THE HISTORY OF SPACE QUALITY EEE PARTS IN THE UNITED STATES

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ABSTRACT

Obtaining true, space quality EEE parts is a very difficult task. There are both major and subtle characteristics, which make space quality parts different than military, commercial or automotive parts. Very few EEE parts are. specifically designed for space applications due to the low volume and sporadic purchasing/manufacturing requirements. The difficulty and apparent high cost of obtaining true space quality parts have caused many space programs to pursue short cuts such as upgrading lower quality parts through testing and taking risks on using lower quality parts as they are. Papers at previous conferences have presented some excellent examples of this experience. This paper reviews major historical milestones in the development of space quality parts in the U.S., some cost examples when space quality parts were not used and some good practices for reliable space quality EEE parts.

1. CURRENT SITUATION WITH U.S. SPACE PARTS

There has been a long and successful history of usage of U.S. manufactured space quality EEE parts in both U.S. and International space programs. Likewise there are examples of poor reliability when less than space level parts were used in space applications. The U.S. has wide experience in the design, development and deployment of large long-life space systems, which have both required and demonstrated a long system-life. Support of this effort has resulted in an EEE parts manufacturing capability, which has provided exemplary support, both in quality and schedule, to space programs. This support structure is continuing, despite the current temporary shrinking size of the military market. At present, the parts manufacturing base is undergoing restructuring in terms of methods to assure continuation of this high product integrity. This change is a result of both changes within U.S. Government specifications and the economic incentives of the parts marketplace.

There is little doubt that there is no unique corner on the parts technology market by U.S. companies, but there are few areas of significance in which U.S. manufacturers are not at or close to the technology forefront. Additionally, the size of the U.S. space parts market is more than an order of magnitude greater than the International space parts markets, and it can therefore easily satisfy non U.S. space market requirements cost effectively.

The comparatively large U.S. military and space market has effectively minimized the EEE parts price, optimized the availability, and led to a wealth of experience in the arena of high-reliability parts.

2. HISTORICAL MIILESTONES

In the 1950's and early 1960's there were no space quality parts, only standard military specification parts (of pretty low reliability) and commercial quality parts.

I have, not been able to identify the parts lists for the Vanguard rocket, but the EEE parts would have consisted mostly of alloy and grown junction transistors (2N45 and 2N335), alloy diodes, aluminum electrolytic and paper capacitors with a few ceramics, carbon composition resistors and lots of relays. Those of you old enough remember one thing about the Vanguard and its small satellite payload, which was suppose to be the first U.S. Satellite, failure, failure and more failures. The U.S. Army had built the Redstone Missile as a derivative from the German V-2 rocket. The Jupiter and Juno rockets were derived from the Redstone with upper stages capable of putting small payloads into earth orbit. However President Eisenhower had given the job of launching the first U.S. Satellite to the Navy on the Vanguard. The Army (Dr. Von Braun and his Redstone staff, later to become NASA-Marshall Space Flight Center) had very explicit orders that anything they launched had better be only ballistic and return to earth without going into orbit. After 3 failures of the Vanguard the President directed the Army to launch the satellite that they had stored in a warehouse. This became Explorer 1, which was built by JPL. It was a very simple satellite with a gyro, Geiger counter and 2 transmitters; however the launch vehicle and the satellite worked perfectly and the U.S. finally had a satellite in space.

The EEE parts used in these systems and the other early Explorers and launch vehicles were:

- Mostly commercial and a few military specifications with a lot of incoming testing and inspection. They were more electromechanical and electrical than solid-state parts.
- The designs were simple with lots of relay logic and diodes were mostly for isolation. Most circuits operated with predetermined sequencing and timing.

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In the early 1960's the military organized a study team to develop improvements in the passive parts specifications. This team was headed by Paul Darnell of Bell Labs and the findings became known as the Darnell Report. This is what led to the passive components established reliability specifications. The concept was to establish a minimum failure rate level (1%/1000 hrs) through qualification testing and use the production lots to generate additional life test data to improve the failure rate level in increments to .001%/ 1000 hrs., which was later increased to .0001%/1000 hrs.

In early 1961 MSFC was working on the Saturn launch vehicle for the Apollo Program. It was decided that significant changes had to be made to improve the quality and reliability of the EEE parts used in the Saturn Program. In the late 1950's the Minuteman contractors, MIT, Autonetics and others, had been working on high reliability techniques and specifications for this ballistic missile program.

The early NASA efforts, MSFC, GSFC and JPL, built on the Minuteman approaches and Bell Labs techniques, which had been used for undersea cables. These approaches involved the following steps:

- Select a good and stable part design.
- Insure the manufacturer had a good quality system in operation.
- Impose stringent precap inspection.
- Perform stress screening and burn-in with tight electrical limits and delta parameters with read and record data to reject the mavericks.
- X-ray inspection for any defects that had been missed.

This technique worked very successfully for most of the Saturn I, IB and V launch vehicles. One of the systems that experienced problems was theSaturn flight computer's Unit Logic Devices (ULD's) built by IBM. These devices were derived from their commercial computer parts, which used bump mounted transistors and diodes. The ULD parts had major design and intermetallic deficiencies, which took a tremendous amount of effort to fix. However once they were resolved excellent reliability was achieved. The greatestproblem with this equipment and some later systems was convincing IBM, the contractor, that there was a problem which had to be fixed.

Marshall Space Flight Center published their first high reliability parts specifications (85M0 ...) in 1962 for the following types of parts:

S2N718A	S2N491 & S2N2419B
S2N697	S2N918
S2N657A	S2N1016C/D
S2N722 & S2N1122	S2N2102
S2N834	S2NI486
S2N335B	

In late 1962 they published the first Preferred Parts List PPL-100. This list contained the above solid-state specs, MSFC relay and connector specs, and military specs for passive components. The military passive components specs also required stringent incoming tests and inspections of the product. Many of the parts on PPL-100 were purchased by MSFC for their stock program to provide ready availability. A good bit of the Saturn I electronics was built in-house by MSFC. Whereas the Saturn IB, Saturn V, and Apollo/LEM were built by contractors utilizing mostly space quality parts, as defined at that time.

During this same time GSFC was developing their PPL and the specifications for SN100 and SP100 transistors for a consolidated procurement. The GSFC philosophy in general has been to use standard military specifications with upscreening and inspection when required. The primary MSFC and JPL approaches define the space quality level needed and have it built by an approved supplier. In many cases the JPL practices would be more stringent than those at MSFC because their applications required a longer operating life.

In 1964, the late J.L. (Larry) Murphy came to NASA from the U.S. Navy and over the next few years was instrumental in planning and implementing the NASA Standard Parts Program, NASA's use of the military components specification system, line certification program and other advancements and R&D in EEE parts.

KEY MILESTONES IN U.S. SPACE QUALITY PARTS

1958 - 1962	- Commercial and military parts with stringent incoming tests and inspection
1962 - 1963	- First solid state space quality parts specifications (85M0---, SN100 & SP100)
1966	- MSFC Microcircuit Q&RA requirements (85MO) - Series 51 RTL specification (85MO)
1967	- AAP (Skylab) PPL and Parts Control Program
1968	- NASA Microcircuit Line Certification Program (Later MIL-STD-976) - MIL-STD-883 was published - Space quality spec for 54TTL and 930 DTL

1969 - MIL-M-38510 published - - Class A and B.
- First microcircuit lines were certified by NASA
- MSFC published first visual inspection standard for transistors and diodes
- PIND test method (2018) was published

1970 - MSFC initiated the development of the CLR-79 wet slug capacitor to replace the CLR-65
- SEM test method (2020) was published

1971 - Opto-isolator spec published and qualified

1972 - NASA Hybrid Line Certification program established
- Class S added to MIL-S- 19500

1973 - USAF-SD published MIL-M-0038510 spec for Class S microcircuits

1975 - Class A changed to Class S in MIL-M-38510 for USAF-SD to eliminate 0038510

1976 - The NASA Standard Parts Lists (MIL-STD-975) was published

1977 - 77-3C First USAF-SD ERE Space Parts Requirements

1978 - Developed low energy, low IR techniques for film capacitors

1979 - NASA Parts Application Handbook (MIL-HDBK-978) was published

1980 - MIL-STD-1546 & 1547 - USAF-SD Parts Requirements which superceded 77-3C
- MIL-STD-1580 DPA requirements

1981 - MIL-C-123 Class S Ceramic Capacitors

1982 - Class S Mica Capacitors, MIL-C-87164

1983 - Revision C, MIL-STD-883, 1.2.1 for compliant devices

1984 - Line Certification Standard for Hybrids, (MIL-STD-1772)

1985 - Class S film capacitors, MIL-C-87217

1989 - MIL-H-38534 QML Program for Hybrids (Class S & B)

1990 - QML Program for Integrated Circuits, MIL-1-38535

3. FALSE COST ANALYSIS

As the many improvements were developed and greatly improved space quality EEE parts emerged another problem with implementation occured. Project managers started resisting the use of space quality because of their perception of greatly increased cost and the impact on delivery terms. Here are three examples of where this philosophy was not cost effective.

Skylab Project

The computer for the first Skylab hardware utilized military grade parts rather than space quality parts to avoid $330,000 in acquisition costs. The computer failed 5 attempts at qualification test, mainly due to solder particle contamination in the microcircuits caused by solder balls. The computer was rebuilt with space quality microcircuits at a cost of $3.3M to the project. This is when Class A microcircuits were developed. There were no further test failures and the system was operating satisfactorily when the Skylab re-entered the atmosphere and crashed into Australia.

HEAO Space Telescope Project

For the spacecraft as a whole, the EEE parts cost for upgraded Class B parts was 30% higher for acquisition when rationalized against the cost of Class S parts used on the similar FLTSATCOM satellite.

Space Shuttle Orbiter

The computer and most electronic systems used a baseline of military parts quality based upon redundancy. To achieve the required reliability, six systems are flown on each Orbiter. The extra weight, plus launch delays due to parts problems and repair actions for parts problems were costly to the project. When the total cost penalty for use of Class B parts is compared to the additional cost for space quality parts initially, it is calculated that the additional cost of ownership for the military grade parts was $77M more than Class S.

These and other examples show that the cost of EEE parts to a space project cannot be merely calculated from purchase order pricing on initial build of hardware. A much more sophisticated and long-term view must be taken of the total program cost impact concerning EEE parts at all phases of the program.

4. LESSONS LEARNED

There are many types of EEE parts made worldwide that give excellent reliability in various types of applications for which they were designed. However some unique characteristics are required of space quality parts that most commercial and industrial applications do not demand, individually or in combination:

- Temperature -55'C to 1250C or wider
- Hermetic packaging - Solid State & relays
- Higher vibration capability
- Control of outgassing & flammability
- Extremely low defect levels (10 ppm)
- Extremely long reliability (1 to 15 FITS)
- Conservative derating & application practices

The current worldwide market for space quality EEE parts is large ($613M non-communist countries) but not large enough to support the thousands of types of parts used and the sporadic production quantities. Therefore the parts for space usage must be derived from other basic designs and manufacturing flow. The space quality parts are derived or manufactured mostly from military parts lines with additional controls such as

- Selection of only highly proven part designs
- Additional manufacturing steps
- Homogeneous lots of materials
- Detailed traceability to every process & lot
- Improved inprocess controls & tests
- More inspection points and strigent criteria
- Goal of zero manufacturing defects
- Comprehensive testing
- Rigorous lot testing
- Last look at lot - DPA
- Acceptance Inspection

I want to emphasize that this approach involves building a military type of part to space quality standards so that when the other design and reliability disciplines are properly implemented the part will demonstrate highly reliable performance. I am not talking about taking a commercial or standard military part and trying to screen test out the maverick parts (the low reliability parts) because we all know you can never improve the reliability of any individual part by more testing. However, it is sometimes possible to remove deviate parts by testing, thereby making some degree of improvement in the average reliability of the remaining population of parts. There is considerable data that proves this concept has a lower success rate and is more expensive than building space quality to begin with.

5. IMPROVEMENTS TO U.S. SPACE QUALITY PARTS

The following improvements are being made in U.S. space quality parts specifications and practices.

Passives and Connectors

- New parts coverage with (ER) established reliability specs
- More Class S specs
- Expanded implementation of MIL-STD-790
- Mandating SPC techniques
- Changing AQL's to PPM quality limits
- Improving usage of environmental stress screening
- Better solderability testing - - lot by lot

Microcircuits

MIL-M-38510 - Streamline qualification to expand QPL
- Rad Hard simplified and expanded
- One part - one part number

MIL-STD-883 - Compliant Class S
- Generic qualification (G.A., ASIC, etc.)

Hybrids

MIL-H-38534 - QML concept
- Covers both S and B

ASIC, VLSI,. VHSIC

MIL-I-38535 - QML concept
- New detail specifications
- Manufacturer has more responsibility

6. CONCLUSIONS

I would like to conclude by reviewing some factors which are very important in obtaining reliable space quality parts.

- True space quality EEE parts require great diligence to obtain — higher costs typically, lower yields Requires stable manufacturing base
- Adequate volume necessary to justify space quality manufacturing lines
- Military design and product base to build upon
- Management personnel must understand and appreciate space quality needs
- Build space quality, don't try to obtain it through testing
- Upgrading through screening should be last resort
- Highest quality and reliability is always the lowest total cost

7. MAJOR CONTRIBUTORS TO U.S. SPACE QUALITY PARTS

I would like to identify some of the early contributors to the development of 5pace quality parts in the U.S. There are many more, to those I have failed to list I apologize.

NASA & JPL

Dr. A.M. Holladay
Filmenio Villella
Ron Barlow
Larry Murphy
Glenn Lindsey
Bill Corder
John Morris
John Berkebile
Hugh Milteer
Harry Ricker
John Adolphsen
Richard (Dick) Scott
Larry Wright
Bob Anstead
John Visser
Bob Sheppard
Wayne Schockley
Mike Nowakowski
Geroge Kramer

USAF & Aerospace Corporation

Joe Brauer
Dr. Gary Ewell
Kenneth Blakney
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Industry

John Moynihan - Sprague Electric
Connie Zierdt - GE Semiconductor
Jay Farley - Fairchild Semiconductor
Sam Carroll - Texas Instruments
Ralph McCullough -Texas Instruments
Bob Howard - Solitron Devices
Leo Bauldhaupt - Boeing
John Devaney - HiRel Labs

Leon Hamiter was employed by NASA-MSFC for twenty three years in the components engineering group and was the manager for eighteen years. This group was responsible for the electronic components engineering for MSFC projects and the NASA Standard Parts Program. After leaving NASA he founded the Components Technology Institute, Inc. which provides engineering, failure investigations, market research, quality assurance and consulting services to the electronics industry and attorney-at-law firms. He is also founder of the worldwide Capacitor and Resistor Technology Symposium (CARTS) CARTS Europe, Commercialization Of Military and Space Electronics Conference (CMSE) in the USA and Europe, Failure Analysis and Component Test Symposium/Seminar (FACTS), long time participant in the International Symposium on Testing and Failure Analysis (ISTFA) and provides components engineering and technology seminars to the electronics industry.

As a NASA representative he was instrumental in the development of the following documents:

MIL-STD-883
MIL-M-38510
MIL-H-38534
MIL-STD-790
MIL-C-123
MIL-STD-1772
MIL-STD-975 & 976
MIL-HDBK-978
Many individual component specifications

His group developed the original "Line Certification" standards which were the basis for the military documents used for integrated circuits and hybrids. After retiring from NASA he audited many microcircuit manufacturers and helped them prepare for their DESC Line Certification audits.

Mr. Hamiter has provided components engineering assistance to the Canadian Space Agency, Japanese NASDA, ESA space projects, NASA, Plessey Electronics and military projects. These services include component specifications, handbooks, reliability predictions, testing, failure analysis, destructive physical analysis, reliability investigations, product improvements, supplier quality surveillance and training programs. He has extensive experience in the procurement and control of electronic components for industrial, commercial, space and military applications including the cost-of-ownership analysis of electronic systems and cost growth projections. He is recognized throughout the United States, Europe and Japan for his contributions and accomplishments in the components engineering field.