The Power Electronics Conference '89℠

Proceedings of the conference held in Santa Clara, California February 7-9, 1989

Sponsored by:

psma power sources manufacturers association

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TABLE OF CONTENTS

POWER SUPPLY RELIABILITY

PER NAVMAT P4855-1

by

Dwight O. Monteith, Jr.

DOM Engineering Services, Inc.

THE POWER SUPPLY A Reliability Problem Solved?

With the introduction of the recent update of the Navy's reliability document NAVSO P-4855-1A NAVY POWER SUPPLY RELIABILITY - Design and Manufacturing Guidelines [1][2], we can ask "Has the power supply reliability problem been solved?" This paper is directed to answering this question.

We will look at the efforts to solve the power supply reliability problem in four sections: the development of NAVMAT P4855-1, the lessons learned on the AN/BQQ-5, the analysis of measured reliability of shipboard power supplies, and observations on the application of the Navy guidelines. Finally we will try to digest this information to form a concise answer the question.

Part of the information contained herein was presented at the National Security Industrial Association conference on Defense Acquisition in October, 1986 by members of the Navy/Industry Ad Hoc Committee on Power Supply Reliability: Donald Hornbeck, Chairman; Bill Singleton, and Dwight Monteith. The author is solely responsible for the pointed observations and viewpoints presented in the last two sections.

DEVELOPMENT OF NAVMAT P4855-1

After examining several Navy programs, W.J. Willoughby Jr., Deputy Chief of Naval Material, Reliability, Maintainability and Quality Assurance, noted that "fleet readiness could be improved as much as 20% if electronic power supplies met their specified MTBFs in service use." The replies to 170 letters to power supply manufacturers and users pointed up four major problem areas: inadequate design analysis and derating, inadequate manufacturing screening, late design specification, and unqualified low bidders.

In April 1981, the Navy chartered the Navy/Industry Power Supply Ad Hoc committee to address these problems and develop guidelines for future programs. In December 1982 the results of the committee's work was published: NAVMAT P4855-1. This document presents guidelines directed at the two most critical areas affecting power supply reliability: Program Management, and Design & Manufacturing.

Program Management

The guidelines for program management are directed to

Development schedule and cost,
Output power density,
Input power specifications,
Power supply standardization, and
Design reviews.

Some the committee observations which led to these guidelines are as follows:

Development schedule/cost issues;

-power supplies traditionally are left until last in electronic system design,

-power supplies presumed low technical risk which leads to insufficient funding and buy-in by inexperienced, unqualified firms,

-typical labor for power supply development is 6600 manhours over an 18 month schedule.

The committee also identified critical areas which impact schedule/cost for program management concern:

power subsystem concerns;

-power subsystem is system and program critical,
-power subsystem design is complex,
-power subsystem is relatively high cost,
-it requires system integration to prove performance,
-it is usually the lowest priority subsystem,
-it is usually last subsystem to be specified, and
-it receives least management attention until .

power subsystem development concerns;

-power subsystem needs more systems engineering involvement,

-power subsystem specs grow and change as system evolves,

-power subsystem requirements are specified near or beyond state-of-the art,

-power supply specifications demand unrealistic performance,

-development program imposes unrealizable schedules, and usually

-serious performance problems are found after system integration and test.

The guidelines were developed in response to the committee's recommendations for

-increased systems and equipment engineering involvement in defining the power subsystem and system integration and test

-earlier system partitioning, definition and specification related to the power subsystem

-more realistic requirements for power subsystem equipment

-centralize responsibility for power conversion equipment

-develop better understanding of vendor capabilities and awareness of past performance

-more management attention to recognize problems early and identify alternative courses of action

-alter contractual conditions through statements of work, contracting practices, source selection, technical resources and program management

-standardize requirements and design

The Navy's response to the committee's recommendations is to

-emphasize power supply reliability,

-seek elimination of power supplies as a serious driver of in-fleet readiness,

-inform DOD that power supply not unique Navy problem,

-seek tri-service support of design and manufacturing guidelines in P4855-1 which will result in more reliable power supplies, and

-propose that power supply standardization should be considered a tri-service issue.

Output power density requirements were identified as a high risk area in power subsystem development. The committee recognized that

-although higher densities are possible using newer design and construction techniques, power supply reliability can be higher as well; however

-output power density exceeding 4 w/cu.in. should trigger in-depth design review by program management to ascertain that reliability is not compromised.

Power density recommendations have been revised, updated, and expanded in the latest revision to the NAVMAT guidelines. Realistic power density goals are the responsibility of program management.

The input power interface has been identified as one of the more critical areas affecting the reliability of the system. The development of fast responding high bandwidth switched mode power supplies coupled with tough EMI requirements and casual power distribution design is an invitation to catastrophic system failure resulting from the power subsystem interface. We recommend sustained worst-case brown-out power system tests to convince naive program managers.

The committee recommends that there be more standardization in power supplies to achieve improved reliability. Standardization includes specification requirements, performance requirements, and physical configuration.

Power supply requirements which should be considered for standardization are

-EMI,

-Environmental,

-Reliability,

-Nuclear hardness,

-Package density,

-Cooling,

-Documentation, and

-Power throughput.

Performance requirements which should be standardized are

-Regulation,

-Load dynamics,

-Transients,

-Noise and ripple, and

-Efficiency.

Program management is responsible for design reviews. The committee identified design reviews as being critical to the development of reliable power supplies. In order for design reviews to be effective, they must be timely, expertly staffed and have an effective agenda. The Navy guidelines provide detailed checklists for design reviews which emphasize the major contributors affecting reliability and maintainability. We recommend that these checklists be modified and tailored to address the peculiar features of each power supply type and application environment. Agendas must be made available with sufficient lead-time so that all participants can arrive prepared.

The design review checklists cover the preliminary design review, critical design review, and production readiness review. Areas of concern addressed by the checklists are

- -electrical design,
- -mechanical design,
- -thermal design,
- -reliability,
- -producibility, and
- -maintainability.

Design and Manufacturing

The Navy guidelines for design and manufacturing are organized to address the following areas:

- -Design for reliability,
- -Design for manufacturing,
- -Design verification testing,
- -Manufacturing considerations, and
- -Environmental stress screening.

The guidelines are tailored to the requirements of switched mode power supplies. Areas considered are

- -Circuit design must avoid common causes of power supply failure,
- -Criteria for component selection and application, and
- -Manufacturing processes and environmental stress screening.

Critical reliability drivers are

- -Application of unproven circuit topologies,
- -Inadequate design analysis and component stress derating,
- -Inadequate provisions for component cooling,
- -Inadequate thermal and mechanical analysis,
- -Lack of worst-case and sneak circuit analysis, and
- -use of unproven packaging/manufacturing techniques.

The Navy's guidelines are tough, justified by analysis, and verified by experience.

LESSONS LEARNED ON THE AN/BQQ-5

A large step in the development of the technical approach to the solution of the shipboard reliability of electronic power supplies was performed by NAVSEA and IBM Federal Systems, Manassas with the AN/BQQ-5 program [3].

Most of these lessons have been incorporated in on form or another in the design review guidelines and checklists.

The lessons learned can be applied to produce power supplies with MTBFs approaching 35 years.

This can be achieved by management and engineering commitment to designed-In Quality. This approach requires:

- -"First-Pass" design by experienced people having adequate budget and schedule resources,
- -In-Depth review by knowledgeable people who share in the product's ownership,
- -Producibility of the design is a first priority consideration (automated ease of assembly/test) at the project's onset, and
- -Life-Cycle-Cost or cost-of-ownership analysis must show costs which are less than that allocated in the procurement requirements.

The AN/BQQ-5 experience uncovered new failure mechanisms which must be considered in all future designs:

-Forward breakdown of bipolar switch transistors (current crowding/lattice damage) is a wear-out mechanism which can degrade in-service reliability.

-Switch transistor failure rate increases at a greater rate as the load line approaches the SOA (safe operating area) limit,

-Transformer core saturation resulting from bipolar storage time variation with life/temperature,

-Work hardening of flying leads,

-Distortion of TO3 package at conduction cooling interface,

-Chloride ion contamination aluminum electrolytic capacitors,

-Capacitor electrolyte evaporation (epoxy end seals),

-Capacitor hot spot temperature problems (ripple current dissipation and unequal current sharing in parallel circuits),

-Capacitor inrush current limiting (surge testing of tantalum),

-Quality control required for thermal compound and resultant loss of thermal interface contact pressure,

-Switch transistor forward Beta degradation resulting from too large Ib2,

-Power supply/EMI filter interface compatibility,

-Schottky barrier breakdown(CdV/dT, snubbing),

-corrosion degradation of connectors, contamination of high Z terminals, and

-component selection/screening/process monitoring

Preliminary and Critical Design Reviews must address

-circuit topology optimization analysis,

-component application (minimize Tj's),

-comprehensive stress analysis analyses (electrical, thermal, environmental)

Post design activities which are critical to achieving power supply reliability are

-PVT (performance verification testing),

-EQT (environmental qualification testing),

-TAAF (test/analyze and fix --->at elevated stress levels),

-ATP (acceptance test procedure) must include burn-in of fully loaded and continuously monitored power supply operation cycled over extreme temperature range,

-Failure reporting and trend analysis reporting for early corrective action,

-In-process and In-production PVT/EQT to ensure quality and consistency over time/product life.

ANALYSIS OF MEASURED SHIPBOARD DATA

In 1985 an effort was initiated by NAVSEA to determine the effectiveness of the lessons learned on the AN/BQQ-5 program and incorporated into NAVMAT P-4855-1. The detailed results of this study are available in reference [4].

The power supply reliability data was collected for the years 1976 through 1985. The measured data was collected from a aggregate of 20,000,000 unit-hours of power supply operation.