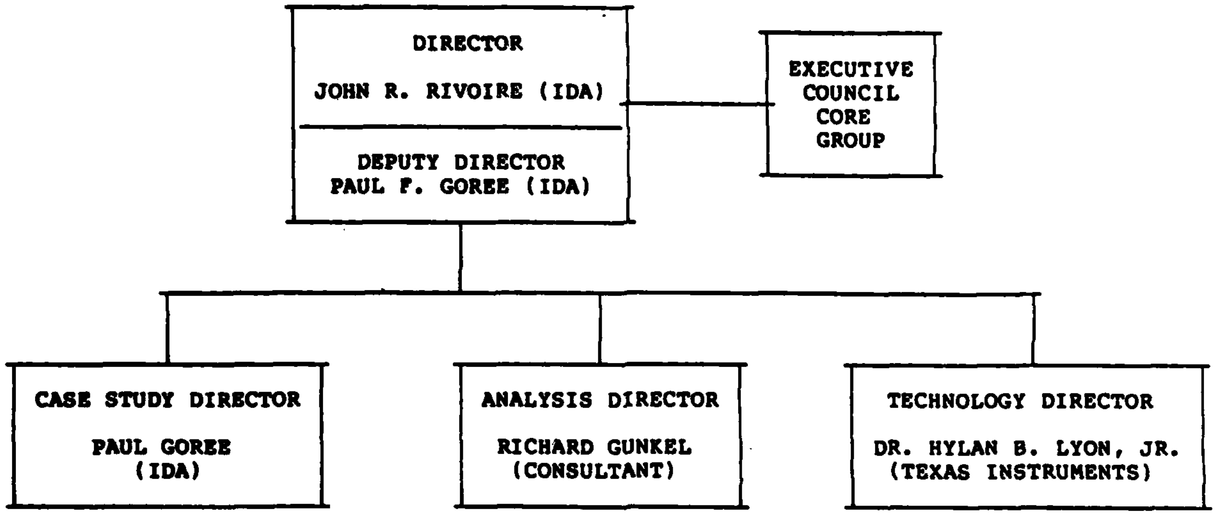


FIGURE P-1. Study Organization

this were existing documents, reports and study efforts such as the Militarily Critical Technologies List. To accomplish the technology studies, sixteen working groups were formed and the organization shown in Fig. P-2 was established.

This document records the activities and findings of the Technology Working Group for the specific technology as indicated in Fig. P-2. The views expressed within this document are those of the working group only. Publication of this document does not indicate endorsement by IDA, its staff, or its sponsoring agencies.

Without the detailed efforts, energies, patience and candidness of those intimately involved in the technologies studied, this technology study effort would not have been possible within the time and resources available.

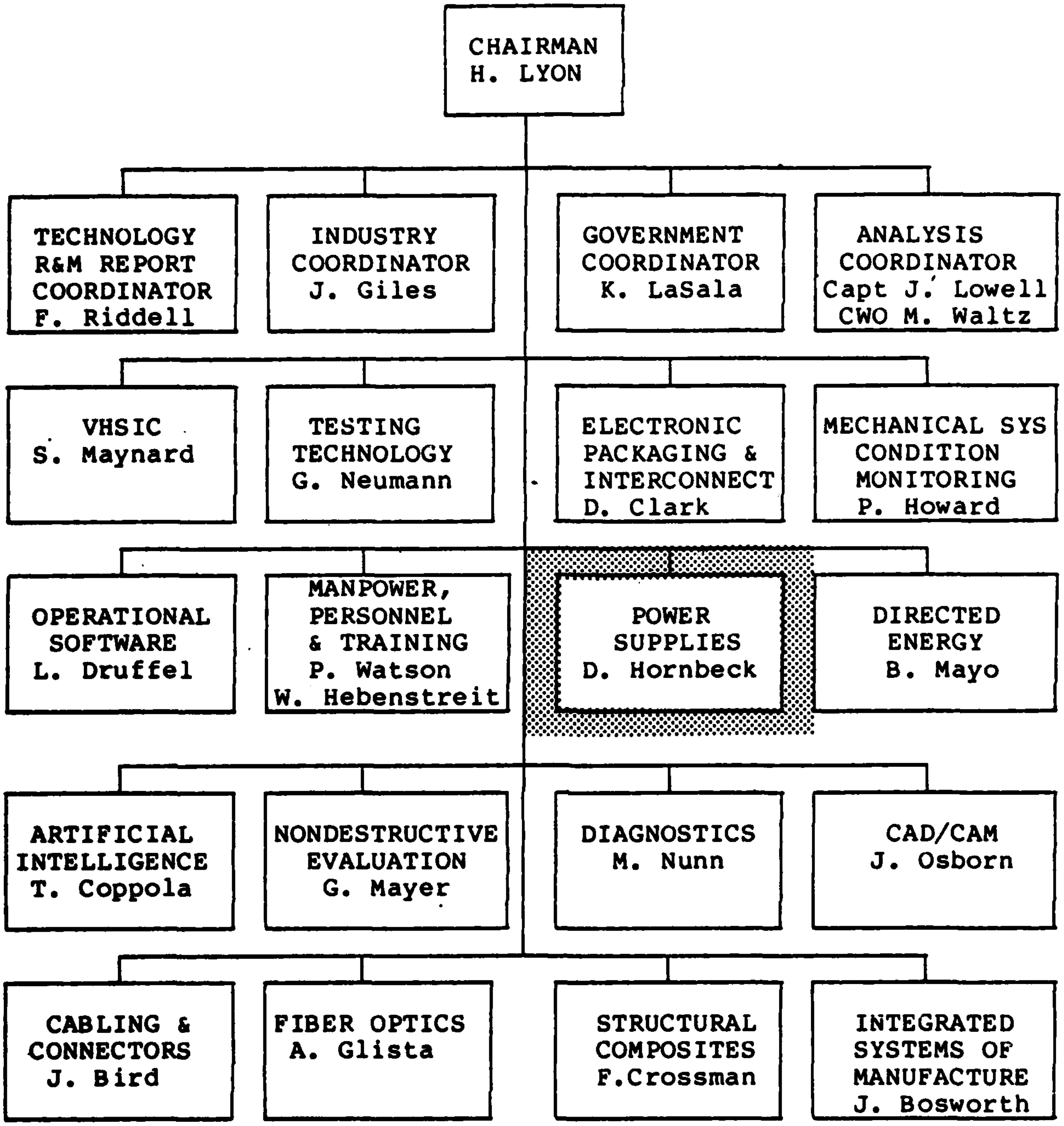


FIGURE P-2. Technology Study Organization

OSD/IDA R&M STUDY

POWER SUPPLY TECHNOLOGY WORKING GROUP

R&M IMPROVEMENT RECOMMENDATIONS FOR 1984 THROUGH 2000

AUGUST 1983

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1.0 EXECUTIVE SUMMARY

The Power Supply Technology Working Group has developed several high-payback recommendations which will ensure a compatible technology in this facet of the complex systems of tomorrow. Qualified organizations must be quickly identified and assigned tasks which will increase the performance density, improve the logistics of readiness, and reduce the life cycle cost of energy conditioning equipments across the broad spectrum of DoD applications. Following is our candidate list in order of descending priority under two categories:

Management Actions

- Impose warranty requirements
- Coordinate standardization
- Emphasize and enforce comprehensive "power-system" engineering and encourage university research and development

Technical Developments

- High efficiency/low voltage components and topologies necessary for VHSIC
- Increase power/current densities
- Hostile environment tolerance
- Improved cooling techniques.

DoD needs to address the management actions and contract industry to address the technology items.

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2.0 INTRODUCTION

The mission of the Power Supply Technology Working Group is to identify the necessary areas of investment to ensure the availability of reliable and maintainable power supplies over the next decade. A power supply in an electric system is the buffer circuit that interfaces with the platform's power source and conditions power to the requirements of the internal electronics and other circuits. Power supplies have been a reliability problem in the past and much work is being done to improve same. As electronics systems become more complex, the burden on the power supplies will also increase. It is, therefore, necessary for the appropriate investment to be made in power supply technology to allow it to keep pace with other advances. For example, VHSIC, with its small geometries, will require the use of very low voltages (e.g., one volt), resulting in poor efficiency and high relative volume with respect to present day technology. We have learned that if power supplies are allowed to take a back seat and not keep pace with on-going developments, they will get attention only at the last minute and reliability and system readiness will suffer.

Two categories, each listed in order of descending priority for investment of resources, are identified: Management actions to be taken by DoD management, and technical advances to be investigated by industry. These are discussed in the body of the report. Following that, an implementation plan is suggested for DoD's consideration.

2.1 ISSUES IDENTIFIED

2.1.1 Management

The issues discussed are warranties, standardization and engineering emphasis. (Paragraphs 2.1.1.1, 2.1.1.2, and 2.1.1.3)

2.1.1.1 Warranties

Reasons:

1. Increase manufacturers' incentive to build-in reliability.
2. Minimize life cycle cost.
3. Reduce technical risk on design and development of weapon systems.

Now. Present system rewards poor performance. Poor reliability experience is followed by product improvement programs, additional spares orders, and repair contracts at government expense.

2000. Future procurement policy will reward good performance. Contractors will have a strong incentive to exceed reliability goals.

Need:

Revised procurement policy and regulations.

Recommendations:

A. Revise government procurement policy and directives to establish the use of warranty to assure reliability of power supplies.

B. Revise present funding policy to use support funds up-front to pay for warranty.

Payoffs:

1. Quantum improvement in reliability compared with recent past experience.
2. Lower Life Cycle Cost via reduced spares cost and fewer product improvement plans.
3. Improved readiness posture based on NAVMAT P4855-1

Cost:

Significantly reduced LCC with minimal increase in acquisition.

2.1.1.2 Standardization - Power Supplies and Equipment Enclosures

Reasons:

1. Improved reliability (mature design required).
2. Lower Life Cycle Cost based on fewer spares.
3. Improved maintainability based on a lower type count.
4. Reduced development cycle time, cost and risk.

Now. Vast proliferation of power supply types; immature (though old) designs; many spare types required; high repair cost.

2000. Fewer number of power supply types resulting in reduced logistic support required; mature proven designs; more effective sparing; lower repair cost.

Needs:

A. Reduction in number of power supply types per system application.
B. Up-front investment (funding).

Recommendations:

A. Standardize equipment enclosures for suitable candidates per platform.
B. Standardize power supplies by consolidation of platform requirements into a minimum family of standard units.
C. Develop requirements to control embedded power supplies.

Payoffs:

1. Improved reliability
2. Lower life cycle cost
3. Cost avoidance (6600 man hours/type eliminated)
4. Shortened development cycle (6 months)
5. Improved readiness and logistics over the useful life of the system

Cost:

The task to establish standardization criteria should come from the DoD cognizant code.

2.1.1.3 Power Systems Engineering Emphasis in DoD Service Branches

Reasons:

1. Inadequate definition of interfaces, environment and R&M requirements.
2. Inadequate enforcement of interface compatibility through system design, analysis and test.
3. Lack of recognition of importance of power system design and analysis.

Now. Interface documents are incomplete; inadequate emphasis on power system design; critical shortage of trained power supply engineers.

2000. Well-defined interfaces; guideline documents in place; an improved supply of adequately trained power supply engineers.

Needs:

A. Improved interface standards/specifications
   - DoD-STD-1399/300
   - MIL-STD-704
   - MIL-E-4158

B. Guideline documents for power systems design
   - Ship
   - Air
   - Missile
   - Ground

C. Increased availability of qualified power supply design engineers.

Recommendations:

A. Establish an industry/DoD clearing house for power supply coordination and information dissemination.

B. Establish a procedure for assigning a point of authority and responsibility for power system integration for each new weapons system and coordination between systems.

C. Establish focal points in Army Research Office (ARO), Office of Naval Research (ONR), Air Force Office of Scientific Research (AFOSD) to initiate and maintain continuous research programs in power supply technology and encourage power supply IR&D in industry.

D. Assign DoD/industry committee to provide guidelines for:
   1. Power systems interface engineering management.
   2. Power systems interface design requirements for compatibility.
   3. Power systems interface evaluation procedures.
   4. Improvement of MIL power system documentation.

Payoffs:

1. Improved reliability through design to known operating conditions.
2. Lower life cycle costs due to elimination of failures which could be caused by interface problems.
3. Lower risk of turn-on problems.
4. More efficient use of total power (less risk of inflated power requirements estimates).
5. Availability of qualified power supply designers.

Costs:

Funding to establish the systems criteria should come from the DoD cognizant codes.

2.1.2 Technical

The issues discussed are low voltage conditioning, power supply density, E^3, and cooling techniques. (Paragraphs 2.1.2.1 through 2.1.2.4)

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2.1.2.1 High Efficiency Low Voltage Power Conditioning

Reason:

Assumption - Trend toward low voltage requirements driven by VHSIC. Forward drop of present rectifiers and ohmic distribution losses as a percent of output voltage is totally unacceptable.

Now

RECTIFIER	DISTRIBUTION
5V output at 100 A	100 A
Forward drop 1V	1 milliohm
Efficiency = 83%	Efficiency = 98%

2000

1V output at 200 A	200 A
Forward drop 0.2V	100 microohm
Efficiency = 83%	Efficiency = 98%

Needs:

Technology breakthrough to maintain 83% rectifier efficiency and 98% distribution efficiency.

A. Component improvement/substitution

B. Rectifier techniques.

C. Distribution techniques.

Recommendations:

A. Development and qualification of candidate devices commercially and potentially commercially available.

B. Pursue technology for new devices at the university or industry level.

C. Develop low-loss high current distribution technology (VHSIC).

Payoffs:

1. The development of improved rectifiers will permit the achievement of the desired 83% efficiency at low voltage for VHSIC.

2. Low loss high current distribution techniques will maintain 98% distribution efficiency.

2.1.2.2 Power Supply Density

Reason:

Mission requirements including such factors as built-in-test (BIT), radiation hardening and EMP are forcing increased electronic density within the constraints of constant volume. Increased power supply density must follow.

Now. Current density/unit volume is 0.5 $Amps/in^3$ for typical ship applications.

2000. 4 $Amps/in^3$ for typical ship applications. (NOTE: In year 2000 technology the generic $watts/in^3$ unit of measure will give way (because of VHSIC) to current density in $Amps/in^3$.

Need:

Increased density per unit volume.

Recommendations:

A. Develop high frequency power conditioning technology.
B. Develop high density current distribution techniques.
C. Develop smaller lower loss magnetic components and capacitors.
D. Develop switching devices having higher voltage, current and speed ratings.

Payoff:

Maintains parity with today's systems with respect to load density versus power supply density. This requires an 8:1 increase in current density.

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2.1.2.3 Electromagnetic Environment Effects (E^3)

Reasons:

1. New mission and threat requirements.
2. New materials (composite materials) will increase susceptibility and radiated signature.
3. New technology (low voltage VHSIC) will be more susceptible to radiation induced transients.

Now. MIL-STD-461B; 300V differential in metal skin aircraft (lightning induced); EMP Handbook, DNA 2114H.

2000. MIL-STD-461 (changes); 100,000V differential in composite skin aircraft (lightning induced); hostile land-sea EM environment prediction, ECAC PR-80-016.

Need:

Define requirements and develop means to be compatible with E^3.

Recommendations:

A. EMI-establish new lower limits of radiated emissions and higher limits of radiated susceptibility for composite skin applications.

B. Define and quantify the new power supply design requirements to meet the needs of hostile land-sea EM environment prediction, ECAC PR-80-016, as they relate to E^3.

C. EMP/RAD HARD and Directed Energy - Develop technologies and circuit techniques for use in applications having defined requirements at expected E^3 levels of the next decade or two. Do this at the university and DoD level to make information available industry-wide.

Payoff:

Survivability of the power supply function and improved combat readiness of weapon systems containing power supplies.

2.1.2.4 Improved Cooling Techniques

Reason:

Inadequate thermal management is a major factor in power supply failures. The trend in power supplies toward increased current density will aggravate this problem.

Now. Internal component heat removal method by conduction is 5 degrees C/watt.

2000. Goal is 1 degree C/watt.

Need:

Reduce temperature of components operating with increased current densities to enhance unit reliability.

Recommendations:

A. Develop a phase change technology to reduce thermal impedance.

B. Improve heat conduction techniques.

C. Develop isolated semiconductor junctions which are needed to alleviate EMI problems while maintaining or improving thermal resistance.

Payoff:

Lower temperature results in improved reliability. For most power components a 10°C reduction in component temperature will reduce the critical component failure rate by 25 to 30% on the average. See Table 1.

CHANGE IN MTBF VERSUS TEMPERATURE

COMPONENT	TEMPERATURE (°C)		% OF IMPROVEMENT IN MTBF
	FROM	TO	
5400 TYPE IC	90	80	3.7
MOS RAM	90	80	28
741 OP AMP	90	80	38
2N3501	90	80	23
2N5664	90	80	22
10-20 AMP DIODE	90	80	24
RESISTOR (25W)	90	80	12
ALUMINUM ELECTROLYTIC CAPACITOR	90	80	36

NOTE: All calculations per MIL-HDBK 217D

TABLE 1

3.0 IMPLEMENTATION

The areas identified in the report as necessary for investment of resources will all have to be administered by DoD and the service branches. Maximum use should be made of various industry working groups such as SAE, ARINC, IEEE, etc. that are active in the various disciplines and have expertise that can be brought to bear on the issues.

Specific recommendations are made in both the management and technical areas. Milestone charts are provided showing the time-frame for each task. Amplification of the milestone is provided in the paragraphs following Table 2.

3.1 MANAGEMENT IMPROVEMENT 1984 THROUGH 2000

Management improvements, 1984 through 2000 are shown in Table 2.

3.1.1 Warranties

Assign DoD/industry committee to revise or provide guidelines for the use of warranties to assure reliability of power supplies.

Revise present funding policy to allow use of support funds to provide up-front warranty coverage.

3.1.2 Standardizations

- Assign DoD/industry committee to define standard equipment for specific platforms.
- Assign DoD/industry committee to define standard type power supplies consistent with standard enclosures.
- Assign DoD/industry committee to develop guidelines to control embedded power supplies.

TABLE 2. MANAGEMENT IMPROVEMENTS 1984 THRU 2000

	85	86	87	88	89	90------------------2000
WARRANTIES						
A_1 DoD/Industry Guidelines for Warranties Policies	Δ	Δ	applicable to any weapon system new/present			
A_2 Revise Funding Policies to Incorporate Warranty Action	Δ	Δ				
STANDARDIZATION						
B_1 DoD/Industry Enclosure Definition	Δ		Δ			Update Δ 92; Update Δ 97
B_2 DoD Industry Power Supply Definition		Δ		Δ		Update 93; Update 98
B_3 DoD/Industry Embedded Power Supply Control Guidelines	Δ		Δ			

TABLE 2 (CONTINUED). MANAGEMENT IMPROVEMENTS 1984 THRU 2000

	83	84	85	86	87	88	89	90------------2000
POWER SYSTEMS ENGINEERING								
C_1 Establish Focal Points ARO/ONR/OSR Power Supply Problems/IR&D	Δ	immediate						
C_2 Establish Power System Integration Authority/ Responsibility		Δ (assigned each new weapons system)						
C_3 Establish Clearinghouse for Power Supply Information and Coordination		Δ______	______	(on going)	______			
C_4 Assign DoD/Industry Interface Guidelines			Δ______	______	______	______	Δ	

3.1.3 Power Systems Engineering

- Establish an industry/DoD clearing house for power supply coordination and information dissemination.
- Establish a procedure for assigning a point of authority and responsibility for power system integration for each new weapons system and coordination between systems.
- Establish focal points in ARO, ONR and OSR to initiate and maintain continuous research in power supply technology and encourage power supply IR&D in industry.

Assign DoD/industry committee to provide guidelines for:

a. Power systems interface engineering management
b. Power systems interface design requirements for compatibility
c. Power systems interface evaluation procedures
d. Improvement of MIL power system documentation.

3.2 TECHNOLOGY IMPROVEMENTS 1984 THROUGH 2000

Technology improvements, 1984 through 2000 are shown in Table 3.

3.2.1 High Efficiency Low Voltage Power Conditioning

- Issue contract to develop and quality candidate rectifier and other devices.
- Issue contract for high current low loss distribution technology.

3.2.2 Power Supply Density

- Issue contract to develop high frequency power conditioning technology.

TABLE 3. TECHNOLOGY IMPROVEMENTS 1984 THRU 2000

		84	85	86	87	88	89	90------------2000
POWER SUPPLY DENSITY								
A_1	Develop High Frequency Power Conditioning Technology		Δ			Δ		
A_2	Develop smaller, lower loss magnetic components and capacitors		Δ		Δ			
A_3	Develop devices which have higher voltage, current and speed ratings		Δ		Δ			
HIGH EFICIENCY-LOW VOLTAGE POWER CONDITIONING								
B_1	Develop and Qualify Candidate Rectifier and Other Devices	Δ		Δ		Update 1		Update 2
B_2	Develop High Current Low Loss Distribution Technology		Δ		Δ			Update 1 92; Update 2 97

TABLE 3. (CONTINUED) TECHNOLOGY IMPROVEMENTS 1984 THRU 2000

	84	85	86	87	88	89	90	92------------2000
ELECTROMAGNETIC ENVIRONMENTAL EFFECTS								
C_1 Assign DoD/Industry Committee Power Supply Requirements Related to Land/Sea Threat Prediction	Δ		Δ					
C_2 Assign DoD/Industry Committee to Specify EMC Limits for Composite Structures		Δ		Δ → ongoing				
C_3 Issue Contract to Develop EMP/RAD HARD/Directed Energy Technology and Techniques to Meet EMC Levels of Next Two Decades			Δ	Δ		Update Δ 92		Update Δ 97

TABLE 3. (CONTINUED) TECHNOLOGY IMPROVEMENTS 1984 THRU 2000

	84	85	86	87	88	89	90--------------2000
COOLING TECHNIQUES							
D_1 Develop Isolated Semi-Conductor Devices Related to EMI and Thermal Resistance	Δ immediately → (ongoing)						
D_2 Develop Phase-Change Cooling Technology		Δ		Δ			
D_3 Develop Heat Conduction Techniques Matrix			Δ		Δ		

- Issue contract to develop smaller, lower loss magnetic components and capacitors.
- Issue contracts to develop devices which have higher voltage, current, and speed ratings.

3.2.3 Electromagnetic Environment Effects (E^3)

- Assign industry/DoD committee responsibility to specify limits of EMI for composite structures.
- Assign industry/DoD committee responsibility to define and quantify for various platforms the power supply requirements as they relate to E^3 for the threat as defined in Hostile Land-Sea EM Environment Prediction ECAC-PR-80-016.
- Issue contract to develop EMP/RAD HARD/Directed Energy techologies and circuit techniques to meet the E^3 levels of the next two decades.

3.2.4 Cooling Techniques

- Issue contract to develop phase change technology.
- Issue contract to develop heat conduction techniques matrix.
- Issue contract to develop isolated semiconductor junction devices to alleviate EMI problems while maintaining or improving thermal resistance.

4.0 BACKGROUND PAPERS

4.1 RELIABILITY IMPROVEMENT BY WARRANTY ACTION*

Time and time again, the military finds reasons for not implementing warranty programs. Many of the reasons are extremely rational and the right decision - for that particular procurement action. However, on the commercial side of the house the airlines have found it to their great advantage to require warranty on almost every item of avionics. For similar equipment (avionics) in similar environments a number of studies have shown that the airlines generally realize better Reliability and Maintainability (R&M) and lower cost than the military. One of the reasons often singled out is the competitive differences between the military and commercial procurements. In the military case there is a great deal of competition early in a program but once a program goes to production the competition tends to cease. The developer that has met the demonstration tests, passed the qualification tests, has the production tooling and meets the intent of the specifications and R&M goals usually is awarded the first few follow-ons. It then becomes very expensive to qualify additional sources, to establish duplicate spares support, training, documentation and data. Even if the equipment does not meet the expected performance and R&M goals, the contractor may in fact get additional funds for improvements, time and material service contracts for repair and advantageous ECPs to correct

*This brief treatise on warranty is almost entirely taken from a technical perspective No. 22 of May 1975 prepared by ARINC Research Corporation.

deficiencies. The DARs (Defense Acquisition Regulations) do not provide good relief from selecting a vendor (lowest bidder) whose strategy is to use this type of action to gain volume, market share, or enter a new market.

In the commercial sector, the competitive climate provides a much better interaction and performance weighted climate. The airlines are not likely to buy equipment from vendors that have performed poorly in the past or that do not have substantial test data to support his equipment, even if the equipment is at a lower price than that of a manufacturer with good reputation and service. The airlines have also taken steps to reduce the risk of accepting unreliable equipment from any vendor through imposition of long term warranty procedures. The warranty provisions require that the vendor provide maintenance services over the warranty period (varies typically from 1 to 3 years), or to reimburse the airlines for necessary unscheduled maintenance performed by airline personnel. This then becomes a financial driver (motivator) to the vendor accepting earlier responsibility to design the equipment to meet not only the design specifications but also to build in producible reliability.

The military may not be able to achieve the same competitive climate as the airlines but it is possible in many cases to apply warranty to a particular procurement.

THE WARRANTY CONCEPT

A warranty may be written to commit the contractor to perform repair services at a fixed price for a specified duration:

A. A suspected failure of a warranted unit is tested by military personnel at the using activity to verify the failure.

B. If the unit tests good, it is put back into service or sent to supply as a ready-for-issue spare.

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C. If the unit tests bad, it is shipped with appropriate data to the contractor for repair.

D. The contractor receives the unit and verifies the failure and warranty coverage.

E. If the failure is not verified or is not covered by the warranty, corroboration by a DCAS representative is secured.

F. Repair of a covered failure is performed at no additional cost to the government, and required data records are generated.

G. The repaired unit is either shipped back to the using activity, placed in a bonded storeroom maintained by the contractor, or sent to a centralized military supply depot.

The monies of a warranty are on the surface repair services for a number of units, however, the underlying fundamental is to achieve an acceptable reliability. It is relatively unimportant whether the contractor or the military furnish the repair cost for the least amount of money; that is a very secondary consideration. If a contractor is committed to perform the repair task on his delivered equipment regardless of the number of returns over the warranty period, he has a strong motivation to exceed the reliability level upon which the warranty price was determined. If during the initial period of delivery a reliability problem is identified, the contractor has a strong incentive to introduce a no-cost ECP to correct the problem in order to reduce the number of future repair actions over the warranty period. This type of warranty operates much more quickly and efficiently because the contractor will have first-hand involvement with field failures rather than a typical problem coming back through an organic maintenance level.

The applicability to impose a warranty clause in a procurement contract should not be treated lightly. It may not be to the government's advantage to include a warranty. It will take a great deal of planning and effort in developing the procurement requirements and a substantial effort on the contractor's part to determine an equitable warranty position. This effort may be reflected in his equipment or Non-Recurring Engineering (NRE) costs. This exercise should not be imposed unless the warranty potential can be realized.

To determine if warranty should be applied, a set of guidelines needs to be established. These guidelines are set forth for each of the three major areas of concern: procurement factors; equipment characteristics; and application factors. Each is considered of equal significance in determining warranty applicability. The factors listed below are qualitative, intended only to provide a general indication of the feasibility of a warranty procurement.

These items are critical and warranty should not be applied unless these conditions are present.

PROCUREMENT FACTORS

- The procurement is to be on a fixed price basis.
- Multi-year funding for warranty services is available.

EQUIPMENT FACTORS

- Equipment design is feasible and reliability growth potential exists.
- Control of unauthorized maintenance can be exercised.
- Unit is field testable.
- Unit can be properly marked or labeled to signify existence of warranty coverage.

APPLICATION FACTORS

- Use environment and operating time exposure are known or predictable.
- Equipment operational reliability and maintainability are predictable.

The failure to apply the elements listed below taken singly would not be sufficient basis for rejecting warranty, but a combination of such events could be.

PROCUREMENT FACTORS

- The potential contractor(s) have proven capability, experience, and cooperative attitude in providing warranty-type services.
- The procurement quantity is large enough to make warranty economically attractive.
- Analysis of warranty price versus organic repair costs is possible.

EQUIPMENT FACTORS

- Equipment has a high operational utilization rate.
- Warranty administration can be efficiently accomplished.
- Warranty may not be appropriate when the duplication of an existing or planned government repair facility would not be cost effective.
- Unit reliability and usage information can be supplied to the contractor.

APPLICATION FACTORS

- Unit is amenable to R&M improvement and changes.
- Unit is reasonably self-contained.
- Unit can be readily transported to the contractor's facility.
- Unit has high level of ruggedization.

RECOMMENDATIONS

There is no question that warranty offers a great potential for improving reliability and reducing life cycle costs. While there has been limited experience with long term warranties in the military, the experience has been generally favorable. Several recommendations for maximizing the realization of such potential through further research and development efforts are offered:

- Develop a set of instructions for guiding procurement, supply, and maintenance personnel in securing and administrating warranty contracts.
- Conduct a training or indoctrination program for key procurement, supply, and maintenance personnel relative to warranty procurement and administration.
- Review military-service data systems and data-analysis products to determine how they can be modified to provide data products to support warranty administration.
- Undertake close monitoring of ongoing military warranty programs to evaluate their success and provide recommendations for future warranty procurements.
- Develop a set of guidelines to ensure R&M procedures are considered when applying warranty requirements on power supply equipment.

This scenario is not all-inclusive and represents an attempt to identify areas that should be included in warranty type contracts. In examples given, the equipment used is an aircraft engine power supply-military-current state-of-the-art.

The scenario must begin with the procurement action. The government accepts responsibility to provide: (1) increased "up-front" money to support the warranty, (2) a good definition of the warranty unit environment and (3) responsible record keeping on the time or date the unit has been utilized.

The intent is to obligate the contractor to provide maintenance service over the warranty period. A Reliability Improvement Warranty (RIW) commits the contractor to perform depot-type repair services at a fixed price for a specified duration of operating time, calendar time or both. The typical warranty-repair process is a follows:

a. A suspected failure of a warranted unit is tested by military personnel at the using activity to verify the failure.
b. If the unit tests good, it is put back into service or sent to supply as a ready-for-issue spare.
c. If the unit tests bad, it is shipped with the appropriate data to the contractor for repair.
d. The contractor receives the unit and verifies the failure and warranty coverage.
e. If the failure is not verified or is not covered by the warranty, corroboration by a DCAS representative is secured.
f. Repair of a covered failure is performed at no additional cost to the government, and required data records are generated.
g. The repaired unit is either shipped back to the using activity, placed in a bonded storeroom maintained by the contractor, or sent to a centralized military supply depot.

While the major expenditures of a warranty procurement are for the repair services involved, the prime thrust of the approach is to achieve acceptable reliability. The question of whether the contractor can provide depot repair services at a cost less than that of military repair is secondary to the objective of reliability achievement. If a contractor is committed to perform repair services on his delivered equipment for an extended period of time at a fixed total price, he has strong incentive to achieve or exceed the reliability level upon which the warranty price was determined. If, during the initial period of the warranty, an unexpected reliability problem is discovered, there is strong incentive for the contractor to introduce a no-cost ECP to correct such a problem so as to reduce the number of future repair actions over the remaining warranty period. Corrections of such problems are made much more efficiently and rapidly than under an organic maintenance concept because of the contractor's involvement with field failure experiences.

RIW Terms and Conditions

Specific terms and conditions of an RIW will depend on economic, procurement, logistic, equipment and administrative aspects. Therefore a standard set of specific terms and conditions applicable to all procurements does not exist. However, we can outline a basic set of terms and conditions indicating the major ramifications and alternatives.

Warranty Statement

This is the basic provision of the RIW, which states that the contractor warrants that the equipment furnished under the contract will be free from defects in design, material, and workmanship; and will operate in its intended environment in accordance with contractual requirements for the period specified. The major distinction between this stated warranty and the usual one-year (public consumer) type is that the period covered by the former is of such duration that each delivered equipment is likely to fail one or more times during the warranty period. The seller therefore prices the warranty to cover his expected repair costs which, especially in a competitive procurement, must be consistent with stated or promised reliability levels.

Definitions:

Supply Warranty
A warranty covering defects in material and workmanship. It is presumed that Supply Warranties are currently in effect and priced in component production procurement purchase orders.

Supplies
The word "supplies" as used herein means the components delivered by the Vendor under any order for components warranted hereunder. The word "supplies" does not include technical data.

Secondary Damage
The words "Secondary Damage" as used herein means damage incurred by a component of a vendor's own manufacture as a result of an unserviceable correlation in a warranty component of the same vendor's manufacture.

Warranty
Vendor warrants, subject to the conditions and exceptions set forth in paragraph 1, below, that the component shall be covered by this warranty. The component delivered under any order by Vendor in fulfillment of any warranty obligation hereunder will be serviceable in accordance with the criteria established by applicable engine or component Technical Orders for (TBD) years from the date of engine acceptance (DD250 date) or a maximum of (TBD) months after delivery of such components from Vendor's facility or for (TBD) hours total operating time, whichever comes first.

Exceptions and Conditions
1. The Vendor shall have no obligation to repair or replace an unserviceable item warranted under Paragraph A if the item is rendered unserviceable as a result of:

   (a) Improper or negligent installation, operation or maintenance of the aircraft or engine (unconfirmed failures are not excluded under this exception)

Exceptions and Conditions, cont'd

(b) Foreign object damage (FOD)
(c) Battle damage/Combat operations
(d) Accident
(e) Act of God
(f) Submersion (unless design requirement)
(g) Uses of parts or components not procured from the Vendor
(h) Experimental Tests as applied to the engine or components and/or the engine operating envelope
(i) Any cause external to the engine

Note: The above exclusions are normal for certain power supplies but in other cases would not be applicable.

Exclusions

As noted in the typical statement above, there are exceptions which void the warranty. Certain failures are not the fault of the contractor and which are completely beyond his control are normally excluded from warranty coverage. Examples include failures caused by fire, explosion, submersion, combat damage, and aircraft crash.

Two very difficult areas are mistreatment and system-induced failures (e.g., power transients). In many cases it is not clear-cut as to what caused the failure. If a contractor is experiencing more repair actions than he anticipated, he will naturally look to broad exclusion terms to reduce profit erosion. Such broad exclusions create the possibility of continual arguments and litigation on warranty coverage. It is therefore recommended that exclusions be limited. One approach used with respect to mistreatment was to define mistreatment as a possible occurrence only if obvious external physical damage or tampering was evident. Exclusions for system-induced failures or abnormal environmental stress are not recommended, since it is extremely difficult to prove such conditions existed.

Besides the advantages of minimizing disputes, this type of broad coverage forces the contractor to consider environmental extremes in his design and equipment modification strategy. For military warranty, the contractor is relieved from liability for special consequential or incidental damages.

Contractor Repair Obligation

Equipment that fails during the warranty period is returned by the government to a designated contractor repair facility, where the contractor is obligated to repair or replace the failed equipment at his expense. The contract may include a test procedure that the contractor must apply to a repaired equipment to verify the repair to the DCAS or government quality assurance representative upon request.

Warranty Period

The period of coverage can be stated either in calendar years, operating hours, or both. The use of a calendar period is best from an administrative viewpoint and for planning for organic maintenance. In considering the period of coverage, the following factors are important:

a. The period should be long enough to provide strong contractor incentive for achieving and maintaining acceptance reliability. As a minimum, the period should be of such duration that at least several failures of each delivered equipment would be expected.

b. On a per-year basis, warranty costs decrease as the warranty period increases since non-recurring costs are amortized over a longer period and contractor "learning" takes place.

c. An over-long warranty period (say over four years) may involve large uncertainities, forcing the bidder to price-in a large risk factor.

d. By providing for negotiated extensions to the initial warranty period, both the government and the contractor can extend the warranty, if deemed beneficial, at a price based on initial performance.

Given below is standard language for inclusions of an RIW warranty when units are returned under the warranty.

Remedies

1. Subject to the terms and conditions of this warranty, sole and exclusive remedy shall be to require the Vendor, at no increase in the warranty or component price, to repair or replace, at the Vendor's election, with a serviceable like component, and within the prescribed time limitations any of the components described in Paragraph "Warranty, pg 4-9" or parts thereof which are unserviceable. Those components returned to Vendor for breach of warranty which Vendor determines to be "unconfirmed" are also covered under this warranty. In no event is the Vendor under any obligation to perform any design or redesign work to meet its obligation hereunder.

   The Vendor's obligation for repair or replacement under this Paragraph includes secondary damage, as defined in Paragraph "Definitions-Secondary Damage pg 4-9". See Paragraph 3 below.

   The Vendor shall ascertain the serviceability of unconfirmed components and repair or replace those that are unserviceable and tender them for acceptance by the Government within ten (10) days turnaround to the prime contractor and within thirty (30) days to operational user.

   Turnaround time periods shall be calculated from date of receipt at Vendor's plant of the components and/or written authorization, whichever occurs later, to the time the repaired/replacement item is tendered for Government acceptance at the Vendor's plant, however shall exclude plant shutdown periods (Summer and Christmas) observed by the Vendor. If the parties agree that an unserviceable item should be subjected to a detailed investigation or if any Government inspection or other action is not performed in a timely manner, the above

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Remedies cont'd

periods shall be extended on a day to day basis until such investigation, inspection or other action is completed. Repaired or replacement components will conform to the applicable Technical Orders including requests for Technical Orders revision which have technically been approved by the Government and communicated to the Vendor.

Vendor shall pay liquidated damages equal to $ (TBD) per day up to but not to exceed $ (TBD) per incident for Vendor component deliveries which exceed the turnaround times specified above. (Vendor's quote shall delineate the above amounts).

Vendor shall furnish all parts or replacement components necessary to perform a remedial action required under this warranty.

Title shall vest in Vendor for all material/components left in Vendor inventory upon expiration of the Lot Expanded Warranty and serviceable components will be suitable for purchase by the Government if no further warranty use is required. Time Compliance Technical Order update, if required, will be funded by the Government.

2. Labor and material required solely by Time Compliance Technical Order or schedule maintenance requirements are excluded from the Vendor's obligation hereunder.

3. If the government elects to forward a warranted item to a depot repair facility (i.e., San Antonio ALC Depot Facility or similar depot facility) and any maintenance is performed other than testing, the Vendor shall be relieved of any further obligation under the warranty of Paragraph "Warranty, pg 4-9" for that time.

4. The Vendor shall not be responsible for Government's labor costs of removal and re-installation of a component or for the replacement costs of consumable items expended by the Government, for purposes of claim under the warranties of Paragraph "Warranty, pg 4-9".

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5. Notwithstanding any other provision of this clause, the Vendor shall be relieved from any responsibility for repair or replacement of any item covered by this warranty which is installed in the end user's equipment which is involved in an incident which results in the loss of that equipment (i.e., an incident where an aircraft is not normally returned to service).

6. The Vendor shall notify prime contractor of the existence of any of the foregoing exceptions or conditions promptly after such condition or exception becomes know to the Vendor.

7. The Vendor shall, notwithstanding any disagreement regarding the existence of a breach of the warranties, proceed with the repair or replacement pending resolution of said disagreement. In the event it is later determined that the Vendor did not breach the warranties, the Vendor will be entitled to an equitable adjustment.

8. Transportation to the Vendor's plant and back shall be via Government Bill of Lading. The risk of loss of any component in the possession of the Vendor shall be governed by DAR 7-104.24(a) including alternate paragraph (g), "Risk of Loss" as set forth in DAR 7-103.6.

Inability to Correct
The Vendor shall not be obligated to correct or replace supplies if the facilities, tooling, drawings, or other equipment or supplies necessary to accomplish such correction or replacement have been made unavailable to the Vendor by action of the Government. In the event that correction or replacement has been directed, the Vendor shall promptly notify prime contractor in writing of such nonavailability.

Access to Data
During the period of warranty and in support thereof, the Vendor shall have access through monthly prime contractor reports to existing Government records relating to operation, inspection and maintenance of engines, modules and components covered by such warranty.

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Data

The Vendor shall upon completion of repair or replacement of warranted components, report to prime contractor the component identification, the cause of the problem, the corrective action taken (except for unconfirmed units in which case Vendor will cite as "unconfirmed" on the report), date of receipt and origin of the rejected component, date of component delivery.

Notification

Receipt of components by the Vendor at the Vendor's plant before the warranty expiration time periods as set forth by Paragraph A shall constitute notification of a breach of the Vendor's warranty in A above. Alternatively, written notification of breach of warranty to the Vendor within the warranty period shall constitute notification.

Corrected or Replaced Supplies

1. Any repair pursuant to Paragraph "Warranty pg 4-9" shall not extend the warranty and repaired items shall be subject only to the balance of the warranted time remaining for those items.

2. The Vendor shall comply with the requirements of specification prime contractor's specification on warranted component for all warranty actions hereunder in lieu of any other quality or inspection requirements.

3. Replacement components shall be of the same or later configuration as the replaced component. New components furnished by the Vendor as replacements will be covered under the provision of Paragraph "Warranty, pg 4-9" through (TBD) hours of component total operating time. Used replacement components will have their own residual time remaining through hours (TBD) total operating time. Calendar limits will start when a component is initially provided as a replacement after acceptance, and is entered into the (Lot___) warranty register.

Unverified Failures

Some returned units will not exhibit failure when tested by the contractor. However, the contractor incurs costs in processing such units, and might feel justified in asking that he be paid for processing each unverified failure. This arrangement is not likely to motivate him to minimize such occurrences through his design, BITE, maintenance manuals, and training procedures. Even so, it is probably unfair to have the contractor absorb all unverified-failure costs. A compromise is to reimburse the contractor for all such returns which exceed a stated percentage within a reporting period. Values between 20 percent and 30 percent have been suggested for avionics. The contractor can use such a rate as a bound for pricing.

If the contractor feels that the combination of his design, BITE, training and manuals will lead to a lower percentage, he may choose a lower rate upon which to price for competitive reasons. In any case, there is continual incentive for the contractor to try to minimize the return of good items.

ECP Control

As the name implies, reliability improvement is the major feature of an RIW. By directly observing all field failures and being responsible for repair, the contractor can quickly identify failure patterns and institute appropriate corrective action through ECP's.

The ECP's, by terms of the warranty, are introduced at no cost to the government. Class 1 ECP's will generally follow normal MIL-STD-480 procedures necessary for configuration control but, because of the no-cost feature, should and can be expeditiously processed. Changes not affecting form, fit, and function can be immediately introduced, with proper notification to the resident government representative.

To assure a standard configuration at warranty expiration, the contractor should be required to incorporate all approved ECP's into returned units and to provide mod kits for the remaining unmodified units. If the warranty period is long enough to result in multiple returns of each unit, the number of unmodified units at warranty expiration will probably be small.

If not, it may be advisable to negotiate for mod kits at warranty expiration so as not to inhibit ECP introduction.

A recent military engine proposal stated the ECP in a slightly different tone, using words, "at a reasonable cost" instead of "no charge" as suggested above.

> Configuration Changes
> The Vendor shall have the right to submit Engineering Change Proposals (ECP) to revise the configuration of the supplied components to correct conditions which result in chronic and excessive claims under this warranty. Prime contractor agrees to evaluate such ECP's in good faith and in a timely manner. If the prime contractor concurs with the need for the proposed change and it does not adversely impact performance, durability or reliability of the engine and can be effected at a reasonable cost, then the prime contractor shall submit the ECP to the Government for acceptance of such change for incorporation into the production configuration or relieve the Vendor from further obligation under this warranty for the affected component condition. In the event the Government rejects a Vendor proposed change submitted by the prime contractor, the Vendor shall be relieved from responsibility for this warranty with respect to the affected component condition to the same extent that the Government relieves the prime contractor for said condition. In the event the Vendor elects, at his sole discretion, to incorporate an engineering change in delivered components at no direct cost to the Government or the prime contractor, the prime contractor will request the Government to make such components reasonably available to the vendor for retrofit.

Shipping

If the expense of shipping warranted equipment is small compared to the cost or repair, it is probably best for the government to bear all such shipping costs. Although this might appear to be contrary to the spirit of the RIW, it probably will be less costly to the government than if the contractor has to pay shipping costs. A contractor who has to do so (one or both ways) would have to estimate where the sets would be deployed, and quite likely would be conservative in the sense of increasing warranty price. Also, if some of the population is deployed overseas, customs regulations would increase pipeline time and therefore increase spares requirements.

By shipping through a Government Bill of Lading (GBL), a shipping discount is generally received and customs delays are reduced or eliminated. However, if the contractor is required to ship repaired uints to a known centralized facility or if shipping costs represent a significant percentage of total repair cost, it may be better to require the contractor to pay for shipping repaired units back to the government in order to maximize the reliability improvement incentive.

Government Obligations

The government's major obligations under a warranty procurement include:

- Testing all suspected failures on applicable test sets prior to return to the contractor.
- Utilizing approved shipping containers.
- Furnishing failure circumstances data
- Minimizing build-up at the using activities.

Meeting these obligations is beneficial to both the government and the contractor, and should not present undue difficulties for military maintenance personnel.

Warranty Data Requirements

The contractor should be required to maintain records and issues periodic reports necessary for assessing the effectiveness of the RIW, negotiating extensions, and making necessary contract price adjustments. Specific records to be maintained for each returned unit include the following:

- Date received by contractor
- Serial number
- ETI reading (Elapsed Time Indicator) if applicable

Government Obligations cont'd

- Condition of Unit
- Failure mode
- Probable failure cause
- Action taken for repair
- Manhours expended by labor category
- Parts and material usage
- Test results
- Date stored or shipped

MTBF Guarantee

A major provision pioneered by the airlines requires that the contractor guarantee the equipment MTBF experienced in the operating environment. Failure to meet a guaranteed level requires the contractor to institute corrective action and provide loaner spares until the MTBF improves. Details of such a procedure are provided in Reference 1.

A typical power supply warranty calculation would be as follows:

MTBF = RT/W

Where W is warranty cost expressed as a multiple net sales per warranty period expressed as a decimal.

R is cost of warranty claim as a multiple of sales price and T is the warranty period in hours.

For example, if cost of repair is 30% of the sales price and the price is increased to cover a 10,000 hour warranty, the MTBF must be 10% greater than:

MTBF = (1000 x 0.3)/0.1 = 3000 hours

Noncovered Failures

Since the government will generally not have a depot repair facility, provision for contractor repair of all returns is required, including those failures not covered under the warranty. This can be accomplished through a separate contract or through equitable adjustment in contract price for each such return.

RIW Development

As can be seen from the discussion of terms and conditions, the development of a complete RIW involves a number of major decisions -- length of coverage, types of exclusions, pipeline flow, turnaround time requirement, unverified failure conditions, etc. Because of limited military experience in long-term warranties, there is little objective data upon which to base such decisions. Therefore, careful analysis of reliability, maintainability, logistic, and cost factors must be performed. Contact with military activities that have used warranties should be maintained and the advice of cognizant personnel solicited.

Close coordination with logistics, using, and training commands is also most important. Since these are the commands ultimately responsible for implementing, administrating, and "working" the warranty from the customer's side, their recommendations and approval of terms and conditions should be sought.

If possible, it is also advisable to maintain continual interface with competing contractors regarding the warranty provisions. The success chances of a warranty are greatly increased if contractors are receptive to the terms and conditions. Of course, care must be taken to ensure that no contractor acquires a competitive advantage. Experience on previous programs has shown that contractors can and will point out deficiencies in draft terms and conditions which, when corrected, proved to be of mutual advantage to both parties.

It is also important that coordination be maintained with procurement, legal, pricing, and contracting offices in drafting the RIW provisions. Coordination should be undertaken as early as is feasible, since the warranty must be integrated with other provisions of the contract (e.g., the escalation clause and method of payment), and delaying such coordination increases the possibility of inconsistencies and errors.

Finally, the responsibility for monitoring contractor warranty performance tests with the Defense Contract Audit Service and Defense Supply Agency, which generally maintain resident personnel at contractor manufacturing plants. It is therefore necessary to coordinate the RIW provisions with the appropriate DCAS and DSA offices to ensure that the warranty is workable from their standpoint.

Several other recommendations concerning RIW procurement might be noted:

- For an R&D program, the government should state its intentions of incorporating warranty provisions in the production contract. In this manner, the development contractors will design the product with the thought of warranty profit through good R&M characteristics.

- Warranty charges should be priced separately so that appropriate warranty and life cycle cost analyses can be performed. This is mandatory if the RIW is an option to be exercised at the choice of the government.

- Funding for warranty services remains an open question. The opinion that initial warranties be funded with production money has been expressed by some government comptroller offices, but other government offices have suggested that an RIw falls under the Service Contract Act and therefore must be funded through O&M or industrial-type funds. Inasmuch as O&M funds can only be appropriated on an annual basis, such a decision can seriously hamper a warranty procurement since there is no assurance of obtaining the money to pay for such services in the future. Hopefully, this question will be resolved in the near future but until such time the procurement agency involved with RIW must be sure that warranty funding will be available.

- Since warranty is a long-term commitment, the contractor should be relieved of the uncertainties associated with fluctuations in the economy. The warranty could be covered by an economic escalation clause in the contract, or "then-year" dollars could be bid in, with perhaps adjustment for abnormal escalation.

- To permit transition to organic maintenance at the expiration of the warranty, consideration must be given to future purchase of test equipment, data, and training associated with organic maintenance that would not be required while the RIW was in force. If the procurement is competitive, these elements would advantageously be fixed price option items, the prices to be valid for a period covering the warranty so that the government can purchase such items as necessary for transition to organic maintenance. If one of the bases for contract award is total life cycle cost, the competitive factor will tend to minimize transition costs for the fixed price option items.

Appendix 1

Definitions used in "typical Warranty Procurement":

- Secondary Damage: The words "secondary damage" as used herein means damage incurred by a component of a vendor's own manufacture as a result of an unserviceable condition in a warranted component of the same vendor's manufacture.

- Engine: The word "engine" as used herein means the complete engine assembly.

- Component: The word "component" as used herein means an engine component included in the Approved Parts List which is specifically identified in Paragraph A of this warranty.

- Total Operating Time: The phrase "Total Operating Time" (TOT) as used herein means engine operating time above Temperature as measured by the engine Events History Recorder (EHR) engine time clock and tracked by the applicable flight and configuration tracking system. Total operating hours accumulated at production test will be counted toward the components total operating time. Components which are found to be unserviceable at production test operations will not be considered for repair under this warranty.

- Foreign Object Damage: Damage to a component resulting from the ingestion of material not resident within the component.

- Vendor's Plant: The phrase "Vendor's Plant" shall mean those facilities of the Vendor and its subcontractors designated by the Vendor to perform its warranty actions.

- Serviceable: The word "serviceable" as used herein means the component will be capable of performing its designed function and meets the test requirements of the applicable component technical order when tested by the vendor.

- Unserviceable: The word "unserviceable" as used herein means the component is not capable of performing its designed function and/or does not meet the test requirements of applicable component technical order when tested by the vendor.

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- <u>Confirmed Failures:</u> Components returned to Vendor for Warranty consideration that, when subjected to component technical order, are found by the Vendor not to conform to those limits and are therefore considered unserviceable.

- <u>Unconfirmed Failures:</u> Components returned to vendor for warranty consideration that, when subjected to component technical order, are found by the vendor to be serviceable within those limits.

4.2 STANDARDIZATION OF POWER SUPPLIES

Standardization of power supplies offers a potential for substantial improvement in Reliability, Maintainability, and the Materiel Readiness Posture, and also for a substantial reduction in Life-Cycle-Cost. The achievement of a highly reliable power supply design requires that the design be mature. The required maturity does not come automatically with the passage of time. It occurs as the result of going through the many phases of the development cycle. The development cycle requires substantial time, effort, and expense. With the high power densities needed, the development cycle problems are compounded. A mature design can only be achieved in time by starting early, with a fully-funded effort. Such an investment can be difficult or impossible to make in the early stages of a weapons system program. However, if the desired reliability is to be obtained, the investment must be made.

Standardization provides a good vehicle for making the nec ssary investment, since the cost may be amortized over a larger market, and the funding source need not be tied directly to specific programs. With a large defined market, industry becomes a source of the needed investment. There is little profit motive for internally funded development of specialized power supplies for a limited market.

Maintainability is improved through standardization by a reduction in the number of different power supply types needed to be spared. Materiel Readiness Posture is improved through standardization by the increased quantity of each specific power supply type in the system, and by the increased practicality of multi-sourcing. In emergencies, standardized assets may be diverted from non-critical to critical programs. The existence of multiple sources greatly increases the available options for

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increasing the production rate during the transition from a peacetime to a wartime footing. Standardization tends to lower Life-Cycle-Cost because of the inherent economy of scale and the pressures of competitive bidding from the multiple sources.

It would be unrealistic to think that all power supplies could be of a standardized design. But there is no justification for the present proliferation of different power supply designs, other than the fact that each of them seemed like a good idea at the time. It would be quite reasonable to expect that standardization at the platform level could be achieved for at least 50 percent of the power supplies applied.

The design of a family of standard power supplies cannot proceed in earnest unless the physical interface is defined and fixed. Even a slight change in physical dimensions can result in a major impact on the power supply design, causing a stretch-out of the development cycle. It is therefore essential that the physical interface be fixed at a very early stage of the standard power supply development cycle.

Clearly, there is also a need to standardize equipment enclosures. The design of the power supply is highly interdependent with the design of the equipment enclosure. An early investment in standard enclosure development can ensure an optimum trade-off of form factor. Higher power supply reliability and better volumetric efficiency of the equipment packaging would result from this trade-off.

Standardization must not be stagnated by an overly institutionalized approach which moves too slowly, too timidly, and which becomes too inflexible once it has moved. Standardization by such an approach is too likely to produce a set of obsolete standards that are never used. Experience has shown this to be the case.

In order for standardization to work effectively, it must outperform the competition. The potential users of the standard power supplies must be receptive to their use. Indeed, there should be direct and immediate advantage to the respective weapons system programs in voluntary selection of the standard designs. The family of standard power supplies must be attractive from the point of view of the selection criteria that are paramount at the critical phase of weapons system development when the power supplies must be selected. These criteria include: performance, power density, off-the-shelf availability, form factor, reliability, diagnostics and non-recurring cost. Although Life-Cycle-Cost is important eventually, it is not included in the above list because it is not likely to receive serious consideration at this critical time.

Standardization brings with it a set of responsibilities. The name of the game changes. Prime contractors have a natural tendency to prefer custom power supply designs. They help protect sole-source turf. It must be expected that a degree of encouragement in the use of standard designs must be provided by the weapons system development agency. This encouragement may range from enlightenment to contractual direction. In any case, DoD must assume a degree of responsiblity for the performance characteristics of the standard power supply design. It is therefore necessary that the standard power supplies be characterized thoroughly, including secondary or stray characteristics. It is also necessary that the system using the standard power supplies be thoroughly evaluated over the full performance envelope permitted by the standard power supply specification, so that proper system performance will be assured when using multiple sources for the standards.

The finite life of standardized designs must be recognized. A period of approximately five to seven years is perhaps the extent of the applicability of a given family of standard power supplies to new weapons systems. In order to utilize the full useful life, the standard designs must have off-the-shelf avail-

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ability, at least in small quantities, at the beginning of this five to seven year period. Any delay beyond this point tends to shorten the applicable life on a day-for-day basis. Timing for the introduction of new standards should be coordinated with major weapons system procurements so as to maximize the market for a given set of standards.

New designs must also be available to support future weapons system development. The standard power supply development must therefore be a continual effort. Future families of standard power supplies should be under development, even as new standards are being introduced, so that mature reliable power supply designs can be offered as standards for the future generation of weapons systems.

4.3 VOLUME AND EFFICIENCY

The next two decades will see a continuing demand to reduce the effective volume used by the power supplies and the power system of electronic equipment. Some of the primary reasons for this are as follows:

- Higher thermal densities will continue to be used in the packaging of electronics. (Near term techniques such as leadless chip carriers, ceramic boards, liquid cooling are examples of the trend). As packaging methods and thermal management improve, new design techniques will evolve which will allow even denser packaging of electronics. As the power density of the electronics goes up, the power supply density must also go up if the power supply is to continue to occupy a reasonable percentage of the volume. This trend was pointed out in the Ad Hoc Power Supply Committee Report - NAVMAT P4855-1.

- The potential requirement for more "built in test" and built in diagnostic aids will require space otherwise available for power processing. This requirement is also applied to the electronic load and is one of the factors that will tend to make it more dense. This need is addressed in the committee report on Testing Technology.

- The increasing need for back-up capability to meet system reliability requirements will require the individual units to be smaller to allow space for additional units.

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- The trend toward more stringent limits on the noise inserted on the input power lines such as line current harmonics, TEMPEST requirements, load changes, and protection from the environment such as radiation, EMP, directed energy and lightning will require special techniques and additional volume, further aggravating the density problem.

As can be seen, the list of things that can cause power system density and complexity to increase can be long. It also becomes clear that what is required is power system engineering that is applied at the appropriate system level. With the application of good power system engineering, the added complexity and high density can be held to the minimum necessary to meet system requirements without exceeding the capability of the technology available at the time. However, the need will still exist to increase density.

The increasing use of VLSI will tend to decrease the power required per function with an increase in functional density. For the reasons cited above, this will result in a higher overall power density in the loads and therefore, in the power supplies. It is anticipated that over this time frame, power supply density will in many cases be driven up by a factor of 2 to 3.

Figure 1 shows the typical increase in packaging density and power density of digital circuit cards that has taken place over the last two decades. The examples used here include 5 x 7 inch and 5 x 5 inch boards. The decrease in power per card shown in 1966 was a result of the introduction of integrated circuits into production equipment. The packaging density has been increasing exponentially while the power density has been increasing linearly. It seems reasonable to assume that the general trend will continue. However, the anticipated increase in power supply density is less than what Figure 1 would indicate because older technologies continue to be used along with the new, and the density increase has not been as dramatic in the non-digital areas.

Figure 2 shows today's typical densities for low voltage power supplies, and what the density goals should be for the year 2000. Although the technology should attempt to achieve that density, every effort should be made to actually utilize lower densities in hardware in the interest of better reliability resulting from lower temperature.

Power supply efficiency becomes an important issue for two primary reasons:

First, as power supply density is driven up, the best way to keep the power supply component temperatures at reliable levels is to reduce the total internal power dissipation so the dissipation per unit volume does not increase excessively.

Second, the trend toward extremely small geometries as used in VHSIC will cause the applied voltage to decrease from today's 5 volts to less than 2 volts. Since a major source of power loss in today's logic power supplies is due to the fixed voltage drop in the output rectifiers, the efficiency at lower output voltages will drop significantly using today's state-of-the-art rectifiers. The problem is further complicated by the fact that the current output will increase as the voltage is reduced, assuming the power dissipated by the load remains constant. It becomes apparent that low voltage supplies of the future will be limited by the output circuitry necessary to handle very large currents efficiently and distribute these in a like manner.

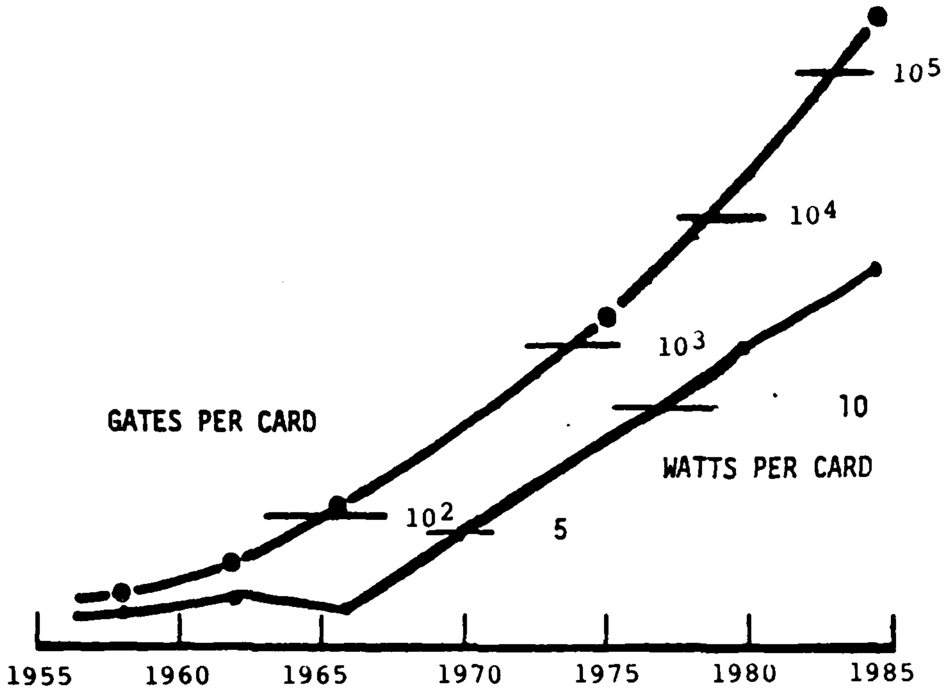

FIGURE 1 Equivalent Number of Gates and Power Dissipated per Card vs Time

FUTURE / PRESENT	SHIP	AIR	GROUND	MISSILE
AIR COOLED	1.5-6 / .5-2	3-15 / 1-5	1.5-6 / .5-2	N.A. / N.A.
CONDUCTION COOLED	3-15 / 1-5	6-12 / 1-6	3-15 / 1-5	6-24 / 2-8

FIGURE 2 Power Supply Density (Low Voltage) Output Watts/Cubic Inch

SUGGESTED INITIATIVES

A management action that can be taken to help improve future combat readiness is to recognize the need for power system engineering so that the power trade-offs are made internal to the power system, and between the power system and the remainder of the system in a manner that is most cost effective. The power system used in a weapon system should receive the same level of design attention as other parts of the system.

Investment of technical resources in the following areas will be of help in achieving the volume and efficiency improvements anticipated to be needed.

- High efficiency rectifier systems for low voltage outputs, both techniques and devices
- Power Supply Technologies most compatible with the Electromagnetic Environment Effects
- Component development and circuit topologies aimed at higher frequency converter requirements
- Smaller storage elements such as input inductance and capacitance
- Switching devices that can handle more voltage and current
- Improved cooling techniques
- Low voltage, high current distribution techniques

4.4 ENVIRONMENTAL CONSIDERATIONS AND INVESTMENTS

The sophistication of equipments associated with the National Defense in the next decade will be of a complexity much more demanding of the user and maintainer. Self-diagnosability with degraded mode reversion and a prompted maintenance scenario will have to become a design consideration. A philosophy and techniques need to be developed and made available to encourage this consideration at the onset of a Program's evolution to ensure incorporation and consistency across DoD and industry.

The energy conditioning equipment of tomorrow will have to be designed to be radiation hardened and EMP and lightning tolerant. Space applications, composite aircraft skins, directed energy weaponry, higher power radar, and the harsh environments of conflict will challenge the designer to ensure the mission and survivability. New techniques for shie'ding/packaging/enclosure sealing along with advanced component developments (Transorbs/Nuclear Event Detectors) will be required to facilitate this improvement. An early task assignment to determine the levels of exposure and that which is the most cost-effective means to attenuation/protection must be made if we are to be ready.

The integrity or security of data with the advance in electronic intelligence gathering techniques will require the broad imposition of TEMPEST and its attendant complications to ensure the effectiveness and readiness of our defense. The additional filters, shielding, and cabling displace volume, increase weight, and add cost. New ways and countermeasures must be developed and made available to equipment designers if the resultant gains of LSI and VLSI are to be realized in the final analysis. Now is the time, and protection of that development must receive commensurate attention.

The gamut of tomorrow's interface considerations is a matrix of combinations and permutations much in excess of the ability of the mind to order. Many different energy sources and power types, each with their peculiar variations and disruptions, must be conditioned to be compatible with the host of complex loads presented by the new circuit families and topologies. Although it will probably never make sense to standardize energy sources across all types of platforms (spacecraft through submarines), it certainly is worth considering the minimization of different types on board a particular category of vehicles. Reducing the number of part numbers and attendant spares via the foregoing would simplify ILS (Integrated Logistics Support), minimize LCC (Life Cycle Cost), facilitate in-depth and mature designs, and improve the overall readiness posture of the power system elements (rotating equipment, distributions, transformers, filters, line conditions and regulators). A joint effort (DoD and Industry), as soon as is practical, is the only chance we have of making this situation a reality of the nineties. Slow but deliberate and directed evolution is the only acceptable mechanism to this end.

Performance density as it relates to power and current density and the compaction of function to be had via such advancements as VLSI and VHSIC has not been given equal and appropriate emphasis. The next generation signal processor or control function will occupy but a small corner of the power supply if some impetus is not afforded this dichotomy. DoD needs to emphasize and invest in development tasks which would net:

- Approximately a 300% increase in power supply density (as it relates to current)

- Plan for change-in-phase cooling and transcalent component development

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- Low voltage technology with candidate and characterized components for synchronous rectification with improved efficiency

- High frequency ($\geq$1MHZ) conversion topology with its attendant component improvements and development needs

- Distributed large system design philosophy as it relates to the needs of VHSIC

Urgency is the underlying but not unfounded message relating to that which needs doing in the arena of energy conditioning if its level of development is to be adequate and compatible with the electronics of the next decade. Heretofore little or no credence was given the power aspect of enhancement or advancement when next generation equipment was planned. Qualified organizations must be identified and assigned the tasks described herein if a timely and comprehensive readiness is to be achieved.

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4.5 SYSTEM INTERFACES

Interfaces important to power supply designers are presently poorly defined and tested from a systemic viewpoint. Inadequate MIL Standards misapplied by those responsible for establishing system requirements more often than not causes unacceptable system performance or even malfunctions, failures or reduced MTBF. At any point in the life of a program, substantial rework to cure any of these symptoms results in unnecessary added system cost and risk with respect to system availability. Often another consequence is compromised performance. In those cases where a new system is found to function acceptably, there is still a reasonable risk that reliability will suffer since components often see stress levels far above that for which they were designed based on imcomplete or non-existent specifications. Other complications arise from the interaction between multiple users on a single power source. If no one assumes or delegates overall system design responsiblity then there is also risk of instability added to all of the above.

Figures 3 and 4 show the important interfaces, from two points of view, as seen by the power supply designer. The perspective to be conveyed by Fig. 3 is that the power supply, in whatever form it assumes, is the major interface between the "outside world" and all of the rest of any given user's equipment powered from any one supply. From this viewpoint it can be seen that power supplies play a key role in the success of any weapons system. It can also be seen that even as power supplies are used at various hierarchical levels in a multifaceted weapons system the need for complete and detailed interface definition is paramount if any power supply is going to fulfill its role. It should also be clear that the greatest possibilities for problems arise when the hierarchical level is such that the interface is between a customer and a supplier.

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4.5

SYSTEM INTERFACES

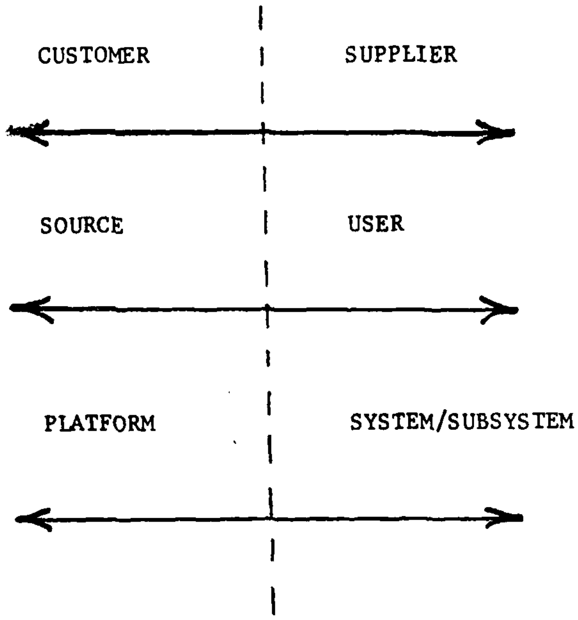

FIGURE 3

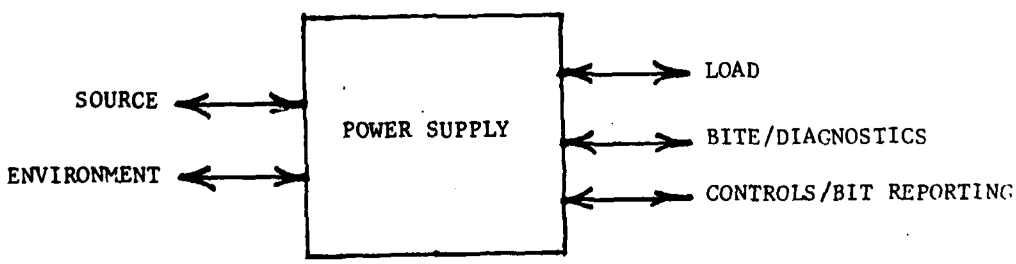

FIGURE 4

It is here that the shortcomings of all existing MIL documentation must be overcome if full compatibility and comformance to requirements are to be achieved. It is also here that interactive systems engineering is critical.

Beginning with the source parameter in Figure 4 the following areas of concern are formulated. When all the power supply designer has to work with for source definition is something like that contained within DoD-STD-1399 or MIL-STD-704, he has no knowledge of such details as source impedance and source generated noise. Following the same line of thought, if several power supplies are driven from the same source, there is little or no control over the load variations of one power supply causing undefined source variations for another. Also neglected is any thought of the impedance of the distribution system. Overall system stability requires an evaluation of the interaction under all circumstances of the source, distribution system and all user input impedance characteristics. Further, the peak fault current available to clear a fuse is of concern to a user who is trying to get off-line under a fault condition. The user is also concerned with the peak voltage overshoot when the current is reduced to zero. Other users also need this type of information for a proper design at their interface. Since MIL-STD-461 only addresses conducted emissions reflected to a source (and an arbitrary one at that) the level of EMC is undefined. Further, MIL-STD461 does not differentiate between differential and common mode emissions. The test configurations of MIL-STD-462 do not reflect any real system impedance, consequently predictions for system compatibility are not well founded. The energy level of the "lightning" transient in DoD-STD-1399 is not defined. Conditions during automatic transfer of power are also not defined. All of the forenamed shortcomings (and there are others) support the observation that there is an extreme lack of uniformity in the manner in which any higher level "system" engineering is

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carried out which could preclude the lack of compatibility between source and user and hence between systems and their intended platform. As indicated earlier, this causes eleventh hour panic "solved" by waivers which result in compromised performance with little regard for any changes in predicted reliability.

The other parameters in Figure 4 also contain areas of concern. For example, if MIL-E-16400 is imposed without modification it establishes arbitrary levels of shock and vibration without regard to real conditions. Also in MIL-E-16400 there is a lack of clarity with regard to relative humidity. The real confusion comes from the requirement in MIL-E-16400 as opposed to the test conditions in MIL-STD-810, Method 507, Procedure IV. Relative to Performance Monitoring/Fault Location (PMFL), which is related to the parameters of Bite/Diagnostics and Bit Reporting, there is a lack of standardization which aggravates the interface situation.

In summary, any effort to

- Improve existing standards and generate new ones,
- Establish guidelines for "power systems" engineering,
- Establish guidelines for interface definition and standardization,
- Establish interface evaluation procedural guidelines,
- Ensure "management" recognition of, and support for, the resolution of "the problem",

will be in the direction of improving the Operational Readiness and Reliability and Maintainability of DoD systems utilizing power supplies while at the same time reducing Life Cycle Costs.

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Recommended actions, therefore, should conform to the following format:

- Form a Government/Industry task force to carefully delineate needed improvements in the interface definition alluded to above.

- Have the task force propose changes as appropriate to any existing MIL documentation. Alternatively, have industry, under contract, provide proposed changes to the appropriate MIL documentation.

- Have various Government Agency/Industry teams or Industry under contract generate appropriate new MIL documentation which might include such topics as:

  - Power systems interface engineering management.

  - Power systems interface compatibility requirements guidelines.

  - Power systems interface evaluation procedural guidelines.

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4.6 SHORTAGE OF POWER SUPPLY DESIGNERS

Power supplies for electronic systems have long been perceived as a simple, mature technology--an ideal assignment for the new engineer out of school. It is doubtful whether this perception was ever accurate, but it is most certainly not accurate at the present time. The switching-mode power supplies now being used in military electronics are complex non-linear multi-feedback control systems using state-of-the-art digital and analog circuitry. This circuitry contains magnetic, capacitive, and semiconductor components pushed to and beyond their conventional limits.

The long term general perception of the simplicity of power supply technology has had a major impact on the availability of qualified designers. Courses essential to the design discipline virtually disappeared from the curriculum of engineering schools in the 1960-1970 time frame. From 1965 to 1975, probably less than ten engineers were educated in power supply technology at the PhD level in all U.S. universities--fewer than the yearly production rate of either European or Japanese universities in the same time frame.

The perceived simplicity of power supply design has also impacted the career path selection of young engineers. Exposed to digital electronics, signal processing, communications, control systems, and similar courses during undergraduate studies, these fields have always appeared more glamorous than power supplies to the new professional. This self-selection process, based upon a distorted image of power supply design, has led to a chronic shortage of qualified power supply design engineers. The few qualified designers have rarely been laid off during the low demand cycles of the past twenty years and it has been virtually impossible to hire qualified power supply design engineers into civil service. While PhD's trained in microelectronics, computer science, communications, etc., can be hired into civil service at the GS-11 and GS-12 level, DoD has yet to hire a PhD trained in power electronics into civil service at this level. In fact, the only DoD hiring of power supply designers has been at the GS-14 level.

Another consequence of the perceived simplicity of power supply design has been the assumption that minimal electronic laboratory equipment is adequate to the design task. Although every electronic system uses a power supply, and well-stabilized control loops are mandatory for good performance, probably fewer than three DoD activities have made the specialized investment in equipment needed to make accurate Bode plots (amplitude and phase versus frequency) of a switching-mode power supply. This measurement requires recovering small amplitude and phase signals (1-10mV) buried in switching noise (10-100V). Many of the DoD contractors and their subcontractors also have not made this investment. The equipment is virtually non-existent in engineering schools. This lack of adequate equipment further discourages engineers from entering the field since the nonlinear characteristics of the design and the feedback system requires adequate measurement techniques to back up the analytical design.

Power supplies presently constitute 10 to 20 percent of the volume and weight of an electronic system with projections that they will constitute 50 percent of the volume or more in the next 10 years unless major, and unprojected, breakthroughs in the technology occur. Perhaps of even greater importance is that they are one of the major reliability problems in present military equipment--equipment using a far simpler power supply technology than will be required in the future. The Navy has stated that Fleet readiness could be improved by as much as 20% if power supplies simply met their specified reliability levels. Power supply managers for contractors serving all DoD have stated that Navy power supply problems are no different than those experienced by the Army and Air Force. In this environment, only a few universities offer state-of-the-art education in power supply technology and only at the graduate level. The support and expansion of these educational resources are essential. The only generally available training outside these universities are short courses, conferences and seminars held in conjunction with conferences. Virtually no training is available at local universities and colleges. All other training is by trial and error, self-study, and on-the-job training, with available expertise for on-the-job training sparse.

Unless corrective action is taken, the lack of trained power supply design engineers, combined with the fact that power supply technology is vital to every electronic-based system, will make power supplies one of the major roadblocks in the next ten to twenty years in achieving the goals of a strong, technology-based defense system.

Several mechanisms exist that can be implemented through DoD policy and through new and continued initiatives to improve the situation. These include: improving the availability, quality, and scope of power electronics education and training; increasing the number of engineering students electing power electronics as a speciality area; encouraging new graduates entering industry to work in the power electronics area; improving the educational opportunities of engineers already working in the power electronics field; encouraging industry to spend more of their IR&D funds on power supply technology; and similar activities. The following specific recommendations are made:

Research: Establish focal points in the Army Research Office, Office of Naval Research, and the Air Force Office of Scientific Research to establish and maintain continuous research programs in power supply technology in the universities. Power supply or power electronics technology should be listed as a preferred area for Research Fellows and similar programs meant to encourage DoD related research in the universities.

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Independent Research and Development: Encourage industry to spend more of their Independent Research and Development (IR&D) funds in power supply research and development by assuring 100 percent reimbursement of any IR&D in this field.

Encourage the publication of government sponsored research in the open literature--which is read by power supply designers, rather than in government reports--which are rarely reviewed by working power supply designers.

Establish computer-based "expert systems" for power supply design and power supply design reviews. Due to the universal use of power supplies in electronic systems, a power supply "expert system" would make an excellent candidate for the application of an artificial-intelligence-based expert system to a DoD problem.

Encourage the attendance of power supply design engineers at short courses, conferences, and seminars related to power supply design by allowing up to 5 percent of the power supply design engineer's direct charges to a DoD contract be allowed for this purpose. Present DoD and industry accounting and educational reimbursement practices discourage this.

Many of the above policies can be implemented with little or no additional cost over present practices. The new initiatives requiring additional levels of funding include the funding of university research in power supply technology, and the establishment and maintenance of a power supply "expert system."

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5.0 APPENDIX

5.1 POWER SUPPLY TECHNOLOGY GROUP VIEW FOILS

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POWER SUPPLY TECHNOLOGY GROUP

MISSION

IDENTIFY WHICH PAYBACK AREAS OF INVESTMENT TO ENSURE AVAILABILITY OF RELIABLE AND MAINTAINABLE POWER SUPPLIES NECESSARY FOR THE REQUIREMENTS OF THE NEXT DECADE.

54/7-2

SELECTED CANDIDATES

MANAGEMENT ISSUES -

- WARRANTIES
- STANDARDIZATION
- POWER SYSTEM ENGINEERING

TECHNICAL

- HIGH EFFICIENCY LOW VOLTAGE CONDITIONING
- POWER SUPPLY DENSITY
- ELECTROMAGNETIC ENVIRONMENT EFFECTS (E^3)
- IMPROVED COOLING TECHNIQUES

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MANAGEMENT

WARRANTIES

- PRESENT PROCUREMENT SYSTEM REWARDS POOR RELIABILITY
  - MANY SPARES REQUIRED
  - PRODUCT IMPROVEMENT PROGRAMS
  - EXCESSIVE REPAIR CONTRACTS
- MODIFY PROCUREMENT POLICY TO REWARD GOOD RELIABILITY PERFORMANCE
  - POWER SUPPLY MANUFACTURER TO PROVIDE REPAIR WARRANTY PROPORTIONAL TO CONTRACTED MTBF.
  - COST OF WARRANTY PAID UP-FRONT WITH SUPPORT FUNDS
  - RESULT - HIGHER RELIABILITY = LOWER LIFE CYCLE COST

54/7-4

MANAGEMENT

STANDARDIZATION

- PRESENT APPROACH RESULTS IN PROLIFERATION OF POWER SUPPLY TYPES
  - MANY NEW IMMATURE DESIGNS FIELDED
  - LONG DEVELOPMENT TIME REQUIRED
  - MANY SPARE TYPES REQUIRED
- STANDARDIZE EQUIPMENT ENCLOSURES AT PLATFORM OR VEHICLE LEVEL - FOLLOWED BY SELECTION OF POWER SUPPLY TYPES FOR STANDARDIZATION
  - PROVIDES A VEHICLE TO IMPROVE NEW TECHNOLOGY AS IT BECOMES AVAILABLE
  - WILL RESULT IN IMPROVED RELIABILITY, LOWER COST AND SHORTER SCHEDULES

54/7-5

MANAGEMENT

DoD POWER SYSTEM ENGINEERING

- POWER SYSTEM ENGINEERING NEEDS ATTENTION
  - EXISTING INTERFACE DOCUMENTS ARE INCOMPLETE
    - IMPROVE AND UPDATE INTERFACE STANDARDS

      DoD-STD-1399/300

      MIL-STD-704

      MIL-E-4158
    - MORE EMPHASIS REQUIRED ON POWER SYSTEM ENGINEERING
    - GENERATE GUIDELINE DOCUMENTS FOR POWER SYSTEM DESIGN

      SHIP
AIR
GROUND
  - SHORTAGE OF TRAINED POWER SUPPLY DESIGNERS
    - ENCOURAGE POWER SUPPLY R & D
    - ENCOURAGE TRAINING OF EXISTING DESIGNERS

54/7-6

TECHNICAL

HIGH EFFICIENCY LOW VOLTAGE POWER CONDITIONING

- VHSIC REQUIREMENTS FOR LOWER VOLTAGE POWER SUPPLIES CREATES NEED FOR LOW FORWARD DROP RECTIFIERS AND LOW LOSS DISTRIBUTION SYSTEMS
  - EXISTING TECHNOLOGY RESULTS IN 40% EFFICIENCY AT 1.0 VOLT OUTPUT
  - GOAL IS TO REDUCE FORWARD DROP BY AT LEAST FACTOR OF FIVE (5)
- DEVELOPMENT AND QUALIFICATION OF LOW FORWARD DROP RECTIFIERS ARE REQUIRED
  - SELECT DEVICES POTENTIALLY AVAILABLE FOR CONTINUING DEVELOPMENT AND QUALIFICATION
  - SUPPORT NEW DEVICE TECHNOLOGY

54/7-7

TECHNICAL

POWER SUPPLY DENSITY

- MISSION REQUIREMENTS AND ADVANCING TECHNOLOGY CONTINUE TO REQUIRE HIGHER DENSITY POWER SUPPLIES
    - LOAD DENSITY CONTINUES TO INCREASE
    - MORE EMPHASIS BEING PLACED ON BUILT IN MAINTENANCE AIDS
    - ENVIRONMENTAL PROTECTION BECOMING MORE IMPORTANT (*EMI, EMP, RADIATION HARD*)
    - CURRENT DENSITY IMPORTANT AT LOW VOLTAGES AS REQUIRED BY VHSIC
- DEVELOPMENT REQUIRED IN SEVERAL AREAS
    - HIGH FREQUENCY (APPROX. 1MHz) POWER CIRCUIT TECHNOLOGY
    - LOWER LOSS MAGNETIC COMPONENTS AND CAPACITORS
    - SWITCHING DEVICES HAVING HIGHER VOLTAGE, CURRENT AND SPEED RATINGS
    - LOW VOLTAGE HIGH CURRENT DISTRIBUTION TECHNIQUES

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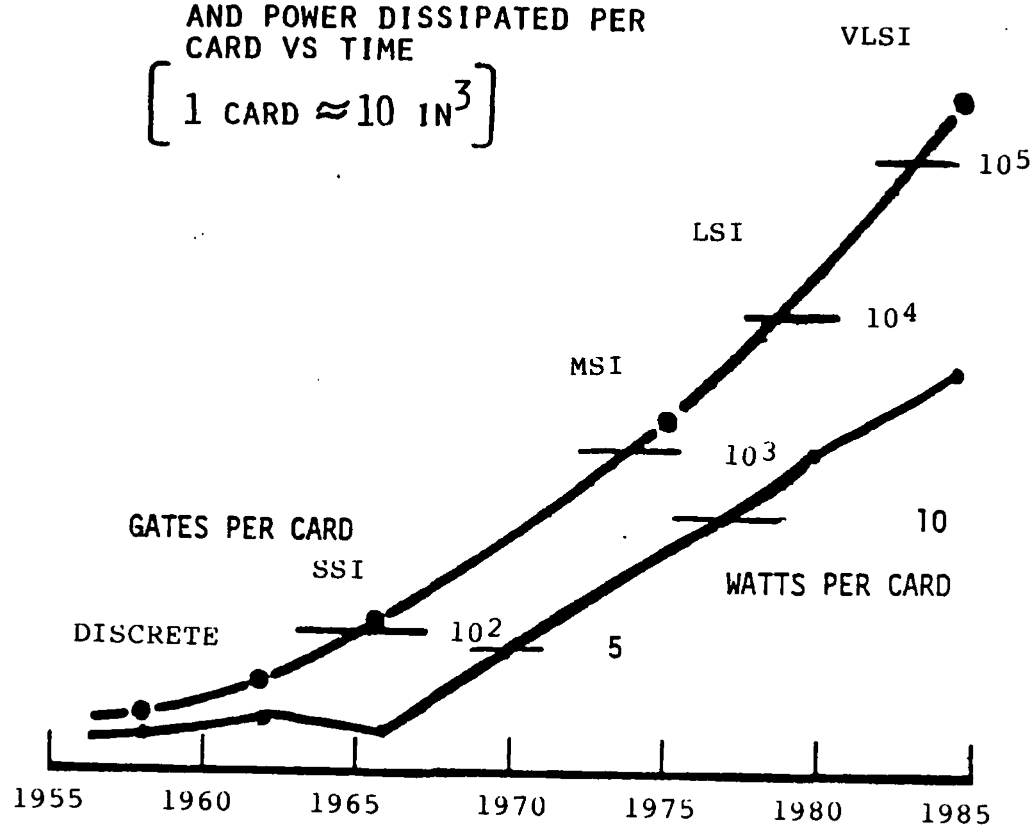
EQUIVALENT NUMBER OF GATES AND POWER DISSIPATED PER CARD VS TIME

[1 CARD ≈ 10 IN^3]



ESTIMATED POWER SUPPLY DENSITY (LOW VOLTAGE) OUTPUT WATTS/CUBIC INCH

FUTURE / PRESENT	SHIP	AIR	GROUND	MISSILE
AIR COOLED	1.5-6 / .5-2	3-15 / 1-5	1.5-6 / .5-2	N.A. / N.A.
CONDUCTION COOLED	3-15 / 1-5	6-12 / 1-6	3-15 / 1-5	6-24 / 2-8

TECHNICAL

ELECTROMAGNETIC ENVIRONMENT EFFECTS

- ENVIRONMENTS BECOMING POTENTIALLY MORE HOSTILE TO ELECTRONICS
  - COMPOSITE STRUCTURES ALLOW LARGE VOLTAGES TO BE DEVELOPED ACROSS STRUCTURE DUE TO EMP LIGHTNING
  - LOW VOLTAGE VHSIC MORE SUSCEPTIBLE TO RADIATION INDUCED TRANSIENTS ON POWER BUS
  - ELECTROMAGNETIC RADIATION LEVELS EXPECTED TO INCREASE
- REQUIRE EARLY DEFINITION OF CHANGING ENVIRONMENT AND TECHNIQUES DEVELOPED TO MEET NEEDS
  - ESTABLISH NEW EMI LIMITS APPLICABLE TO EQUIPMENT IN COMPOSITE STRUCTURES
  - DEVELOP TOPOLOGIES AND TECHNIQUES FOR USE IN HIGH RADIATION ENVIRONMENTS

54/7-11

TECHNICAL

IMPROVED COOLING TECHNIQUES

- IMPROVED COOLING IS REQUIRED TO MINIMIZE TEMPERATURES ENSURING RELIABILITY WITH INCREASING POWER/CURRENT DENSITY
  - FURTHER DEVELOP PHASE CHANGE COOLING TECHNOLOGY AS APPLICABLE TO POWER SUPPLIES
  - IMPROVE HEAT CONDUCTION TECHNIQUES INCLUDING DEVELOPMENT OF NEW COMPONENT PACKAGES
  - DEVELOP AND QUALIFY POWER SEMICONDUCTORS WITH ISOLATED JUNCTIONS WITH REDUCED THERMAL RESISTANCE

54/7-12

IMPLEMENTATION PLAN

TASK DoD, THE SERVICES AND INDUSTRY WORKING GROUPS FOR SPECIFIC SOLUTIONS TO MANAGEMENT ISSUES

- WARRANTIES
  - DEFINE METHODOLOGY AND CONTRACTOR FUNDING TECHNIQUES
- STANDARDIZATION
  - DEFINE REQUIREMENTS FOR STANDARDIZATION EFFORT AT PLATFORM LEVEL
- POWER SYSTEM ENGINEERING
  - TASK APPROPRIATE SERVICE ORGANIZATIONS

SOLICIT INDUSTRY SOLUTIONS AND FUND MOST PROMISING PROPOSALS FOR:

- HIGH EFFICIENCY LOW VOLTAGE POWER CONDITIONING
- HIGHER DENSITY DESIGNS INCLUDING COMPONENT DEVELOPMENT AND QUALIFICATION
- DESIGNS APPLICABLE TO MORE HOSTILE ENVIRONMENTS
- IMPROVED COOLING TECHNIQUES

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POWER SUPPLY TECHNOLOGY WORKING GROUP

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54/7-14

NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: New mission threats, new materials (composites), and new technologies (VHSIC) present unsolved problems of susceptibility with respect to electromagnetic radiation induced transients.

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90)

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)

RESEARCH REDIRECTION: Universities in conjunction with industry must be immediately contracted to develop new shielding techniques and radiation hard circuit topologies appropriate for non-metallic enclosures if we are to meet the survivability requirements of the nineties with respect to lighting, EMP, directed energy weaponry, and data integrity (TEMPEST). Approximately two million dollars would be required for a joint two-year program.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84 - 1M$ } 6.2
FY 85 - 1M$

STANDARDS & INSTRUCTIONS TO BE CHANGED:

DEMONSTRATION PROJECTS: Included in the expenditure above would be several power supply candidate circuits packaged in composite enclosures which would have been characterized, irradiated (continuous monitoring), and retested to prove the "hardness" of these designs. The final report would delineate this data and be made available to all industry/agencies requiring this knowledge to design tomorrows weapon system.

Contact Point: D. Hornbeck

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NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: High efficiency/low voltage power conditioning

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90) Subproject WF 62-585. Synchronous Mosfet rectifier work being done at General Electric for C.D. Caposell.

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)
Grossly Inadequate!

RESEARCH REDIRECTION: Develop improved high current/low voltage rectifier: a) extend present day Schottky technology and b) conduct long term research into materials, processes and geometries. Task should start immediately and extend through 1995. Proposals should be solicited from industry with university participation through industry for item b.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84 - $1X10^6$ - 700K for Task A - 300K for Task B
FY 85 - $1X10^6$ - 500K for Task A - 500K for Task B
FY 86 - $.5X10^6$ - Task B
FY 87 - $.5X10^6$ - Task B

STANDARDS & INSTRUCTIONS TO BE CHANGED: None

DEMONSTRATION PROJECTS: Demonstration of rectifier performance with goals as follows: 0.2V/200A@T_J=100°C, V_R=20V MIN,T_{MAX}=175°C MIN. Suitable operation up to 500KHZ. Hermetically sealed package capable of good termal efficiency and high current distribution. Must be capable of MIL qualification.

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NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Standardization of power supplies provides a great potential for reliability improvements and life-cycle-cost reduction. Experience has shown that the present proliferation of different power supply types would be unnecessary if a coordinated effort were applied to consolidate power supply requirements at the platform level early in development phase.

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90) Navy Standard Power Supply Program is developing a family of standard power supplies for use in the SubACS system. Nad Crane is developing the specifications. IBM is developing the standard power supplies.

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)

RESEARCH REDIRECTION: This sort of standardization of power supplies at the platform level should be expanded to other platforms

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)
$150K to survey and identify candidate weapons systems programs and platforms for power supply standardization. Candidate power supply types should be identified.

STANDARDS & INSTRUCTIONS TO BE CHANGED:

DEMONSTRATION PROJECTS: A study report should be prepared to identify the candidate weapons systems programs and platforms suitable for power supply standardization. The report should also identify basic top-level performance characteristics for the power supply types which are proposed for standardization.

Contact Point: D. Hornbeck

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54/7-18

NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Standardization of equipment enclosures is essential to the standardization of power supplies. Because of the severe impact of form factor, dimensional and thermal constraints imposed by the enclosure, these factors must be firmly established in order to permit the attainment of mature, reliable power supply designs.

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90) The Navy is currently developing a standardd equipment enclosure family for use in the SubACS program. This enclosure family is designed to be compatible with the new Navy standard power supplies

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)
Funded as part of SubACS

RESEARCH REDIRECTION: This approach of equipment enclosure standardization needs to be expanded to other platforms

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category) $100K
To survey and identify suitable weapons systems programs and platforms for equipment enclosure standardization.

STANDARDS & INSTRUCTIONS TO BE CHANGED:

DEMONSTRATION PROJECTS: A study report should be prepared to identify candidate weapons systems and platforms suitable for electronic equipment enclosure standardization. The report should present the form factor and basic characteristics of the equipment enclosure families proposed for standardization.

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54/7-19

NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Power systems engineering

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90)
Believed to be none.

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)
Not applicable.

RESEARCH REDIRECTION: Solicit industry for proposals on the generation of: (1) power systems interface engineering management, (2) power systems interface design requirements to assure compatibility and (3) power systems interface evaluation procedures. The effort should be initiated immediately and include cooperative work with cognizant DoD representatives.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)
FY 84-$500K ($500K-Task 1, $300K-Task 2, $150K-Task 3)
FY 85-$250K ($100K-Task 2, $150K=Task 3)
6.1 Funding Category

STANDARDS & INSTRUCTIONS TO BE CHANGED:

DEMONSTRATION PROJECTS:

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54/7-20

NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Compaction of electronic function and the attendant increase in current density (VHSIC) will but compound the thermal management problems of the nineties. Cooling (component temperature) is the major factor determining power supply reliability.

CURRENT RESEARCH PROGRAM SUMMARY: (FY 83-90)

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category 6.1,6.2 etc)

RESEARCH REDIRECTION: Industry must immediately be contracted to develop phase change and improved conduction techniques for power supply components if we are to have the necessary relative volumetric displacement ratio between the power supply and its utilizing electronics which meet the reliability requirements of the system. Two million dollars over a twenty-four month period is necessary to the end.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84 - 1M$
FY 85 - 1M$ } 6.2

STANDARDS & INSTRUCTIONS TO BE CHANGED:

DEMONSTRATION PROJECTS: Two brassboard power supplies of a low voltage/high current type (lone conductor cooled/one utilizing phase change) would be constructed to facilitate impirical verification of that developed. A final report delineating the data and subsequent recommendations would be made available to all industry/agencies requiring this knowledge to design tomorrow's weapon system.

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85/2-1

AD-A137 525 POWER SUPPLY TECHNOLOGY WORKING GROUP REPORT (IDA/OSD R&M (INSTITUTE FOR..(U) INSTITUTE FOR DEFENSE ANALYSES ALEXANDRIA VA SCIENCE AND TECH.. D HORNBECK AUG 83 2/2

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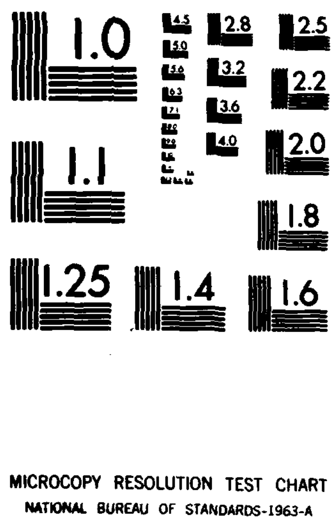
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1.1
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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

NEW TECHNOLOGY ISSUE SUMMARY

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Shortage of Power Supply Engineers

CURRENT RESEARCH FUNDING PROFILE: Research (6.1) and Exploratory Development (6.2) in Power Supply Technology (excluding pulse power) in Universities, less than $200K/year and declining.

RESEARCH REDIRECTION: Increase University Research (6.1) to $200K/year, and Exploratory Development (6.2) to $600K/year to expand the foundations of power supply technology and to provide support to academic programs training graduates needed by industry and the government in power supply technology. Fund a three year demonstration project ($300K, $300K, $200K) of a power supply expert system based on production rules and make available to all DoD (contractor and government) power supply design activities.

NEW FUNDING PROFILE: K$

	FY84	FY85	FY86	FY87	FY88	FY89	
6.1	200	200	200	200	200	200	* * *
6.2	900	900	800	600	600	600	* * *

STANDARDS AND INSTRUCTIONS TO BE CHANGED: Change policy statements and instructions to: 1) Encourage ARO, ONR, and OSR, to encourage research in power supply technology in the Universities and provide grants supporting professors, research assistants, and students studying these disciplines. 2) Provide full reimbursement to Industry for IR&D in power supply technology. 3) Allow direct charge to DoD contracts of time, travel, and fees, of applicable conferences, seminars, and training, of engineers doing power supply or power electronic design (up to 5% of time).

DEMONSTRATION PROJECTS: Design, demonstrate, and make available to DoD design activities, a production rule based expert system to store DoD corporate experience in power supply design, train new technologists, increase efficiency of existing technologists, guide R&D, and serve as a template for similar expert systems.

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85/2-3

REQUEST FOR PROPOSAL

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Under the over-all "umbrella" of power density and cooling, one of the component types that deserves special consideration is the power semi-conductor first level package. The most commonly used packages, and the only ones that are MIL-STD parts, are the TO-3 and the TO-61. The TO-3 which is only available in the 2-level unisolated package requires isolation hardware which is expensive to assemble and subject to breakage and failure. The capacitance from case (hot) to chassis is reasonably large and becomes of greater concern as faster devices (FETs) are used. The TO-61, which is available in isolated cases, has a form factor which is inconsistent with normal/packaging techniques and is very expensive.

CURRENT RESEARCH PROGRAM SURVEY: (FY 83-90)
The only activity that I'm aware of is specific semi-conductor vendors are looking at different approaches. However, they have limited investment funding on their own and cannot get adequate funding from other companies (potential users) to really develop. Chances are that if these companies did go ahead and develop on their own, we would end up with as many package styles as there are companies involved.

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category-6.1, 6.2, etc.)
This is the crux of the problem. To my knowledge there is no one agency that is willing to invest the dollars to come up with a "standard" package for the power semi-conductor.

RESEARCH REDIRECTION: (Who, What, When, How Much)

1. Survey the industry to define the form factor, mounting, heat conduction (imbedded heat pipes should be revisited), electrical isolation (should meet 1400 VDC hi pot), etc. As a result of this survey, generate a specification for the package.

2. Solicit at least three major vendors to construct the package.

3. Have three power semi-conductor manufacturers mount chips in package.

4. Evaluate.

Request for Proposal cont'd

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84	Task 1	50K
FY 84	Task 2	500K
FY 85	Task 3	250K
FY 85	Task 4	250K

STANDARDS AND INSTRUCTIONS TO BE CHANGED: Addition of new "standard" package to MIL-STD parts.

DEMONSTRATION PROJECTS: (Description, Cost, Schedule)
Twenty samples each from three different power semi-conductor vendors will be procured where each vendor mounts his device (preferably a power MOSFET) in the packages obtained from two or more sources. Samples will be subjected to electrical and environmental testing to verify conformance to requirements established and to characterize physical evaluation, including destructive analysis on a limited sample, will be performed to assure compatibility of package and vendor chip mounting processes.

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REQUEST FOR PROPOSAL

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: VHSIC technologies leading to much lower voltage (0.7 to 3.0 Vdc) requirements difficult to achieve with current power regulators and distribution topologies without unacceptable voltage variations and noise.

CURRENT RESEARCH PROGRAM SURVEY: (FY 83-90)

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category- 6.1, 6.2, etc.)

RESEARCH REDIRECTION: (Who, What, When, How Much)
Solicit proposals from industry for design and development of (1) "on chip" post-regulator design suitable for VHSIC die and would provide "small correction regulation" to low voltage power enabling more forgiving power system requirements; and (2) single die regulator design and fabrication of test devices - the primary use of this device would be as part of a multiple die package including several VLSI devices; the intention of the device would be to regulate low voltage power required by several adjacent VLSI chips.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84	0.2M$	
FY 85	0.3M$	6.2

DEMONSTRATION PROJECTS: (Description, Cost, Schedule)

Demonstration of "on-board" regulator test site.

Demonstration by vendor of single die regulator.

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85/2-6

REQUEST FOR PROPOSAL

TECHNOLOGY AREA: Power Supply Technology Working Group

ISSUE: Power Supply Density

CURRENT RESEARCH PROGRAM SURVEY: (FY 83-90)

Some items discussed in WF 62-585, by C. D. Caposell.

CURRENT RESEARCH FUNDING PROFILE: (FY 83-90, $M, Funding Category- 6.1, 6.2, etc.)

Adequate funding not provided for above.

RESEARCH REDIRECTION: (Who, What, When, How Much)

Solicit industry to:

a. Continue investigation of high frequency power conditioning technology, including high density current distribution, at the university level.

b. Develop high frequency (500 KHz) lower loss materials for power transformers; high DC saturation capability inductor materials; low ESR, high CV product capacitors for both input energy storage and output filtering; and switching devices having higher voltage, current, and speed rating.

NEW FUNDING PROFILE: (FY 83-90, $M, Funding Category)

FY 84	$1x10^6$$	Task A = 250K	Each Year
FY 85	$1x10^6$$	Task B = 750K	
FY 86	$1x10^6$$		
FY 87	$1x10^6$$		

STANDARDS AND INSTRUCTIONS TO BE CHANGED:

None

DEMONSTRATION PROJECTS: (Description, Cost, Schedule)
Performance of the components and topologies developed shall be demonstrated in a candidate prototype power supply. Specific requirements shall be determined by soliciting industry. Initial demonstration of improved components to be one year after start. Follow on demonstrations yearly.

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85/2-7

REQUEST FOR PROPOSAL

This request for a proposal is directed primarily at Universities and at industry where advanced work is being done on power conditioning topology and analysis. The objective of this task is to develop, analyze and evaluate topologies leading to higher density switchmode power supplies. The information generated should be available to the public, and if appropriate, should be published.

The proposal should address the following as a minimum:

1. Suggested specification for a low voltage military power supply

2. Plan to upgrade specification to represent widespread future needs

3. Preliminary list of topologies to be evaluated and evaluation criteria

4. Analysis to be applied

5. Proposed method of disseminating information learned

In all of the above, particular attention should be paid to the low voltage anticipated to be required with the advent of VHSIC and the distribution problems associated with that low voltage.

It is anticipated that this effort will extend over a two year interval starting in 1984.

Additional background material is provided in the following documents which are enclosed.

A. Report of the Power Supply Technology Working Group. (This task is covered under item A1 in Power Supply Density, page 3-5.)

B. New Technology Issue Summary - Power Supply Density (Referred to here as Task A.)

REQUEST FOR PROPOSAL

This request for a proposal is directed at organizations with experience in the design and application of switching mode power supplies or in the development and production of components for use in switched mode power supplies. The primary thrust of this effort is directed at the continuing development and qualifications of the unique components used in these power supplies in a direction compatible with increased power output density and reliability.

Specifically, the components to be addressed are:

Input inductors

Input capacitors

High frequency transformers

Output inductors

Output capacitors

Power switching transistors

The proposal should include the following as a minimum:

1. Specification for these devices that represent state of the art.
2. Improved specifications that represent tentative goals for future requirements.
3. A plan to be implemented after contract award that will result in updated goals that are consistent with industry and DoD future needs.
4. The techniques planned to be investigated to achieve the goals.
5. Plans for military qualifications or equivalent.

Proposals covering some, but not all, of the component types listed will be considered.

It is anticipated that this component development effort will extend over approximately a two year interval starting in 1984.

Additional background material is provided in the following documents which are enclosed.

A. Report of the Power Supply Technology Working Group (This task is covered under items A2 and A3 in Power Supply Density - page 3-5.)

B. New Technology Issue Summary - Power Supply Density (Referred to here as Task B.)

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