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NAVSO P-3641: Navy Power Supply Reliability Design & Mfg Guidelines (NAVMAT P4855-1)

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3.3 OUTPUT POWER DENSITY - LOW VOLTAGE

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Output power density and reliability are closely linked, since, with the same techniques and components, an increase in output power density is often accompanied by a decrease in reliability due to increased temperature and decreased component derating. However, a new design to the same requirements using a newer topology, fewer components and new packaging techniques can result in improved reliability. This section discusses the levels of output power density of reliable low-voltage power supply designs which are generally achievable using standard switching-mode power supply components and topologies widely available in industry today. These levels are inadequate for many new applications. Future output power density requirements imposed by military electronics have been examined and the reliability values which may be considered realistic for such power supplies are estimated. Advanced design techniques and nonstandard components which must be utilized to achieve the joint objectives of higher output power density and high reliability are summarized.

Program management should be aware of the complex interrelationships between output power density and reliability to ensure that a proper design approach has been implemented.

DETERMINING FACTORS - LOW VOLTAGE

It is generally recognized that a number of specification-imposed design factors adversely affect low-voltage power supply reliability by increasing the output power density beyond what is inherent in the technology. These factors may be broadly grouped into mechanical and electrical categories.

Mechanical Design Considerations

Allowable volume should be maximized. Failure to do so will result in a design which runs hotter, operates with greater component stress and uses more nonstandard components.

Conduction cooling to a heat exchanger is the preferred method for heat removal, since it minimizes the power supply volume and is applicable for tactical applications.

Electrical Design Considerations

Although EMI is always of importance, the allowable level in each case depends upon the application and system requirements. The specification of "full MIL- STD-461 compliance" at the power supply level imposes a significant burden on the designer due to the volume within the supply which must be dedicated to EMI filtering.

Two areas should be addressed so as to minimize the impact on output power density due to EMI requirements: (1) the EMI specification should be tailored to actual system requirements, and (2) equipment, cabinet or system EMI filtering should be employed wherever possible.

When tailoring the EMI specification, consideration should be given to providing up to 10 dB relaxation of the CE-01 narrowband limits between the first and tenth harmonic of the power line frequency at the system level and relaxation of the RE-01 requirement at the individual power supply level. The former allows the power supply designer flexibility in the use of multiphase rectification and the placement of filter resonances.

Accepting low frequency EMI and line-frequency harmonics responsibility at the equipment, cabinet or system level will result in significant power supply output power density improvement. Any equipment/system level EMI power line filter can cause instability or performance degradation of the power supplies. The designer of the power supply must specify the characteristics of the equipment/system level power line filters that, working in conjunction with the filters internal to the power supply, will ensure equipment/system EMI requirements are met without degradation of power supply characteristics. This requires verification that the combination is satisfactory by both an open loop stability analysis that includes the specified filter and by empirical measurements. The required techniques are described in MIL-HDBK-241.

Shipboard systems have special requirements, not imposed on aircraft or shore systems, to limit the harmonic currents flowing in the ship electrical system. These requirements are imposed by MIL-STD-1399 Section 300 which limits individual harmonic line currents to 3%. Present techniques for meeting this requirement employ either multiphase rectification with line-frequency magnetics or multiswitching techniques with increased complexity and reduced efficiency. Imposition of the 3% harmonic line current requirement at the power supply level, with its resultant size, weight, cost and reliability penalties, should be carefully weighed against the advantages of providing a system level solution, such as DC prime power.

Two methods of meeting the more stringent shipboard requirement are shown. The first method approaches within 6 dB of meeting the 3% harmonic current requirement. This method uses multiphase rectification on the secondary of a stepdown power transformer and a single section L-C filter. The second method replaces the filter with an electronic line conditioner to fully meet the 3% harmonic current requirement. The relative factors of this method could be greatly improved by using one of the numerous topologies that are available, whereby the line conditioning and power conversion may be integrated.

As can be seen, there is a substantial weight and volume impact in meeting the MIL-STD-1399 Section 300 requirement. A "brute force" EMI filter used to meet the requirement could be larger than the power supply. Since the impact on power supplies designed to meet the shipboard 3% harmonic current requirement is both severe and not often addressed by many program managers, additional information on the subject is provided in Appendix C.

Some systems, particularly those containing signal processing memories, require an electrical warning signal in advance of an output power failure. This warning signal is usually generated at the time prime power degrades below a predetermined level, whereas the output power continues for a period dependent upon the energy stored within the power supply. Energy storage requires volume, so it is advantageous from the standpoint of power density and reliability to specify the minimum hold-up time required. A desirable technique which should be considered to minimize stored energy is partitioning system power into critical (requiring hold-up) and noncritical outputs.

Performance Monitor/Fault Location (PMFL) and Built-In Test Equipment (BITE) circuitry can reduce reliability by increasing component count. Wherever possible, output monitoring should be performed at the system level, minimizing diagnostic circuitry within the power supply.

The following alternatives to requirements which impact output power density should be carefully considered:

(1) Prime power switching and input/output fusing

Provide prime power from the system circuit breaker. Control output power with logic signals and protect outputs with electronic current limiting inherent in most power supply circuit designs. This eliminates the bulky and sometimes inaccessible switches, circuit breakers and fuses from the supply.

(2) Crowbar overvoltage protection

Retain overvoltage protection, but eliminate the crowbar requirement. Positive protection for most switching-mode power supplies may be provided by modifying or terminating the switching action. This eliminates the large, seldom-actuated, silicon controlled rectifier (SCR) crowbar devices and the associated circuitry.

(3) Isolated multiple outputs

Allow all outputs to be connected to a common point within the power supply. Some systems require isolation to eliminate ground-loop problems, with the output returns ultimately connected at remote points. In these systems, specify the maximum voltage difference between returns. This will minimize the number of internal auxiliary power supplies needed for post regulation circuitry.

TYPICAL LEVELS TODAY

Output power density is most often expressed in terms of "watts per cubic inch" where the power is rated output power and the volume is total power supply volume, including cooling fins or fan (if so equipped) and integral EMI filter. Because of the permutations of output power, prime power and diversity of output configurations and voltages, the parameters for this section have been restricted to those in Table 3-2 which describe the low-voltage baseline power supply characteristics.

Reliability is a function of many factors including the ratio of operating to rated stress, temperature and environment. Typical MTBF data is presented in Table 3-3 for various environmental applications. These MTBF figures should not be used as guides for specifying requirements, but rather as thresholds above which program management must be especially attentive to the development schedule and cost requirements (Section 3.2) and rigorous application of the design and manufacturing guidelines (Section 4).

Figures 3-2 and 3-3 display the range of power densities in watts/cubic inch and watts/pound which are presently achievable for power supplies with the baseline characteristics of Table 3-3, employing standard design and construction techniques. For power supplies exhibiting greater complexity, it is suggested that the worksheet in Appendix D be utilized to more accurately predict the corrected power density expressed in terms of a Power Density Index. The worksheet in Appendix D may be applied to a personal computer to obtain an interactive spreadsheet. This allows the user to make "what-if" changes in power supply characteristics and packaging volume which directly affect density, complexity, reliability, maintainability and development cost. Actual package density, reflecting standard packaging techniques, remains relatively constant in the range of 0.04 to 0.06 pounds per cubic inch.

FUTURE REQUIREMENTS

Rapid technological advances in computer and signal processing electronics packaging, utilizing large-scale integrated (LSI) circuits, very-large-scale integrated (VLSI) circuits and very-high-speed integrated circuits (VHSIC) have resulted in significant reductions in the volume required to implement complex electronic functions. The technological advances have not been as great in power supply electronics. Reliable power supplies with power densities of 1 to 6 watts per cubic inch will not satisfy the need of sophisticated systems now being designed, much less those in the near future.

System volume required for the power supply is a function of both the system thermal density and the output power density of the power supply. Figure 3-4 presents a graphic illustration of the percentage of system volume required by the power supply for various system load densities. As the system thermal density increases, it is obvious that the power supply density must also increase to avoid a condition where the majority of the system volume is occupied by the power supply. The following is the methodology for using Figure 3-4 in conjunction with the worksheet in Appendix D when system volume and power are known.

Step 1: Select System Load Density Curve.

Step 2: Determine Power Supply Volume as a percentage of System Volume from:

```
System Volume - Load Volume

----------------------------------------   X  100

        Total System Volume
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Step 3: Locate Power Supply Output Density from the intersection of the "Supply % of System Volume" with the selected System Load Density Curve.

Step 4: Compare the determined Power Supply Density with Calculation from Appendix D to assess effort/risk.

If the results are unacceptable, perform tradeoffs and repeat.

TECHNIQUES FOR HIGHER OUTPUT POWER DENSITY

This section highlights some of the techniques which are currently being used to obtain higher output power densities. Power supplies exceeding 6 watts per cubic inch are available from industry today and even higher power densities are currently under development. Increasing switching frequencies from 20-40 kHz to 100-500 kHz or higher is the most significant approach to increasing power density at this time. This reduces the size of the magnetics and filter capacitors.

Magnetics

A major design effort is required for the development of magnetic components used in power supplies. As the switching frequency increases, the power transformer becomes a greater design challenge. If the flux density is restricted to reduce self-heating, most of the common core materials (i.e., ferrite, powdered iron, tape core and others) are suitable at switching frequencies below 200 kHz.

While high-frequency magnetic components can be wound with standard magnet wire, better copper utilization is gained with either Litz wire, multifilar magnet wire, or copper ribbon. These materials reduce skin effects, which become increasingly important above 100 kHz.

A challenge lies in winding higher frequency magnetics, not only to reduce the leakage inductance but also to produce symmetrical and predictable secondary voltages.

Several techniques are available, including interleaving, multifilar windings, twisted wires and coaxial transmission lines.