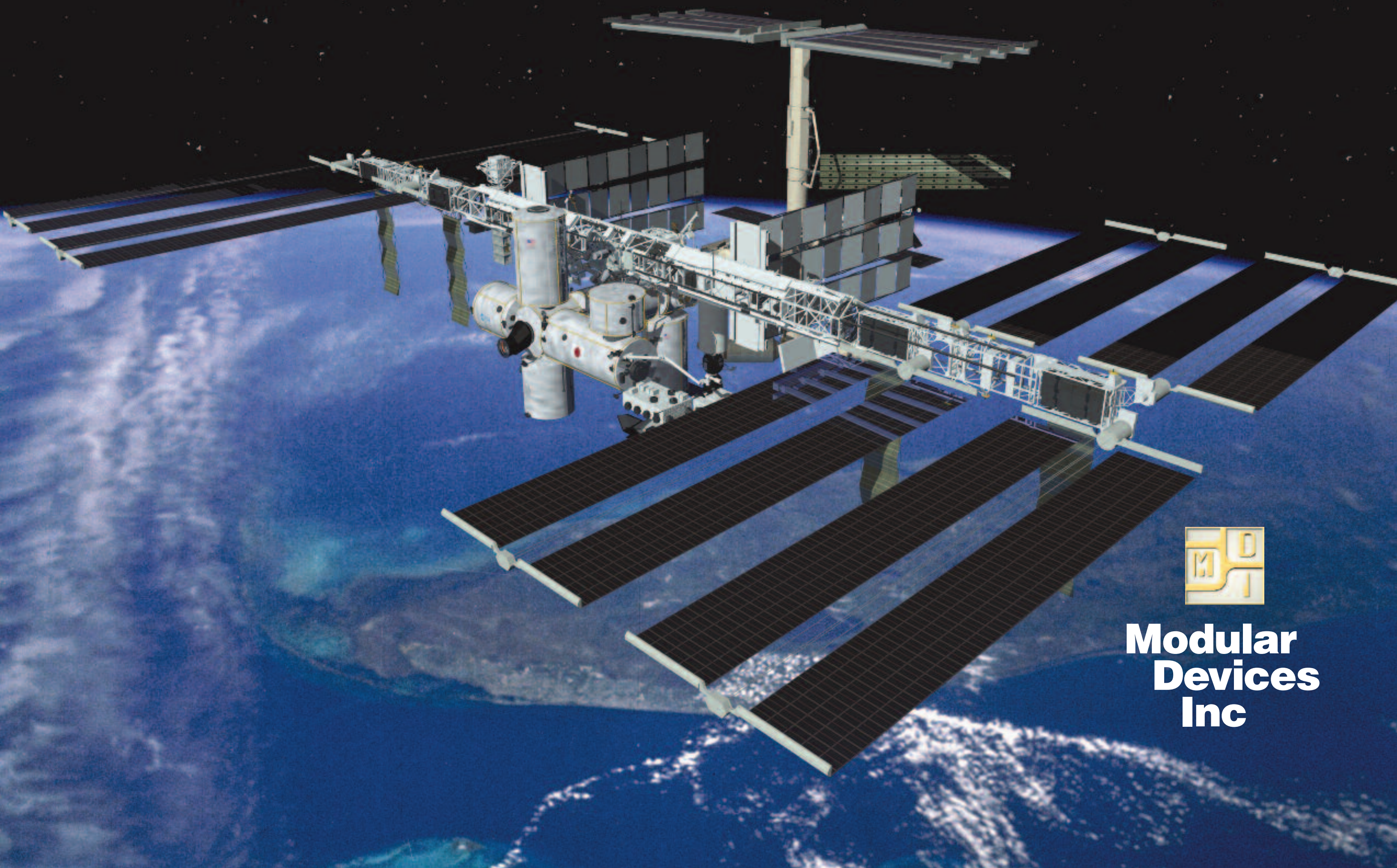
SPACE
Power Supplies

Assemblies of Hybrid Modules



Modular Devices Inc

Space Power Supplies

Assemblies of Hybrid Modules

Overview

Hybrid DC/DC converter modules dominate the design of current spacecraft power supplies. The reasons for this are:

- Hybrid DC/DC Converter Modules reduce size, weight and development cost
- Hybrid DC/DC Converter Modules cut design and manufacturing time
- Most customers do not have the specialized staff to design, analyze and manufacture the equivalent module function in house.

Standard catalog listed hybrid DC/DC converters satisfy many space applications. However, they can be a problem for some applications, either because the program has special requirements or the module manufacturers will neither give full design disclosure nor make design driven changes within the module.

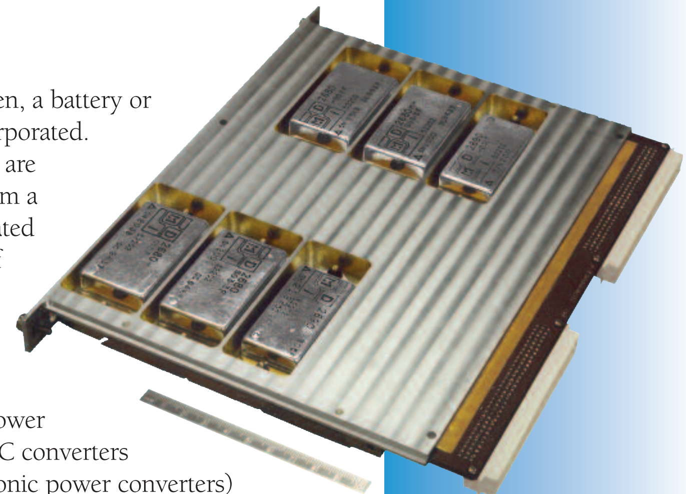
MDI is a unique supplier of space power supplies because MDI not only manufactures state of the art hybrid DC/DC converter modules, but MDI also integrates these modules into space worthy power supply systems. MDI believes in an open design disclosure philosophy and will customize the modules for its customers. MDI is the best choice for both modules and complete space power supplies.

Designing the Space Power Supply

In the space environment there is no atmosphere and heat may be removed only through conduction to an ultimate radiator. This requires thermal testing to be performed under high vacuum conditions.

Also, because of the lack of an atmosphere, the nuclear radiation environment is severe. Natural radiation effects may include total ionizing dose, single event effects of energetic particles, proton and neutron fluence. Man made nuclear effects such as prompt dose and SGEMP may also be present. The orbit and the amount of shielding provided by the spacecraft are additional variables to be considered.

Spacecraft and satellites have self contained electrical systems where the power source is usually solar cell arrays, sometimes radioisotope thermal generators. Often, a battery or fuel cell is incorporated. These elements are regulated to form a relatively regulated electrical bus of limited power capacity. The equipment on the spacecraft will then use power supplies, DC/DC converters or EPCs (electronic power converters) to provide power for the many types of equipment on the satellite.



Assembly of 30 watt converters from Mars Pathfinder— Photo Courtesy JPL

The important issue facing space power supply applications is that extremely high reliability must be achieved in a harsh environment with quantities of power supplies that are relatively low. The low quantities discourage learning curve and experience improvements.

The methods used today for designing and producing space power supplies are intended to capture past lessons learned to overcome the burden of small production quantities.

One method of capturing past lessons learned is the use of "heritage" designs. These are designs and processes that have been successfully used on other spacecraft. To the extent that the new application provides the same type of environment as the heritage application, there is benefit from this approach. As time passes between the heritage design and the present design, the benefit decreases. This is because the heritage parts become more difficult to get, heritage processes may have changed, and finally, heritage employees throughout the supply chain are no longer involved.

Piece parts on preferred parts lists become harder and harder to get as years pass. Many of the components may be commercially obsolete, leading to so called "high rel" parts actually coming from the scrap barrel. Equipment designed with obsolete, but preferred parts becomes heavier and larger than equipment designed with up to date parts.

A successful design takes what's best from heritage combined with the careful use of what's best from current practice.

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Space power supplies are unique because:

- Quantities are low, but reliability must be high
- The unique space environment is harsher than terrestrial environment

The Peripheral Circuitry

To make a complete space power supply, additional functional elements are commonly added to the basic DC/DC converter module functions.

On the power input side, these functions can include bus selection relays, transient suppression, input power fuses, input current limiters, inrush current limiters, reverse polarity protection, input undervoltage lockouts and additional EMI filtering and damping.

On the output side, these functions can include post filtering, post regulation, output cross strapping, output switching, output crowbars, output voltage monitoring and output decoupling capacitors.

Control and telemetry functions can include standby and inhibit control, fast shutdown for nuclear events, voltage telemetry, current telemetry, temperature telemetry, synchronization inputs and outputs. These additional circuit functions match the capabilities of the "bare bones" DC/DC converter modules to the requirements of the customer specifications.

Piece Part Selection and Qualification

The ultimate objective of piece parts selection is to improve the reliability of the space power supply. Parts applications review is the responsibility of the Component Engineer. One of the distinguishing features of space power supplies is the care with which piece parts are selected. The power supply design is reviewed in order to maximize the use of preferred space grade parts. Preferred parts lists may be MDI generated, customer generated or established by the government (such as NASA PPL-21).

Various preferred parts lists (PPLs) exist, many derived from MIL-STD-975. The advantage of using parts from these lists is that they represent mature parts with considerable heritage. Preferred parts lists solely based on heritage may lag the present day by twenty to thirty years. Many of the components may be commercially obsolete, leading to lower reliability. The equipment becomes heavier and larger, leading to other design compromises. The manufacturing processes to make the piece parts accumulate change over the years, invisible to the activities maintaining the preferred parts list.

The motivation for these types of designs is not only using parts on the PPLs, but also the monetary costs for minimum lot costs of the parts.

Very often, large excess amounts of space qualified piece parts have been purchased on earlier contracts, and the designers are mandated to use these parts until stock on hand is depleted. The resulting designs may be non-optimal.

Parts Qualification

Another important technique to improve reliability is the separate qualification of piece parts. This may be performed on discrete parts as well as hybrid and chip elements. The piece parts are qualified to environmental levels much higher than they will experience within the completed assembly, giving a factor of safety to the designer. Designs sometimes are less reliable than they might be because some aspect affecting reliability has been overlooked. This can be avoided by complete review and scrutiny. This oversight requirement can be satisfied by the submission of complete and comprehensive drawing packages. This is also necessary to assure control of the configuration.

Competitive space power supplies will inevitably use some quantity of what are termed "non-standard" parts. This may include parts that are military standard but not on the PPL, or parts that are custom, such as magnetics. For a full hybrid design, all chip components may be considered non-standard.

Materials Application Usage List

Many spacecraft applications contain optical and other systems that are affected by out gassing of volatile materials. Therefore, all materials must be categorized and selected for low out gassing.

To control the materials used in the space power supply, a materials application usage list is generated which contains all items used within the power supply, as well as all items used to assemble or clean the power supply. This list also lists the TVCM (total volatile condensing mass) of each item.

Analysis

To supplement or as an adjunct to any overall testing program, various analyses should be performed. These analyses verify that all piece parts are properly applied and that the customer's overall expectations for reliability will be achieved.

Analysis proves that the space power supply meets its requirements. Although many aspects of the space power supply's design are best characterized by testing, some areas also demand substantiation by analysis, which establishes the design margins. In the development of a space power supply, the most frequently required analyses are circuit (SPICE), electrical stress, thermal, derating, worse case, MTBF, FMECA, EMI, environmental and radiation effects. There is a hierarchy to these analyses, and just like in college courses, many have prerequisites.

The Link between Analysis and Engineering Changes

Although the goal of analysis is to prove that the space power supply meets the customer's requirements, what analysis inevitably shows is that the customer's requirements can be met with some modification of the initial design.

When using hybrid DC/DC Converters as part of a space power supply, visibility into the modules is usually mandatory because it is needed for

- stability assessment
- derating analysis
- thermal analysis
- worse case analysis
- radiation assessment

It should be anticipated that issues arising from analyses to a customer's specific requirements may require a design change within the hybrid DC/DC Converter modules.

SPICE Models

The fundamental analysis is the circuit analysis, which usually employs a form of SPICE Modeling. The SPICE Model establishes the operating points and provides a sound analytical framework for later work. For a power supply, the SPICE Model gives data on the stability of the closed loop.

Stress Analysis

Typical Slice Design of a large assembly—Photo Courtesy Geolite

Using the SPICE Model to confirm operating points over a range of conditions, the worse case electrical stress for each part can be computed. Many parts have several parameters which must be assessed. For example, for a capacitor, working voltage as well as ripple current must be determined. For a resistor, it is power rating as well as maximum current or voltage. For diodes, it may be reverse voltage, reverse current, forward current and AC effects. The electrical stress information for all of the parts feeds into the thermal, derating and worse case analyses.

Thermal Analysis

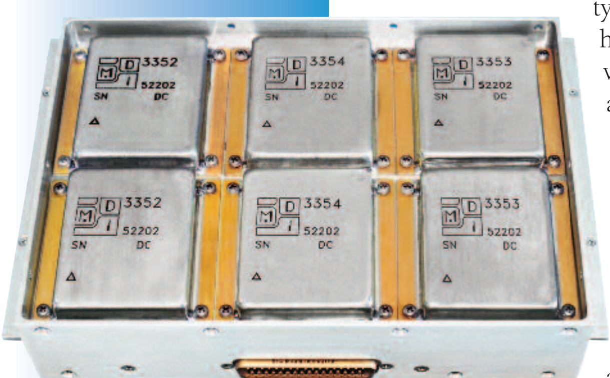
For the thermal analysis, the power dissipation for each part is computed. The goal of the thermal analysis is to determine how hot each component gets and verify that the computed temperatures meet design requirements. Since space power supplies are required to operate in vacuum conditions, heat removal is limited to conductive cooling and radiation. Practically, radiation is not significant. One of the most useful tools for thermal analysis is the finite element analysis technique. This is represented by programs such as ALGOR FEA. The method of analysis proceeds in the following sequence. All heat paths are characterized. The physical construction is broken up into infinitesimal elements and the heat flow is computed by matrix manipulation. The resulting output of these programs is a node listing which can be portrayed as isothermal lines. This allows the hot spot temperatures to be readily determined.

If a component exceeds its required temperature, the thermal design can be iterated and the analysis re-run.

Derating Analysis

The thermal analysis and electrical stress analysis feed into the derating analysis. Overall specifications, such as MIL-STD-975 and related specifications, impose derating limits for piece part application, many being temperature dependent. The derating analysis is usually in tabular form, comparing each piece part's rating with its stress level. Often a customer will only explicitly need the derating analysis, however, the SPICE Model, electrical stress and thermal analysis are all required for a meaningful input.

A worse case analysis may take the SPICE Model and vary the tolerances of the various components in a random way. This is also called Monte Carlo analysis. Or, the drift of component tolerances may be assessed for an End of Life analysis. This type of analysis predicts how the power supply will operate at the end of a long duration, for example a 30 year Space Station application.



Six 80 watt hybrids in VME chassis for Space Shuttle/Space Station

MTBF Analysis

MTBF (Mean Time Before Failure) analyses predict the failure rate of the space power supply. Using mostly experiential information and methods derived from MIL-HDB-217, and drawing on the temperature and electrical stress levels derived from earlier analyses, the failure rate may be computed. Computer programs to perform the computation are available. Simplified assessments using only the parts count are possible. However, they are not as precise as the actual stress method. Clearly, the electrical stress and thermal stress of the piece parts must be determined to accurately predict MTBF.

FMECA (Failure Modes Effects Criticality Analysis) is often required to be performed for a space power supply, as this allows more reliable units to be achieved. A knowledge of the functional operation as well as the failure rate of each piece part is needed to prepare a FMECA. Therefore, the MTBF and all subsidiary analyses are required for a FMECA.

EMI Analysis

EMI analyses are often required as an adjunct to testing. The benefit of an EMI analysis is that it may be performed before hardware is constructed, or may assess areas that may be difficult or costly to test. EMI analyses are often based on SPICE Models. Filter configurations may be readily modeled, as well as parasitic effects. This gives the designer a look ahead so that the design can anticipate and solve EMI problems before the (possible) long lead hardware is assembled.

Radiation Effects Analyses

Radiation effects analyses can include shielding analysis, total ionizing dose analysis, low dose rate analysis, proton fluence analysis, transient neutron analysis, photo-current burn out analysis, Single Event Upset analysis and EMP analysis.

A shielding analysis starts with the total ionizing dose impinging on the power supply. Then, the shielding effects of the mechanical structure are determined to arrive at the total ionizing dose experienced at each piece part. If additional shielding is necessary, this analysis determines the amount and location.

A total ionizing dose analysis considers the known effects of radiation on piece parts, such as the Vgs shift in power MOSFETs and the leakage current increases in semiconductors due to radiation induced defects. Pertinent post radiation parameters for each part are determined by researching parts data bases or from radiation lot acceptance test results. These effects of part degradation are analyzed using the SPICE Model and the worse case analysis.

Certain parts can be susceptible to very low dose rate effects. A low dose rate analysis examines potentially susceptible parts for adequacy and margin.

Ionizing radiation from proton or neutron fluence can cause some types of parts to be damaged more than they would be from an equivalent ionizing dose of gamma radiation. This effect can be analyzed and quantified.

Some space power supplies may be exposed to bursts of high energy radiation such as those produced by nuclear weapons. These bursts can cause circuit upset or burnout due to photo-currents. A transient radiation effects analysis considers these circuit upsets and a photo-current burnout analysis examines the circuitry for burn out potential. Nuclear events can also cause electromagnetic pulses (EMP). The adequacy of the power supply to resist burn out or malfunction caused by EMP may also be analyzed.

Worse Case Analysis

Worse case analysis assesses the ability of the space power supply to meet its requirements after the effects of tolerance, temperature, aging and radiation.This analysis starts with the establishment of a parts data base which takes all these factors into account.

Each pertinent circuit area is then examined, with the assistance if the SPICE model, for performance. Either a root-sum-squares (RSS) or extreme value analysis (EVA) may be performed, depending on the requirements and the correlation between the component input variables.

Structural Analysis

A structural analysis usually consists of two parts. The first part is to construct a simplified model of the structure, using finite element analysis. The second part is to subject the model to mechanical inputs, such as shock and vibration. The effects of the mechanical inputs upon the space power supply can then be analytically determined.

Environmental analyses primarily consider the effects of mechanical inputs to the power supply, including vibration, shock and acceleration. These are most useful before actual hardware is built, although analysis may also help to fix inadequate mechanical designs. Finite element analysis techniques are mostly used, with the worst case elements modeled.

Packaging the Space Power Supply

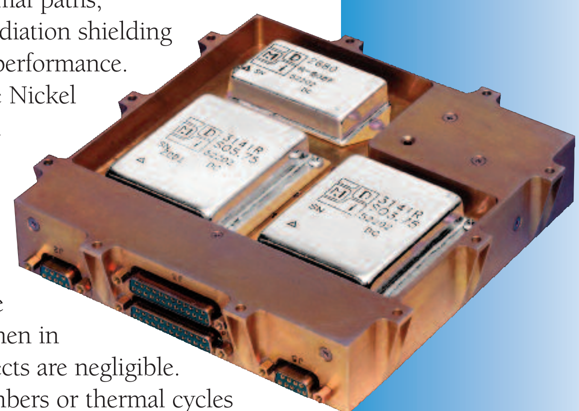
Space Power Supplies can be fabricated with all discrete piece parts, fully in hybrid microcircuit form or a mixture of both. A full hybrid approach is more expensive and takes longer to develop. An all discrete design will be non-competitive for all but high power designs. The part hybrid, part discrete construction is best for most applications, and combines one or more hybrid DC/DC Converter modules in a housing with other discrete circuitry.

Discrete construction also encompasses surface mount piece parts and techniques. In this mixed construction, the principal building block circuits are contained within the hybrid. The higher power and bulkier discrete components are packaged separately. This gives the part hybrid, part discrete construction good volumetric efficiency and allows better thermal paths for the higher power dissipators.

In addition, the part hybrid, part discrete construction allows mechanical provisions for EMI filtering, such as EMI plenums, making EMI filtering easier to implement than in full hybrids.

The enclosure method of choice for current generation space power supplies is the NC milled aluminum chassis. This offers many benefits, such as minimal weight, structural strength, good thermal paths, opportunities for radiation shielding and excellent EMI performance. This chassis may be Nickel plated for corrosion resistance.

In wiring the space power supply, wire insulation resistant to vibration damage should be used. When in space, vibration effects are negligible. However, large numbers or thermal cycles can occur. Therefore, the design of the wiring must be such that connections do not fail due to thermal cycle induced damage. In wiring to DC/DC converter modules, it is always best to use a compliant lead wire, rather than soldering a pin directly to a printed wiring board.



Multi-hybrid Assembly for a satellite

Design Documentation

Space Power Supplies require extensive design documentation efforts for two general reasons. The first reason is design disclosure. This allows the customer to thoroughly review the design and construction prior to hardware fabrication. The second reason to document all aspects of the unit is for configuration control and to assure that the unit was built exactly as intended.

A comprehensive documentation program may be streamlined by drawing heavily on existing engineering documentation. It is important to distinguish between customer review of existing documentation and customer approval of existing documentation. The former has modest cost impact as no drawings or procedures will be changed. The latter has greater possibility of cost impact since changes are usually inherent in the approval. Drawing packages may be generated to DoD-STD-1000 guidelines. There are three levels of drawing packages in this document, Level 1, 2 or 3. Level 1 is an engineering drawing package, and is intended solely for the purposes of design disclosure. Levels 2 and 3 are suitable for use to document configuration control, as differentiated from design disclosure packages. Level 3 is the most comprehensive, and theoretically gives sufficient information for re-procurement if necessary.

The types of drawings contained in a Level 2 or Level 3 package follow a hierarchy, starting with the outline/ installation drawing, next the top assembly drawing, then the lower level assemblies. This is followed by detailed fabrication drawings. When components are purchased, the drawing package includes source and spec. control drawings. These are supplemented by schematics, block diagrams, manufacturing procedures, etc. Very often, due to schedule requirements, there will be more than one configuration supplied. In that event, "as built" drawings are provided, depicting specific configurations.

Schematics and block diagrams are used as tools for design reviews and later analysis. With space power supplies, if any repairs or modification is required, only the original source should be entrusted with this work, so schematics and block diagrams are not needed as submittals for customer maintenance.

Block diagrams and schematics are also useful in conjunction with theories of operation, which describe how a unit operates.

Generating SCDs for Piece Parts

The typical procedure for using a non-standard part begins with the generation of a source or specification control drawing. This document not only specifies all the electrical and mechanical parameters of the part, but also defines the qualification and quality conformance requirements. When generated for chip components, these drawings may be called detailed device specifications. Qualification is the initial testing that qualifies the part to meet the requirements of the drawing, and usually includes environmental testing as well as electrical testing. Quality Conformance Inspection testing (also known as QCI) qualifies the particular lot of parts, and is usually done at periodic intervals. QCI normally has a smaller subset of tests than qualification testing, so is less expensive. QCI is also known as group A, B, C, D and E testing. Depending on the type of parts, the "group" testing may be just group A and B, or A through E. In the QCI process, one or more units are destroyed, adding additional expense. There are various strategies for reducing QCI cost, which require the informed direction and approval of the customer.

The qualification process for chip components with a hybrid microcircuit is called element evaluation, and is performed in accordance with MIL-PRF-38534. This is also used for quality conformance inspection.

Magnetic components for space power supplies are almost invariably non-standard. The usual governing specification for magnetic components is MIL-STD-981, which builds on MIL-PRF-27 and related specifications. Like many other detailed parts specifications, MIL-STD-981 allows qualification (not QCI) by similarity, provided the "similar" part meets certain tests of "closeness" with the previously qualified parts. This permits cost savings in many instances.

Many of the parts will be covered by specification control drawings or source control drawings. The former type is used when the requirements are not highly critical and source qualification is not deemed mandatory. The latter restricts procurement of the part from approved sources. Source control drawings usually list requirements which must be satisfied to qualify a part.

In practice, source control drawings are frequently preferred over specification control drawings when the component engineer is aware of indefinable parameters that are important or that only one acceptable source exists. Another reason for source control drawings may be that the component engineer knows the recommended source has unique test equipment or capabilities not available elsewhere.

Manufacturing Techniques

Space power supplies are normally assembled in a controlled environment, class 100,000 or better. During and after assembly, they will be subjected to precision cleaning operations.

In fabricating space power supplies, great reliance is placed on documenting detailed procedures for all manufacturing operations, as well as training and certification of all operators. Quality requirements such as NHB-5300 and MIL-Q-9858A mandate procedures for all manufacturing operations.

The purpose of the procedures is to allow review of the operation, consistency in its application and as a criteria for training.

For a typical hybrid module, approximately 40 procedures may be required. For magnetic component manufacture, approximately 20 procedures may be required. For discrete assembly, approximately 30 procedures may be required. The hybrid procedures are written around MIL-PRF-38534, the magnetic procedures around MIL-STD-981 and the discrete assembly procedures are based on NHB-5300.

The operators performing these procedures are trained (in accordance with a training procedure), tested on their knowledge and ability to perform the procedure, then are certified for that procedure. Outside agencies have cognizance of the certification of procedures as well as instructors, which is renewed at periodic intervals.

The intent of generating all these procedures and methods is that nothing be left to chance or to interpretation. This overcomes part of the learning curve that would otherwise occur with a small unit quantity.

Qualification Testing

The purpose of a qualification test program is risk mitigation. Unlike terrestrial power supply applications, environmental testing is performed in conjunction with analysis, not as an either/or situation. Testing alone may not reveal design margins or weak spots. Analysis alone may be flawed. Therefore, a balanced combination of analysis and testing is generally favored. The most significant tests are usually shock, vibration, thermal vacuum, EMI and radiation.

Most applications for space power supplies have a relatively benign shock and vibration environment on orbit, but a severe requirement during transportation and launch. Pyrotechnic shocks are normally the most challenging requirement for low mass units. Thermal vacuum testing is another important area that cannot be confirmed without testing. Every heat dissipating component must have a reliable path of conductive heat removal. Many power supplies designed for non-space use neglect this necessity, and so fail when exposed to the hard vacuum environment of space.

EMI is another important area that varies widely from application to application. Because of the small capacity of most space electrical bus systems, there has been little standardization of bus specifications. This translates to a wide diversity of EMI requirements. Test plans, always important, assume an even greater importance in light of this diversity.

Successful testing programs characterize the equipment with minimal cost and schedule impact. One of the best ways found to facilitate this is to precede a formal qualification test program with an informal pre-qual program.

A pre-qual program is designed to hit the hot spots, or technical high risk areas of the development task, at an early stage in the program and at a modest cost. An assessment is made of the highest technical risk areas, and only those areas are tested. Test plans, procedures and reports are kept informal, which holds down costs. Source inspection is not invoked, streamlining the schedule. A pre-qual program can be performed with a brassboard, prototype or pre-production unit, and does not require flight level hardware.

A pre-qual program has two benefits. If it precedes a formal qual program, it gives early assurance of a satisfactory design. If testing shows that changes are necessary, changes can be made on non flight hardware, avoiding the high costs and long lead times of flight hardware.

The second benefit of pre-qual testing exists when the next higher assembly beyond the power supply will be subjected to formal qualification tests. In that event, the pre-qual program will give reasonable justification for combining the formal qualification test of the power supply with the testing of the next higher assembly.

Test plans are an important part of any test program. It is not correct to assume that specifications covering environmental or EMI testing are in themselves sufficient for conducting tests. What is missing is the mechanical configurations, electrical connections, ambient conditions and pass/fail criteria. These elements must be reviewed by the test activity, as well as the customer, prior to conducting the tests. The test plan is the vehicle that describes the missing information prior to test execution.

When the test plan is approved by the customer, a test procedure is generated, covering the actual testing. This embodies the elements of the test plan. The test procedure describes the testing in greater detail, listing the equipment or facilities to be used as well as the sequence of testing.

Following the actual testing, test reports are generated. They describe the test results, and are often accompanied by photographs. If any anomalies have occurred during testing, they are noted in the report.

LAT Tests and Piece Part Screening

Radiation effects are normally tested on piece parts because of the great expense involved in testing complete units. The piece parts tested are those that are known from experience to be most susceptible to radiation. In addition, since relatively few facilities can perform tests such as SEU resistance, long lead times and high costs for testing are common.

After the piece parts have been documented, qualified and built, the parts may be subjected to a further screening known as Destructive Physical Analysis (DPA). DPA is a process wherein representative parts from a lot are dissected to verify construction meets detailed requirements. If the samples from the lot pass the DPA, the entire lot is accepted. If they fail, the entire lot is rejected or otherwise dispositioned. Many piece part specifications have specific DPA requirements. However, it is not unusual to impose other specifications, such as MIL-STD-1580, which have other DPA requirements. Sometimes, the specific requirements differ and a part that meets its detail requirement will not meet an overall DPA specification. Resolving these specification conflicts is a usual recurrence.

The economic and schedule result in requiring QCI and DPAs on discrete components often results in a full hybrid construction being less expensive and more readily available than discrete construction since element evaluation is a quicker process than QCI on many discrete items.

Acceptance Testing

Electrical acceptance testing of space power supplies tends to be more comprehensive than for other types of power supplies. Often, "connector savers" are used to protect the electrical integrity of the flight connectors. To preserve the high level of cleanliness, the space power supply may be tested while enclosed in a protective barrier.

In addition to the electrical tests, environmental tests may be performed on an acceptance basis. These include acceptance vibration tests (AVT) and thermal/ vacuum tests.

The acceptance data package is assembled and reviewed prior to shipping the space power supply. This includes travelers for all assemblies and hybrid DC/DC converters, LAT results, DPA results, etc.

Space Power Supplies from a Program Management Perspective

Space power supplies are unique from a program management perspective because designing, analyzing, testing and manufacturing is more like contracting than volume manufacturing. With space power supplies:

- Quantities are usually low
- The mean time to failure must be very high, since power supplies can't be repaired in space
- The space environment is more harsh and different than the terrestrial environment
- There are unique assembly and testing requirements

The best way to build space power supplies today is to use pre-designed hybrid DC/DC converter modules. Modules are physically compact. Using hybrid DC/DC converter modules saves time and money and promotes the incorporation of heritage designs.

Incorporating modules in the space power supply is necessary, but not sufficient. Since the module function is limited to give greatest commonality, most applications require additional components and circuits, which are best added external to the modules.

Changes within the hybrid modules may be required due to special customer requirements. These include changes due to:

- Changes as part of the conceptual design
- Changes directed by analysis results
- Changes directed by customer reviews

These changes often go in opposite direction to performance or functions required in the general market. The module manufacturer nevertheless must accept the need for the changes within the module and make the changes correctly and expeditiously.

Typical Program Development Plan

A description of a typical assembly timeframe follows.

Day -60 Customer's requirements received at MDI. Specification and Statement of Work reviewed by marketing, engineering, operations and quality. Questions formulated for customer response. Conceptual electrical and mechanical design started. Technical and Cost Proposal started.

Day -30 Proposal with technical, cost and schedule elements submitted to customer. Customer review with exchange of customer/MDI questions and clarifications. Update of MDI proposal and customer's requirements, if needed.

Day 0 Customer places order with MDI. Project team for work is established. Kick off meeting; Tasks are assigned. Conceptual design is converted to initial design. Preliminary schematics, parts list and mechanical packaging concepts developed.

Day 30 Initial design is complete. Preliminary stress and derating analysis is started. Preliminary weight analysis is started. Preliminary thermal analysis is started. Preliminary test plan and procedures are started. Breadboard/ prototype parts are ordered.

Day 60 Materials and Parts application lists are initiated. A listing of required spec or source control drawings are generated. Requirements for parts screening, LAT or piece part radiation tests are established. Preparation for PDR preliminary analysis completed.

Day 90 PDR conducted. Preliminary analysis reviewed. Breadboard results reviewed. Approval to procure and fabricate qualification and flight hardware is given. Procurement of flight components begins.

Day 120-270 Material received and screened. LAT tests performed.

Day 150 CDR Conducted

Day 210 Manufacturing Readiness Review (MRR) conducted. Assembly commences.

Day 330 Qualification hardware assembled and tested. Qualification tests start.

Day 360 Qualification tests complete. Assembly of flight units commences per schedule.

Conclusion

Space Power Supplies made with hybrid DC/DC converter modules are the best solution for most applications. Over the years, a body of knowledge has developed that offers guidance for producing highly reliable supplies. In the transition to smaller, faster development and less expensive power supplies, it is important to use good judgment to wisely achieve these goals without fatally compromising the mission reliability.

MDI advantages:

- •MDI understands space power supplies
- •MDI manufactures hybrid DC/DC Converter modules
- •MDI designs complete space power supply systems
- •MDI is an agile and cooperative supplier

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