Electrical, Electronic, and Electro-mechanical Parts for Space Flight Use, A Review

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This paper will review the various philosophies (e.g., established reliability, Class S) used in developing the military and NASA specifications for the various types of electrical, electronic, and electro-mechanical parts. The paper will show how the specification requirements can be combined with applications guidelines, such as derating tables given in various NASA and military documents, to choose appropriate parts to meet the reliability goal of the particular space flight project.

Introduction

Product or quality assurance and reliability are not the same thing. Quality means that a product meets the specification that it was manufactured or procured to. Reliability means that a product will perform for a certain period of time. A quick example will suffice. A manufacturer will have specifications for two connector contacts. One calls for 50 microinches of gold plating and the other requires 100 microinches. If the manufacturer makes both parts to their respective drawings, he has produced two quality parts. But the part with the thicker plating will survive more mating cycles and is a more reliable part.

The many military and NASA specifications for electrical, electronic, and electro-mechanical parts are product assurance documents that control how a part is manufactured and tested. Some define reliability goals for the part. These specifications are identified by subtitles such as established reliability or high reliability. Specifications with no reference to reliability in the title will often have multiple levels of product or quality assurance, one of which is designated for space flight use. These documents reflect the philosophies of the different preparing activities and the times at which the documents were first developed.

There is one major philosphical difference between the various specifications and the documents used to calculate system reliability, such as MIL-HDBK-217, Reliability Prediction of Electronic Equipment. The specifications use a parametric shift as the definition of failure when a life test, usually at maximum stress conditions, is performed. MIL-HDBK-217 makes its calculations based on catastrophic failure of the part.

Since most circuit designers are looking for a happy medium between the parametric shifts of the specifications and catastrophic failure, they can find guidance in derating guidelines given in sources such as MIL-STD-975, NASA Standard (EEE) Parts List; MIL-STD-1547, Electronic Parts, Materials, and Processes for Space and Launch Vehicles; or similar

documents from various NASA centers and the European Space Agency.

Specification Philosophies

Established Reliability

The oldest effort at defining reliability in a specification is shown in the Established Reliability (ER) specifications for capacitors, coils, relays, and resistors. The concept is that enough device hours are accumulated at maximum rated conditions to demonstrate a failure rate of 1.0%/ 1000 hours to 0.001%/1000 hours at a certain confidence level. The failure rate for relays is given in %/10000 operations. The confidence levels are usually 90% for most capacitors and 60% for tantalum capacitors and the other part types. These values are developed using an exponential distribution. For more information, see MIL-STD-690, Failure Rate Sampling Plans and Procedures. Recently, the specifications for solid electrolyte tantalum capacitors (MIL- C-39003 and MIL-C-55365) have adopted a Weibull distribution for calculating failure rates at a 90% confidence level. The advantage to this approach is that every lot is tested under greatly accelerated conditions and its failure rate determined before the manufacturer can ship the product.

It is important to remember about ER specifications that most parts receive the same processing and testing regardless of their failure rate. Failure rate is strictly a function of the manufacturer demonstrating enough device hours (e.g., 231,000 hours for 1.0%/1000 hours at 90% confidence) without a parametric failure to show that the product meets the requirement. Also, the failure rate is only valid for the amount of time used for the life tests that demonstrate it. For many parts, this period is 10,000 hours at maximum rated temperature and maximum rated voltage or wattage.

High Reliability

These specifications were developed for space flight use and are sometimes referred to as Class S specifications. The first specifications were developed for capacitors. Two examples are MIL-C-123 for ceramic capacitors and MIL-C-87164 for mica capacitors. Subsequently, fiber optic connectors and resistors have been added. Although these specifications do not guarantee a failure rate, one can be implied from the life test conditions and the number of samples used. The importance of these specifications is the imposition of mechanical design constraints on the parts to address known reliability problems and the use of in process tests to identify defective pieces and lots For example, MIL-C-123 imposes a minimum dielectric thickness and a maximum dielectric constant and then requires nondestructive testing on the unleaded, unencapsulated capacitor bodies to detect delaminations and voids. In comparison, the ER specification, MIL-C-39014, has no specified value for dielectric thickness or in process test for voids and delaminations. Parts are acceptable if they pass the lot acceptance tests. Some manufacturers object to the mechanical design constraints on the grounds that it hold them to a design that may no longer be the best one because of improvements in materials and processes.

Reliability Not Specified

This is the category containing the largest number of specifications and part types, including cable, connectors,

crystals, filters, fuses, microcircuits, semiconductors, switches, thermistors, transformers, and wire.

Although reliability is not mentioned in the titles of these documents, a value can be inferred from the life or endurance test conditions. For example, MIl-C-24308, the specification for "D" type connectors requires 500 cycles of mate-demate testing as its endurance test for qualification.
Many of these specifications have multiple product assurance levels with the "best" one designated for space flight use. At this point, it is good to remember that NASA and the US Air Force do not agree on the use of "space level" parts for satellites. The Air Force wants them for everything while NASA in its preferred parts list gives two categories of parts to use depending on mission criticality and only "Grade 1" programs require space level parts.

The part type in this category that is of greatest concern and the greatest source of confusion is the microcircuit.The two product assurance levels in MIL-M-38510, Classes S and B, differ in the severity of the inspection requirements and in the imposition of tests on Class S on a lot by lot basis where Class B product is only tested periodically. Looking back to the life test requirements of the ER specifications, microcircuits present an interesting phenomenon. The life test for both classes is the same at a lot total percent defective (LTPD) of 5 with 90% confidence. A quick look at the sampling plan in Appendix B of 38510 shows it to be the same as the exponential plan in MIL-STD-690. Thus microcircuits only demonstrate a failure rate of 5%/1000 hours for parametric failure.

The biggest problem with microcircuits, for a user, lies in the fact that MIL-M-38510, the general specification for microcircuits and MIL-H-38534, the general specification for hybrids, are the only military specifications that do not contain the screening, qualification, and quality conformance procedures for the part types. The historical reason for this was that the microcircuit specification was to mirror the semiconductor specification, MIL-S-19500, and have a companion book of test methods like MIL-STD-750. When the time came to issue 38510 and its companion, MIL-STD-883, 883 was ready to go and 38510 was not. A decision was made to include the screening and qualification procedures in 883 to get them out to the users.

The release of these procedures in a military standard rather than in a specification made them available to everyone with the preparing activity having no control over their use. Thus was born the 883 equivalent or manufacturer's in-house high reliability part. These parts, which the government has no control over despite many misconceptions to the contrary, are processed in any way that the manufacturer desires. The biggest differences from military specification parts have been in the burn-in conditions and parameter limits. Military specifications usually load a device's outputs for burn-in. Many manufacturers do not use any loads. A comparison of a military detail specification sheet and a manufacturer's data sheet for his part may show a factor of two or three or even an order of magnitude between the values for the same parameter. The commercial data sheet will have the looser value. The effort in the last several years to force manufacturers to clean up their acts regarding 883 parts and to comply with the procedures is

succeeding only because of the clout of the government as a customer.

From Specification to Design

Most space craft electrical circuitry is not operating at the temperature extremes and stress levels used to qualify parts to military specifications. Obviously, catastrophic failure is the worst case situation. For most circuits, parametric drift is the more prevalent problem. The parts themselves often have aging characteristics that the designer has to consider before choosing them for the circuit. Bringing all of this disparate information together to assure a successful design is not as difficult as it seems.

Application and Derating Information

For application information on various part types, NASA has produced MIL-HDBK-978, the NASA Parts Application Handbook, and the military have various standards and handbooks on parts selection. Manufacturers have much applications literature available.

Derating guidelines are available from several sources. Some were mentioned in the introduction of this paper. They are based on accumulated experience or laboratory tests and can be used to develop design guidelines for parts that are not mentioned explicitly. NASA does not state explicit lifetime goals with its guidelines but the Air Force says that the values in MIL-STD-1547 are aimed at a ten year mission life.

Does the choice meet the need?

The bane of many designers is the dreaded MIL-HDBK-217 on reliability prediction. Many people agree that the quality factors, especially for microcircuits, sometimes seem to have no relationship to reality. Ignoring this problem, there is much valuable information that can be used for temperature and electrical stress factors. Even though this information is based on catastrophic failure, the tables of base failure rates showing temperature versus ratio of operating to rated voltage or wattage can be used to calculate the factor by which derating will increase lifetime. Wire, cable, and connectors are not covered by 217. NASA's derating values for these parts are based on laboratory tests in vacuum. This testing was done for the Apollo program because the biggest concern was the lack of convective cooling in a vacuum.

An Example

For example, let's use a film resistor, type RLR. The life test on this part is at 70°C at rated wattage for 10000 hours. Table 5.1.6.2-4 in 217 assigns this a value of .0031. NASA requires 60% of rated power as a maximum. At 70°C, the value for a ratio of 0.6 is .0017. This means that the lifetime has almost doubled. At an ambient of 30°C, the value becomes .0013 and the time to parametric failure will have increased by a factor of almost 2.4 to approximately 24000 hours.

Conclusion

This paper has attempted to present a brief overview of the varying philosophies used in developing the military specifications for parts. It then discussed how to use the reliability information in the specifications to determine if the part can meet the lifetime requirement of the application.