Commercial versus COTS+ versus Qualified Passive Components in Space Applications

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INTRODUCTION

The paper has been written specifically for the ESA 2nd SPCD symposium with a target to initiate an open panel discussion on commercial/automotive versus COTS+ versus qualified passive components use in space applications. The paper provides a summary over the gained and recently published experience and discuss the possible next directions for passive components application in space environment in order to succeed in the new upcoming era of space commercialisation. The paper is intentionally written more in "black and white" style to inhibit thoughts, agreements or disagreements and thus initiate wider industry debate between the agency, space prime companies and manufacturers. The paper summarise position of the space industry, attitude of different passive component manufacturers towards the commercial, COTS+, space applications and conclude it in some recommended steps for the future space passive component selection guide.

SPACE PASSIVE COMPONENTS INDUSTRY

Electrical Industry Growth Cycles

The electrical industry went through a number of changes, challenges and growth cycles since the last century. One can distinguish about four fundamental eras in the history of electronic industry with different key drivers that strongly influenced the "typical" entity behaviour within the whole supply chain at that time.

- **Pioneers (~1800 – ~1920)**, from the first discoveries and experiments by individuals to a "real" production by enterprises
- **Military, State, Space (~20th – ~70th)** - the electronic industry is driven by orders from military, state and space competition needs
- **Enterprises (~70th – ~90th)** – industry automation, PCs for business use, etc. are dominating the el. industry orders and requirements
- **Individuals (~90th – today)** – personal PCs, DCR, mobiles … individuals and its purchasing power are controlling the industry

The first "real" electrical industry market was slowly raised during the beginning of the 20th century when the "new discoveries in the field of electricity found its practical daily use applications. The World Wars accelerated the development and manufacturing of new electrical devices and requirements for electronic components. The main drivers for industry at that time were orders from States, Governments and Space. The "Cold War" politic situation also initiated the space competition. The needs for space applications became significantly influential including requirements for the space electronic devices and components. During the 70th of 20th century the electronic industry main consumers were step by step shifting to business, industrial machines, office PCs, controllers, automation etc. The space industry also, under the warmer political climate, was not any more the prime end-customer with key decision power to define the trends and needs for mass volume component market. The major change in the electronic industry happened during the 90th when the new individual electronic devices such as personal PCs, Notebooks, Digital Cameras, and Mobile Phones etc. began to dominate by far the high volume production needs. The move of the power to "individual consumers" has caused a dramatic change in the business model from Business to Business to Business to Consumer. The drivers for "mass market success" has become the cost, cost, cost ... achieved by high flexibility, short time to market, high volume production with high yield. As a consequence, **the space industry lost its past historical influence and decisive power to drive the major mass volume part of the electronic industry. The willingness of global manufactures to focus**

product development and support to space industry began to decline. On the other hand, the SME specialist component manufacturers has become of the critical importance bringing innovations, flexibility and speciality solutions.

The electronic industry growth cycles from 1970 to 2011 is illustrated in the Fig.1.

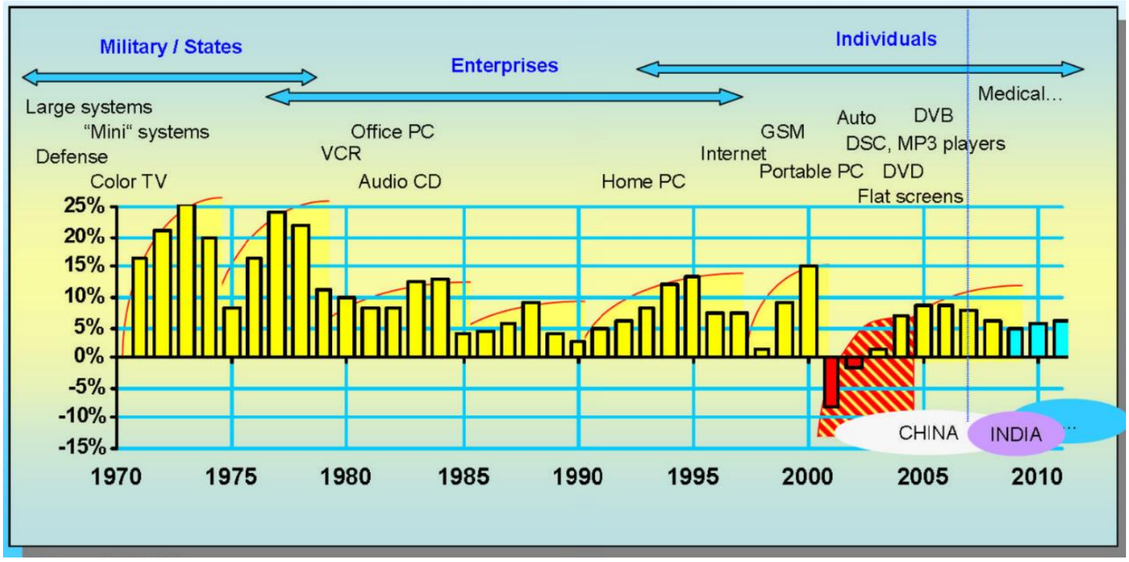


Fig.1. Growth Cycles of the Electronics Industry 1970 – 2011, source: Decision

Passive Component Market Notes

<u>Space Electronic Components Market</u>
According to [1], the space-based passive components represents a minor subset of the $1.6 billion global specialty passive components market with explosive growth in the commercial sector and continued rapid growth in the government sector.

This is a result of commercialisation of space industry in agency driven programs for private (non-government) subjects, low cost study missions (CubeSat, NanoSat …) as well as by the activities from the new private space companies' focused primarily on the space exploration commercial aspects (SpaceX, Virgin Galactic, Boeing …). **The value of worldwide government spending on space-based electronics increased from $27.6 billion U.S. dollars to $79.2 billion by 176% in past ten years,** making it one of the fastest growing electronics segments in the World. The value of demand from the commercial sector for space-based electronics between 2005 and 2015 has grown substantially. **The commercial market for space-based electronics, which did not exist in 2005, is now at least as large as the government market.**

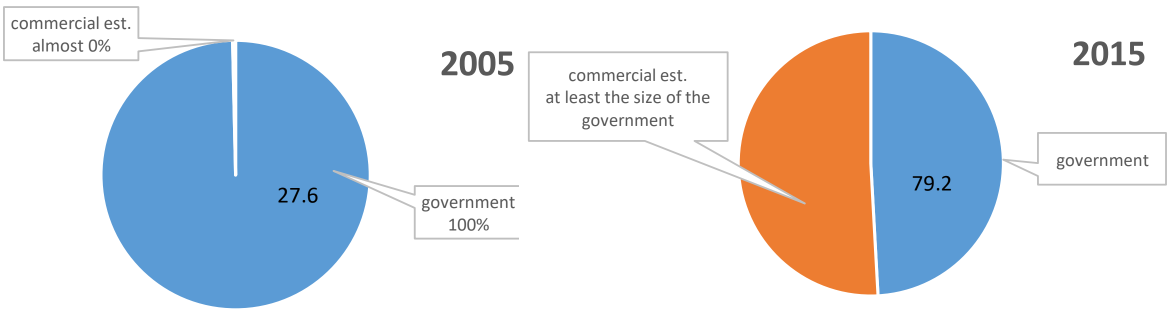


Fig.2. Worldwide Spending on Space Based Electronics in Past 10 years, datasource: Paumanok

Passive Components Development Background

Passive components are often considered by design engineers as "the simple & easy" parts of the circuits and the main attention has been paid towards the active components. In many ways this view is persistent for a whole passive component industry perception since the discovery of transistor in 50th of last century. The leading R&Ds, academia and laboratories worldwide has been focused on fundamental research projects for strategically important active components under a strong financial support from governments and public sources. In consequence, the "simple & cheap" passive components were "left behind" for a development mostly driven by the passive component manufacturers. It has not been financially viable for passive component manufacturers to continue investing in the fundamental research with deeper exploration of new materials, processes and mechanisms knowledge. Thus the **development and continuous improvement within the passive components industry has been practically performed by the individual private companies based on an applied experimental research with pragmatic goals to "resolve technical issue" or to develop something for a secured market with confidence in investment return.** The increasing cost pressure since 90th of the last century together with the fact that a significant cost portion for many passive components has been the labour cost, caused a move of many passive component manufacturing plants outside of Europe (and USA) to cheaper labour countries. Passive components, based on its nature, have been in many ways the "first pioneers" within the electronic industry for the cost saving driven re-location of high volume manufacturing elsewhere.

The situation with perception of passive component industry, particularly in Europe, has improved in past few years per my subjective view. The active component knowledge "counting single electrons" is on such a high technology and knowledge level, that any further small upgrade is taking a lot of effort and investment. However, looking at the PCBs, passive components still occupy more than 70% of the board space. This makes passive components as the "hot target" for the next generation step up upgrade in miniaturisation of electronics. We have already seen some latest practical results to adopt active components technology to create a new generation of nano-scale passive components such as for example silicon capacitors from IPDiA, France or CMOS IO technology based nano-supercapacitors from Smoltek, Sweden achieving very promising capacitance volumetric densities bringing new features to wide range of possible applications.

Passive Component Suppliers for Space

One can distinguish two basic types of space component manufacturers per its size, market and behaviour:

1] High volume manufacturers with a more or less dedicated line for space components
2] SME space component specialists

High Volume Manufacturers

The typical high volume manufacturers are today globalised companies with R&D, headquarter and centralised offices located mostly in EU, USA or Japan and high volume manufacturing production in cheaper labour countries worldwide. Their prime focus is to maximise their profit for its shareholders by leveraging the risk between the high volume, low cost manufacturing and the high end, higher added value products. This includes space applications that are representing small business share of the global company product portfolio, but the space segment is providing them the longer term stability that worth attention especially during the "down cycles" of consumer usage and global economy downtimes.

Typical high volume manufacturers' advantages from the space application perspective:

- financial strength, long-term presence and experience on the market
- **low cost manufacturing potential**
- **high volume production**
    - **knowledge of the "true ppm failures" of the component technology**
    - **availability, short time to volume**
- prime interest in low cost, high volume = high yield target linked with continuous investments into the technology stability and improvements.
- experience from wide range of industries & global markets – automotive, industrial, medical – applicable to new space missions
- automotive suppliers with well-defined and audited quality system, "0" ppm and continuous improvement goals, mandatory single failure unit return analysis …

Limitations:

- **space, not necessary the prime focus application, some better profit interests may exists elsewhere with higher risk of:**

- move of manufacturing to new locations outside the region
  - space product obsolescence
  - lower cost driven technology changes across the product range
  - limited interest in component reliability > ~ 2k hours
  - limited interest in physical life modelling based on fundamental research
  - limited interest / slow response to provide special tests and data for space needs
- decision making far from the production – issues for innovation, product knowledge oriented decisions, fast decisions
- some low cost driven innovations may have an impact on overall product performance (sometimes actioned without notice)

SME Space Specialists

SME Small and Medium Enterprises represent a wide area of different kind of manufacturers from sub ten to 250 employees making the real low volume specialities up to a "serious" volume scale production competing with large companies on a global market.

The general advantage of SME specialists for space applications:

- **close to the product = new ideas, innovation, fast decisions, responsiveness**
- **usually excellent product knowledge / problem solving capability**
- flexible in low volume, high variability product versions
- **can be space application oriented = high motivation to succeed**

Limitations:

- limited financial stability
- limited investment capabilities
- limited access to market and market knowledge (compare to global companies)
- **small production – the ppm failures unknown or statistically not reasonable**
- can be limited to space applications only = too much dependent to space industry
- limited liability

COMMERCIAL VERSUS SPACE COMPONENT REQUIREMENTS

Commercial applications are representing a wide area of different requirements, usage conditions, basic & special requirements, life expectations etc. The main applications are usually split into the following typical segments: aerospace, automotive, consumer, defence, industrial, medical and telecommunication.

See the following table Fig.3. for requirements and aspects of the selected applications and their typical parameters. It is evident, that each application has its own specialities and there are no "real close" conditions in the other industries similar to the space requirements. Automotive industry can be considered the "closest friend" from many aspects of the product and quality/system requirements, but it should be noted that the car is most of its life in "OFF" state unlike the space systems, on the other hand humidity/harsh conditions are of much higher concern in the case of automotive product lifetime. Industrial applications, as the next example, can cover very demanding applications were product capability and life time has to be many times carefully evaluated at their operation limits, however the requirements at each industrial sub-segment are so different that a central certification authority and standardisation would be difficult to establish and maintain. The qualification is well defined and controlled in the case of medical life support devices, but the product requirements are completely different based on the body implantation specifics. Consumer industry, with the largest volume manufacturing share, is focused primary on low cost and it can tolerate some level of faults that would be completely unacceptable for high reliability markets such as space, medical or automotive.

Parameter		Space	Automotive	Industrial	Medical (life support)	Consumer
Market size (component volume)		small	high	medium	small	very high
Component cost		high	medium	medium - high	high	low
Main Component Feature 1 - 5 (5 most sensitive)	reliability	5	4	4	5	2
	cost sensitivity	1-2	3	3	1	5
Time to Market		2-10 years	2-3 years	~ 2-5 years	~ 10 years	3-6 month
Component Longevity		2-25 years	10 years	15-20 years	10 years	1-2 years
Component "ON Time"		90%	**5%**	60-90%	100%	30 - 80%
Specification & Test Methods	responsibility	**agency**	**AEC**	custom,CECC, IEC	**FDA**, custom	CECC,IEC
	requirements	strict	semi strict	strict	strict	custom
Manufacturing & Quality System	responsibility	agency	ISO,TS16949	ISO 9000, IRIS ...	ISO13485	ISO 9000
	Requirement	mandatory	expected	expected	custom strict	recommended
Alert System		**Yes**	No	No	No	No
Certification / Compliance		**agency**	self	self/customer	**FDA**	self
Periodical Audits		agency	customer	customer	FDA/customer	NA
Typical Load / Qualification	life at Hi Temp	> 2000 hrs	2000 hrs	>2000 hrs	BT operation	1-2000 hrs
Environment	Hi/Lo temp	No/Yes	Yes	Yes / Harsh	No	No
	thermal shock	Yes	Yes	Yes	No	No
	vibrations	strong	continuous	appl. specific	No	No
	radiation	High	No	No	No	No
	humidity	No	Yes	Yes / Harsh	Yes	Yes
	oxidisation	No	Yes / Harsh	Yes / Harsh	No	No
Typical Application Characterisation		highly derated	rarely harsh	demanding	benign	no margin

Fig.3. Some Component Applications Requirements, source: EPCI

Nevertheless, the **automotive industry** can be considered as the closest-to-consider component level specification for the space applications based on the following advantages:

- common AEC standards under control of AEC council
- large, homogenous, cost competitive market (space industry non-dependence)
- common accepted qualification standard AECQ-200
- expected (not mandatory) quality system TS16949 (audited by third party) including PPAP, FMEA, 8D Problem Solving …..
- change notification system in place

with notes on differences / limitations:

- minimum modular order quantity may apply
- commercial drivers for component technology (pure tin)
- manufacturer may reserve a right to supply a "better" part than ordered (incl. different construction)
- manufacturers "self-certification" to AECQ, no independent compliance verification
- region of origin, can be in labour cheap countries (self-certified to AEC, most are TS16949 certified but it is not mandatory AEC requirement)
- unique automotive PN not strictly required (issues with traceability at distributors …)

Space Applications

Space environment is indeed a very complex range of possible applications with diverse operating conditions and criticality level.

1. Based on the <u>space application usage</u> criteria we can considered the following main application areas:

   Ground infrastructure (launch, radar, instrumentation…)

   - known environment and risks
   - typically benign conditioned environment
   - operation time from few hours (launching equipment) to years (radar)

Close to Earth flying hardware (low orbit, high orbit)

- wide experience and “known” issues
- mostly benign conditions: stabilised “room” environment
- humidity / oxygen-free conditions
- high vibration during the launch of prime concern
- lifetime from years (low orbit) to tenth years (high orbit)

Deep space missions flying hardware

- limited knowledge of operation conditions
- extreme harsh environment may occur
- tenth years operation lifetime

2. Based on mission criticality – el. circuit position / lifetime criteria:
   - mission critical (main power supply)
   - mission limiting (key support function)
   - supporting function (not influencing mission aim)

Up-Screened Components

Definitions:

COTS: An assembly or part designed for commercial applications for which the item manufacturer or vendor solely establishes and controls the specifications for performance, configuration, and reliability (including design, materials, processes, and testing) without additional requirements imposed by users and external organizations. For example, this would include any type of assembly or part from a catalogue without any additional parts-level testing after delivery of the part from the manufacturer.

COTS Plus: A COTS part supported by test data available to end users establishing random failure rate assumptions, performance consistent with the manufacturers data sheet and methods to exclude infant mortal parts, parts with latent defects, weak parts, or counterfeit parts. For example, automotive electronics council-certified or compliant automotive parts are one type of COTS Plus.

Parts Qualification: Sample-based mechanical, electrical, and environmental tests at the piece parts level intended to verify that materials, design, performance, and long-term reliability of parts on the same production line are consistent with the specification and intended application until a major process change.

Parts Screening: A series of tests and inspections at the piece parts level intended to remove nonconforming and/or infant mortal parts (parts with defects that are likely to result in early and/or cluster failures) and thus increase confidence in the reliability of the parts selected for use.

The up-screening process of COTS+ components can be prepared by a third party independent company or the manufacturer itself. Both ways have their advantages and limitations – the manufacturer can gather a wider technology process data, product history and the technology knowledge incl. awareness of the current issues etc., the third side company provides independent verification of the product performance and it reports every single failure.

The COTS+ up-screening is also usually available in different levels, typically containing extra burn-in to remove infant failures, DPA destructive physical analysis and high temp, high humidity test for military use. See Fig. 4 for example on manufacturer MLCC COTS+ up-screening options offer.

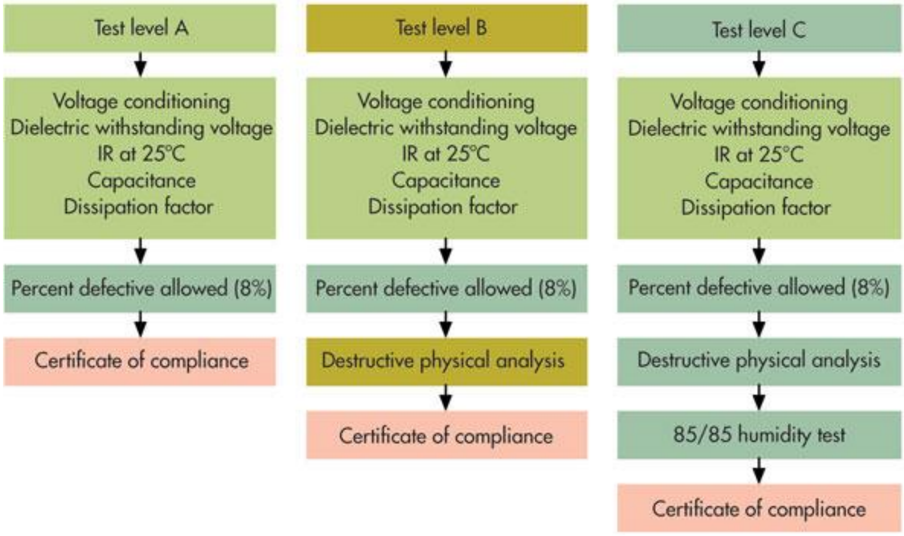


Fig.4. Manufacturer's example of COTS+ option. Level A involves statistical lot defect testing, level B adds destructive physical testing, and level C adds 85/85 humidity testing. (source: Kemet)

COTS+ considerations:

- "quality must be manufactured, not screened", basic ppm failure level of the technology is the same as the original commercial product
- "burn in" is not mandatory for commercial parts
- main purpose of COTS+: remove infant failures, minimise risk of maverick lot and maverick part and quantify the individual batch reliability level (at least relatively) using statistical tools (Weibul) & stress factor calculations.
- reference MIL document for failure stress acceleration factors is tenth years old, validity for todays / new technology ?
- the statistical tools – Weibull – has been set up for relatively "high level" of catastrophic failures that regularly occurred on older components under accelerated conditions. The new high tech technologies may need to use higher acceleration stress factors to see catastrophic failures to be able to make the life prediction calculations … are we stressing the components too much to see at least some failures caused by mechanisms that have no relevance to the real application environment under the high derating policy in space ?
- parametric shift is of more serious concern today than catastrophic failures.

EVALUATION AND EXPERIENCE OF COMMERCIAL PARTS IN SPACE APPLICATIONS

The following section is providing an overview of the recently published results and feedback on procurement, evaluation and testing of commercial components by space companies as mostly presented during the ESCCON symposium in March 2016 at ESA/ESTEC:

<u>COTS validation for the Solar Orbiter, ESA & Alter, presented at ESCCON 2016, [2]</u>

EEE parts were procured for instruments on Solar Orbiter project. The main driver to set up the instrumentation separately from the main project was that ESA need to assure that the instrument consortia would succeed in procuring in a timely manner components compliant to the quality and technical requirements of the Solar Orbiter mission. After a quite extensive standardisation activities and proposals of alternative qualified parts still many exotic parts and commercial parts were needed without any valid qualified alternative suitable for the specific instrument design.

Experience / Lesson learnt:

- *issues with credibility and completeness of datasheets*
- *issues with communication with manufacturers – slow response, wrong information provided*
- *re-tinning process and solderability issues*
- *film capacitor low temperature application issues*
- *lack of knowledge on product capability and performance*

Commercial Satellite Perspective on EEE parts, SSL, presented at ESCCON 2016, [3]

The commercial satellite industry is robustly competitive on a global scale. Nine years summary of EEE parts usage on some fifty spacecraft. While the trend of late unit failures due to EEE parts is much improved, any EEE parts issue can become significant. As the industry evolves, new technology parts are becoming "standard" without flight heritage. COTS parts are being considered where the reliability and quality can be demonstrated. "Standard" usage parts are the parts with highest ESA qualification, "non-standard" parts are screened and qualified to be equivalent to the closest MIL standards. T grade capacitors are used where available, but R/S acceptable.

Experience / Lesson learnt (cross program issues):

- *1uF ceramic capacitor caused a million dollar rework issues in 2006 and modification of the internal process program*
- *rigorous use of the highest available EEE parts has reduced but not eliminated the number of issues*
- *tantalum capacitors improved with surge screening, still issues with ceramic capacitors*
- *resistors general reliability is excellent*
- *strong pressures to lower costs using COTS parts*

NASA Automotive Component Reliability Studies [4]

NASA is actively evaluating commercial components for its capability to risk associated with use for space systems. Automotive components testing & procurement experience were summarised in [4]:

Experience / Lesson learnt from purchasing:

- *Anybody can buy catalogue "AEC Q" parts via authorized distributors. However, many large volume automotive electronic system manufacturers DO NOT buy "catalogue" automotive grade EEE parts. Instead, they procure via internal SCDs based on "AEC Q" catalogue items*
- *SCDs used to tailor and control specific needs (e.g., unique test requirements, internal part numbers)*
- *Some distributors demonstrated no knowledge of AEC components and suggested other parts they had in stock as replacements*
- *Traceability needs careful control – distributor documentation may not have same details as manufacturers*
- *Some AEC Q ceramic chip capacitors may be supplied with either "flexible termination" or "standard termination" at the discretion of the supplier. Manufacturer decided to sell an equivalent part "better than" the one ordered. Not just an issue for capacitors, potential for all part types*

Testing

See Fig.5. below with results on automotive parts testing:

Commodity	Test	Status	Comments
0805 Size 0.47uF, 50V 3 Different Mfrs All Use BME Technology	Construction Analysis	Complete	• All 3 Lots use BME Technology • At their own discretion a manufacturer supplied devices made with "flexible termination"
	Initial Parametric Measurements	Complete	• No Failures • DWV known to produce negative cap shift • Mfrs recommend bake-out to restore cap
	Life Test* (2x Vrated, 125°C)	> 8000 Hrs Complete (Progressing to 10k hours)	• 1 lot exhibits 8 catastrophic short life test failures (120pc) • 2 fail @ 3.1k hrs; 3 fail @ 4.7khrs; 1 fail @ 6.2khrs ; 2 fail @7khrs • 2 other lots starting to exhibit IR degradation after 7.5khrs
0402 Size 0.01uF, 16V 3 Different Mfrs 2 BME & 1 PME	Construction Analysis	In Process	• 2 Suppliers advertise BME and 1 advertises PME
	Initial Parametric Measurements	Complete	• No Failures
	Life Test* (2x Vrated, 125°C)	> 2000 Hrs Complete (Progressing to 10k hours)	• No Catastrophic Failures • PME lot has most stable IR through 2k hrs • Both BME lots showing initial signs of Hot IR degradation at ~500 Hrs

DWV=Dielectric Withstanding Voltage
IR = Insulation Resistance
PME = Precious Metal Electrode

* MIL requires 2000hrs, 0 failures for qualification

Fig.5. NASA automotive ceramic capacitors testing results, source [4]

Experience / Lesson learnt from testing:

- *so far, all parts tested, passed datasheet limits as received (basic electrical parameters)*
- *ceramic capacitor testing showed need for a bake out after DC Voltage to "reset" capacitance*
- *0805 Capacitor DPA showed different termination materials*
- *Datasheet gave a typical value for only one electrical parameter at high temperature and testing showed actuals were about 2x this "typical" value*

Summary of the commercial / automotive parts evaluation

There is indeed a limited number of test results and practical experience with automotive parts usage in space systems to conclude any statistically reasonable conclusions, nevertheless the indications can be present as follows:

- when automotive parts are used in real space applications (under the space derating rules), the failure rate is so low that it can be consider as not significantly different to the base reliability level to the space qualified components
- some automotive part failures are occasionally occurring during the qualification / AEC testing at the corner conditions (max load), few failures on qualified parts (with significantly lower occurrence)
- more often to see issues of automotive parts performance at the corner conditions are today parametric failures rather than catastrophic issues.

Based on such observation we can visualise a stress factor failure rate life model for different manufacturing technology attitudes – see Fig.6.

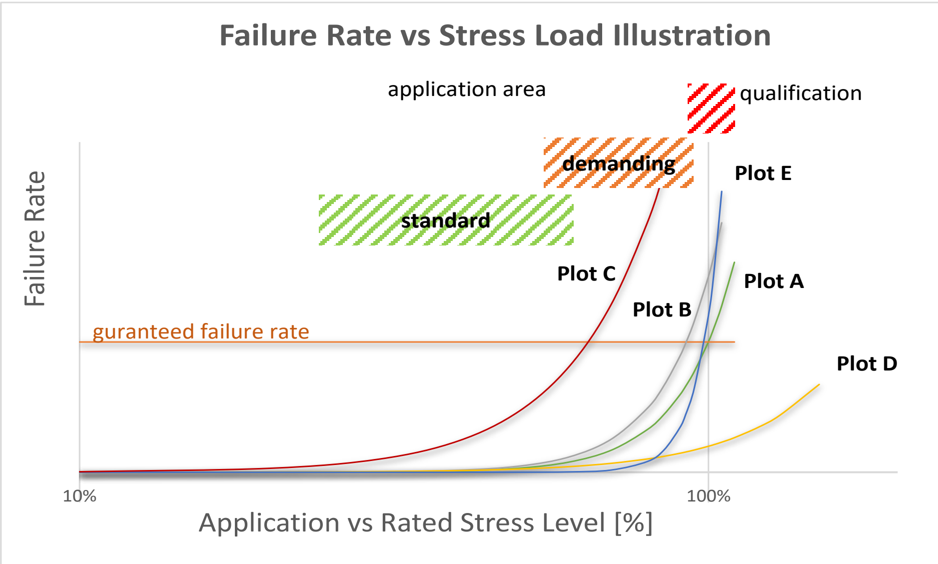


Fig.6. Failure rate versus Stress Load life model for different manufacturing technology attitude, source: EPCI

The model in Fig.6. is based on illustration of a "typical" attitude of different manufacturers towards their specific markets and applications. The failure rate is usually increasing exponentially with stress level applied (temperature, humidity, voltage …). The guaranteed failure rate is the specified worst case failure rate at referenced conditions (100% load = for example at 125C, 0.66Vr, 2 000 hrs …). This level is used for qualification testing, failure rate verification and the product capability approval.

We can imagine the following component behaviour based on the manufacturing technology and design attitude:

PLOT A – **"honest player"** represents the worst case of the "acceptable" component failure rate where the product exactly or with a small margin meets the criteria. This approach might be typical for specific demanding markets, where the "true players" behaviour is the key advantage and the long product life time at harsh conditions has to be maintained. … but it might be too expensive for a highly competitive and cost sensitive commercial market.

PLOT B – **"consumer high volume supplier".** Cost is the prime focus and market advantage, thus the design/technology reliability level can play a little way of "Russian Roulette" with some minor risk of qualification failures. The real application may be mostly benign and thus field failures may not be of a huge concern. Randomise failures at certain level are acceptable, if the cost is right. The question is how many "bullets are put into the gun" for the qualification roulette. Setting the right risk balance between "fail and loose customer" and "have a cost advantage" at the consumer application is a very sensitive decision for the company.

PLOT C – "**looser**", example of a short term low cost oriented product. The component may still be usable at the derated application with some non-negligible risk, but the qualification data may be a "complete fake" and hazardous game with customers.

PLOT D – "**reliability guardians**" the product is tuned and made to minimize the risk of failures. Its capabilities are far better than the specified reliability. This is the wish list from space, medical life-support and other mission critical applications … nevertheless the product is by nature more expensive (exponentially higher with its performance). The aim is to achieve the performance by leading HiTech technologies not justifiable for the other markets to achieve the best in class results … as of course, providing the extra reliability in double the size and twice heavy packaging using the conventional technology may be out of the right attitude for space applications.

PLOT E – "**technology masters**" the target is to use the Hi-Tech technologies to improve the product performance within its required operation range that can starts to deteriorate with stress at "just" or close to the specification limit. This can be achieved for example by using new Hi-Tech "Nano" materials that dramatically improves the product reliability, but at the same time to reduce thickness of dielectric layers, conducing pass etc and thus achieve targeted cost saving due to the usage of less amount of more superior materials. It may still be a little bit of Russian roulette for qualification but product performance with some application derating may still perform well at fully acceptable level. This may be a target approach on automotive high volume component manufacturers, where cost still matters, but the "0" ppm failures as well.

The conclusion from this modelling is that **the basic failure rate level of automotive components may not be far different to the space qualified components when <u>the appropriate application derating is applied.</u>** However, **the automotive components may not be suitable for operation in demanding conditions close to their specification limits.** Higher number of qualification failures (mainly parametric) seen on automotive parts compare to the space qualified components supports this conclusion. Thus logically, the "recommended" derating guidelines for automotive versus qualified components in space environment should follow the illustration in Fig.7

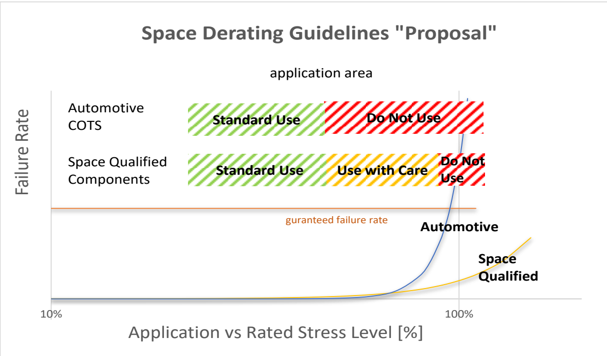


Fig.7. Proposal on derating guidelines for Automotive and Space qualified components, source: EPCI

CHALLENGES FOR AUTOMOTIVE COMPONENTS USAGE IN SPACE APPLICATIONS

Apart of the life performance and the basic reliability level, there are some next considerations that may limit use of the COTS "strait from the box" automotive parts in space applications:

<u>Technologies with (un)known issues in space applications</u>
There are some technologies that are not suitable for space application, but they are qualified and used in automotive. Some of them have been already identified based on the past issues and listed for example in ECSS-Q-ST-60C 6.2.2.2. The specifics of space environment compare to the automotive may include:

Requirements for higher **vibration** robustness during the launch time. The components of concern are typically parts with potential mechanical issues such as thin / narrow wires (thermal sensors, low Amp wire fuses, relays), mechanical position monitoring (potentiometers) etc.

Some space missions may also require components to withstand a **wide operating temperature range, continuous temperature cycling or vacuum operation under the limited thermal power dissipation.** Certain components on the commercial market may have difficulties with the heat control and thermal dissipation under vacuum environment such as hollow core resistors.

Passive components are considered as non-radiation sensitive devices based on the wide experience with conventional discrete components, nevertheless the new technologies may adopt some new organic based materials and getting closer to active component technologies … so it may be better to have a confidence about the **radiation hardness** with such new technologies.

… What are the other cases that we are not yet aware? … **There is always some risk associated with the use of commercial components in space flights without a flight heritage.**

<u>Lead-Free / Pure Tin</u>

Lead-Free is obviously one of the major challenge and concern while using commercial parts for space. Tin whiskers have a number of reported issues in space industry, thus no lead-free policy is a strong requirement for electronic hardware by space agencies. **Re-soldering of commercial components by solder dipping is increasing cost, but even more importantly, it may also cause some additional issues with solderability/joint mechanical strength. The additional thermal shock load during the re-soldering process may also impact the overall product ppm failure rate or cause some electrical parametric issues.**

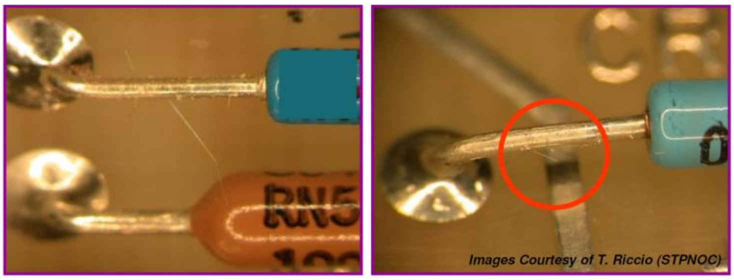


Fig.8. Tin whiskers on tin coated through hole leaded components, source: NASA

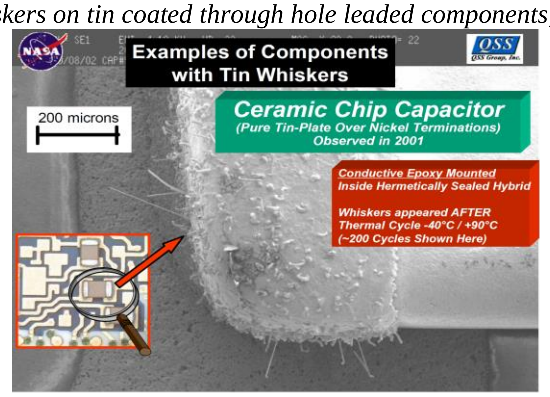
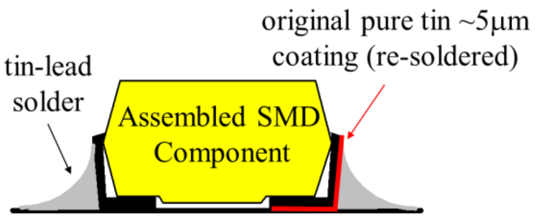


Fig.9. Tin whiskers on SMD pure tin coated capacitor assembled using conductive epoxy, source: NASA http://www.nepp.nasa.gov/whisker

Tin whisker risk on soldered component leads such as coated relays, through-hole wires etc. are of serious concern - See Fig.8 as an example. …, but is it possible to find a way for future to allow use of pure tin in some well-defined cases? There is, of course, another risk of mixing, and a careful traceability/process control is the "must" condition - see Fig.9. – Tin whiskers found on pure tin SMD part (supplied by an error), assembled by a conductive epoxy (non-resoldered). Nevertheless, it may worth to double think about all the consequences of the strict lead-free ban policy across the board.

A **safe way of "controlled" lead-free SMD components usage in microcircuits SMT applications using tin-lead solder paste assembly,** could become for example a lower cost and re-soldering issues eliminating solution for a significant portion of the future space micro-electronic hardware.



Small SMD commercial component leads are typically coated by a 3 – 10 µm pure tin solder. Such thin layer is completely melted by the solder paste during the reflow assembly processes. Thus, no pure termination leads are exposed after the assembly process – se Fig.10.

Fig.10. small SMD pure tin coated leads component after assembly by tin-lead solder paste

There are already existing ESA activities on lead-free technology - lead-free PCB assembly has been among the funded activities, ECSS-Q-ST-60-13C standard for commercial components is introducing lead-free component risk analysis steps opening a possibility to discuss the tin whisker considerations at the individual project / component level.

Traceability / Counterfeit Control

A clear supply chain using authorised distributors only is a mandatory condition for space procurement of commercial parts without any exclusion. The components shall be identified by its dedicated automotive PN (not used by all manufacturers and components) to avoid mixing with non-auto grade components. Control Source Inspection CSI may still be required on 100% basis with some data gathered from the manufacturer based on the practical experience with errors that occurs in real life such as - errors in datasheets/specification, lack of manufacturer data, distributor offered incorrect alternative part, manufacturers used its right to supplier "higher grade" parts without notice … These principle are also necessary steps to avoid counterfeit parts procurement.

Hermeticity / Storage Conditions

Majority of commercial / automotive parts are not hermetically sealed, and humidity/oxidisation may degrade its electrical, mechanical or solderability performance during a longer term storage. Dry pack (Moisture Sensitivity Level MSL level 3) is becoming a common practice to minimize ppm assembly failures in automotive industry even on the originally MSL level 1 (non-sensitive components) as a preventive measure. The "part logistic history issues" lessons are learnt - such as non-dry pack parts are transported by a sea boat in an open salt & humid & high temp environment, re-packed, and then having solderability / el. parametric / corrosion issues at the customers with manufacturer fault claim. Thus most manufacturers are offering MSL3 dry pack on automotive parts as a mandatory or at least as an option. MSL3 dry packing shall be a mandatory requirement from space industry for commercial component procurement specification.

COMMERCIAL IN SPACE COMPONENT GUIDELINES

The commercialisation of space yielded in a strong competition with pressure on cost down initiative, higher flexibility and shorter lead-times. All space agencies have already raised some programs and studied to evaluate suitability / conditions of commercial parts usage in space environment:

ESA / CNES / ECSS

CNES has started with first projects on EEE parts commercialisation in 1995 resulting in first CNES commercial component use standards in 2004, the approach was then consolidated in 2010 with the French space industry including Airbus DS, Thales and Thales Alenia Space [8]. The outcome of the work was reflected in co-operation with ESA and its published **"Commercial electrical, electronic and electromechanical (EEE) components" ECSS standard ECSS-Q-ST-60-13** issued in 2013. This standard is defining important elements of EEE component requirements including component programme management, component selection, evaluation and approval, procurement, handling and storage, component quality assurance, specific components, and documentation. **However, this standard is covering active components only and it is not applicable to passive components.**

ECSS-Q-ST-60-13 is defining 3 component classes – Class 1 "minimized risk", class 2 "risk vs cost compromise" and class 3 "minimize cost".

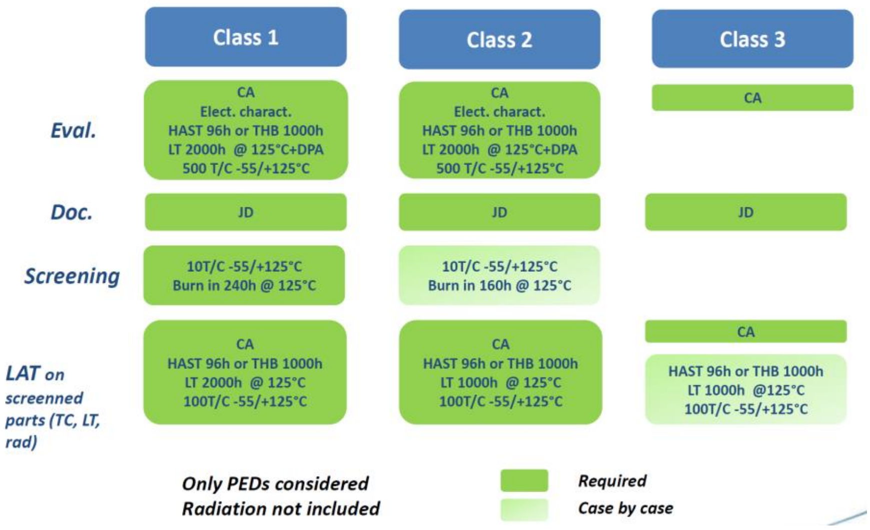


Fig.11. ECSS-Q-ST-60-13 component class definition (active components only)

<u>NASA</u>

NASA is also working intensively on the commercial component evaluation to establish guidelines for its use in space. All space EEE parts are following the NASA policy and the space part grade description guide [5]:

- Every EEE part intended for use in space flight and critical ground support equipment shall be reviewed and approved for compatibility with the intended environment and mission life, as applicable.
- Parts shall be selected so that flight hardware meets all performance and reliability requirements in the worst-case predicted mission environment

EEE Part Grade Description

GRADE	SUMMARY	RELIABILITY	RISK	MTBF	COST	TYPICAL USE
1	Space quality class qualified parts, or equivalent.	Highest	Very Low	Longest	Very High	Spaceflight
2	Full Military quality class qualified parts, or equivalent.	Very High	Low	Very Long	High	Space flight or critical ground support equipment
3	Low Military quality class parts, and Vendor Hi-Rel or equivalent. Screened automotive grade (AEC) EEE parts	Medium	Mediu m	Variable	Moderate	Space flight experiments, aeronautical flight experiments, critical ground support equipment, test demonstrations and ground support systems
4	"Commercial" quality class parts. Qualification data at manufacturer's discretion. No government process monitors incorporated during manufacturing.	Variable	High	Variable	Lowest	Aeronautical flight experiments noncritical ground support equipment, ground support systems, test demonstrations and prototypes. Limited critical GSE.

Fig.12. NASA EEE Part Grade Description, source NASA [5]

Another point to consider for commercial parts usage raised by NASA [7] is to focus also on the application side of the circuit by a "Fault Tolerant Design" approach. Notional EEE parts selection guide could look as presented in Fig.12. All fault tolerance must be validated. Good mission planning identifies where on the matrix a EEE part lies.

Notional EEE Parts Selection Factors

Criticality				
	High	Level 1 or 2 suggested. COTS upscreening/ testing recommended. Fault tolerant designs for COTS.	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.	Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.
	Medium	COTS upscreening/ testing recommended. Fault-tolerance suggested	COTS upscreening/ testing recommended. Fault-tolerance recommended	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.
	Low	COTS upscreening/ testing optional. Do no harm (to others)	COTS upscreening/ testing recommended. Fault-tolerance suggested. Do no harm (to others)	Rad hard suggested. COTS upscreening/ testing recommended. Fault tolerance recommended
		Low	Medium	High
		Environment/Lifetime		

Fig.13. Notional EEE parts selection factors. Source: NASA [7]

"Optional"
- Implies that you might get away without this, but there's residual risk.

"Suggested"
- Implies that it is good idea to do this, and likely some risk if you don't.

"Recommended"
- Implies that this really should be done or you'll definitely have some risk.

NASA's Commercial Crew Program (CCP) is in addition stimulating efforts within the private sector (Space X, Boeing …) to develop and demonstrate safe, reliable, and cost-effective space transportation capabilities to the International Space Station. One initiative involved investigating the possible use of commercial grade electronic parts in launch vehicle and spacecraft designs. The fundamental question is "Can commercial-off-the-shelf EEE parts with limited screening be used in crewed flight hardware systems?" [9]

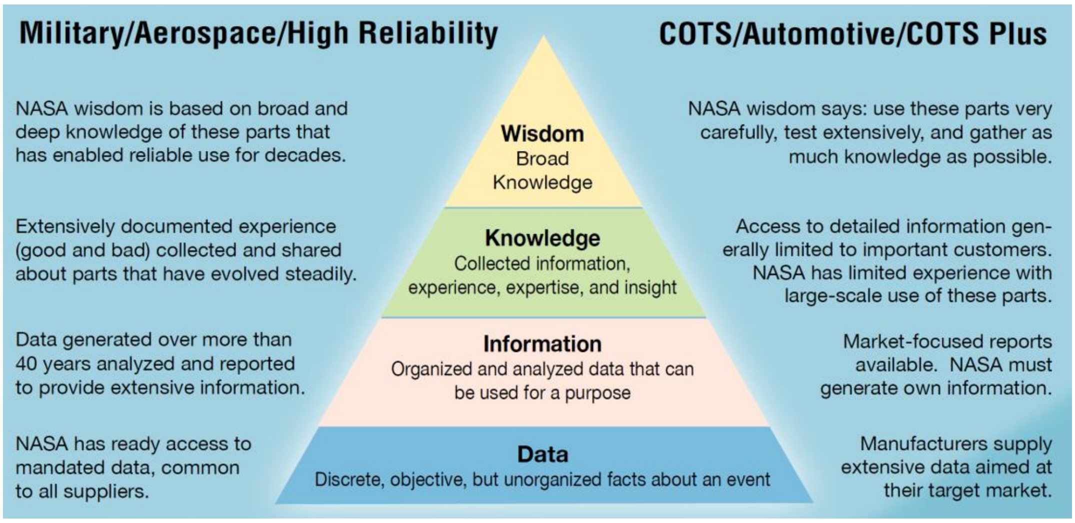


Fig.14. MIL vs Commercial component selection system comparison. Source: NASA [9]

NASA has successfully used commercial parts in spacecraft for specific and sometimes mission-critical applications throughout the Agency's history. This has been achieved by careful selection, qualification, and screening. The level of screening required for commercial parts to ensure they will work successfully is highly dependent on the mission, intended application, environment, mission duration, and part technology. The level of screening is quite well characterized in existing NASA parts documents such as EEE-INST-002. NASA flies non-MIL (non-military) grade parts when the required functionality and/or performance is not available in MIL parts. If a MIL part can be used, they are preferred. [9]

SUMMARY & RECOMMENDATIONS

The space based electronic market has doubled in past ten years, showing a vital growth in the government projects and explosive growth in the commercial space sector. The commercial market for space-based electronics, which did not exist in 2005, is now at least as large as the government market. The increased competition is looking for new lower cost commercial based solutions that would be applicable in space environment. This is true also in the segment of EEE components and passive components.

Commercial space-ready to use components shall bring the following benefits:

- Lower cost
- Shorter time to market of new technologies that may enable new functionality/missions i.g.:
    - Availability
    - Faster Qualification
- Reliability level and performance that meets the mission objectives

The related challenges on the application / procurement / system requirements may include:

- Lead-free components – re-soldering or defined conditions for use (SMD microcircuits)
- Operation lifetime - at defined operation conditions (environmental exposure, mission lifetime, criticality of application)
- Country of origin acceptance
- List of "No-Go" technologies
- Fault tolerant design systems
- Special CSI, Customer Source Inspection

The lessons already learnt from the use / evaluation of the commercial components in space applications suggests that the commercial and automotive parts at present stage are not bringing the sufficient confidence to accept them as COTS, "strait from the box" components. The basic reliability level of the automotive component technology at the derated application condition may be as good as the space qualified level parts, nevertheless there is a higher risk of infant failures, maverick lots, maverick parts and procurement/shipment errors that needs a careful attention. Some technologies are also not suitable for space environment and acceptance of pure tin lead-free finish on SMT micro-components may need to be addressed. Thus some level of screening and CSI may be mandatory requirement nowadays – it means the use of COTS+ components might be necessary at present time.

Nevertheless, the use of automotive passive components with COTS approach (use of non-screened parts) – **the real low cost solution and quick qualification** - may be possible in future upon meeting the following criteria:

- The mission profile allows to use such components
- Use allowed only in circuits with a relevant space application derating applied
- The component is listed on "approved automotive technology ready for space list" that needs to be prepared by agency. (evaluation to include review of non-space compatible technologies, radiation hardness …)
- The part is "fully automotive grade" = manufacturing location is TS16949 certified, product with dedicated automotive PN, MSL3 dry packed, AECQ data package ready …
- The parts are procured under CSI rules (defined by agency)
- The manufacturer has implemented dynamic statistical screening of electrical parameters. (agency may need to keep list of "evaluated & approved" manufacturers and their products)
- Fault tolerant circuit design in place

<u>Recommendations (To Do List):</u>

- Closer active co-operation with AEC council. Agencies should re-gain its power over the large volume manufacturers – for example joint component failure alert system, implementation and active participation in AECQ200 random pick qualification test verification of products on the market (by "lower cost" testhouses… reported back to AEC council and issued to all auto makers.)

- Together with AEC council, push manufacturers to establish screening practice that would include burn-in and dynamic statistical screening to remove infant failures, maverick lots and maverick parts – it may well suit automotive zero ppm goals … (also in agreement with TS16949 continuous improvement policy)
- Re-examine lead-free acceptance and guidelines (SMD microcircuits?)
- Need clear usage guidelines for such new class of components versus mission criticality application position / life expectancy / fault tolerance circuits.

When the above items are met, quick qualification of new automotive parts is realistic = review of AECQ manufacturer data, plus critical space parameters (agency questionnaire, DPA, additional tests …) etc. Development of "fault tolerant" systems should be part of the "automotive for space" acceptance procedures as well.

Challenge	Proposed Solution
Faster Adoption of New Technologies	New Evaluation & Qualification Procedures
Component Technologies without Flight Heritage ("unknown risks'	Cont. Nanosattelite Space Flight Prove Program
Vibration, Radiation Hardness, Vacuum operation …	List of Qualified / NO GO Technologies
Lead-Free Pure Tin Termination Coatings	Lead-Free Policy for Specific Micro Electronics
Supply Chain Control & Traceability, country of origin, incl. storage	Specific COTS Control Inspection
Distribution Suport Level	Qualified Distributors
Fault Tolerant Systems	New Application / Circuit Design Practices
Basic Failure Rate	Insisting on Space Derating
Controlled Quality System	Use of Automotive Components with dedicated PN
Failure Alert & Investigation, Get power over Large Manufacturers	Co-operation with AEC Committee, joint Alert system
Burn-In, Statistical Control, Maverick lot/part Control	Joint push with AEC Committee to Auto Suppliers

Fig.15. Summary Table of Challenges and Proposed Solutions

- **Trust but Prove** … lessons learnt are saying "copy & paste" from automotive to space usage may not work, however the low cost space is achievable using automotive parts under some controlled way (it may need some effort to develop all the necessary tools & steps)

CONCLUSION

We are indeed living in an important milestone era in the space industry history now. The commercialisation of space in past ten years has changed significantly the traditional look at the space market based on the government / institution directions and orders. There are new commercial projects and customers for the existing space supply chain on one side, but there is also a growing number of new private, profit-oriented, companies with a vision to create and enter new, future space market. The companies like Space X, Deep Space Industries … have been working on policies, international laws in past fifteen years to open up the space for private commercial companies. This initial phase is step by step completed and we can see realisation of the first practical private space projects such as "back to Earth rocket return" or "Moon travel mission" implemented by significantly lower cost at relatively short preparation time.

It is up to the agencies now to pick up the challenge. Join this effort from private companies to prepare new policies, specifications, guidelines, expertise based on their deep & wide knowledge towards the lower cost, availability and "quick to qualify" safe solutions. If they succeed, they will continue to drive the "mass" of the space industry, unless the private companies may create their own company standards and selection guides that will apply (without influence from agencies) within the attractive "high volume" and fast growing "New Age" of space industry. The space market is opening up for new commercial era, lets' be part of the vision – and make the move together – see fig.16.

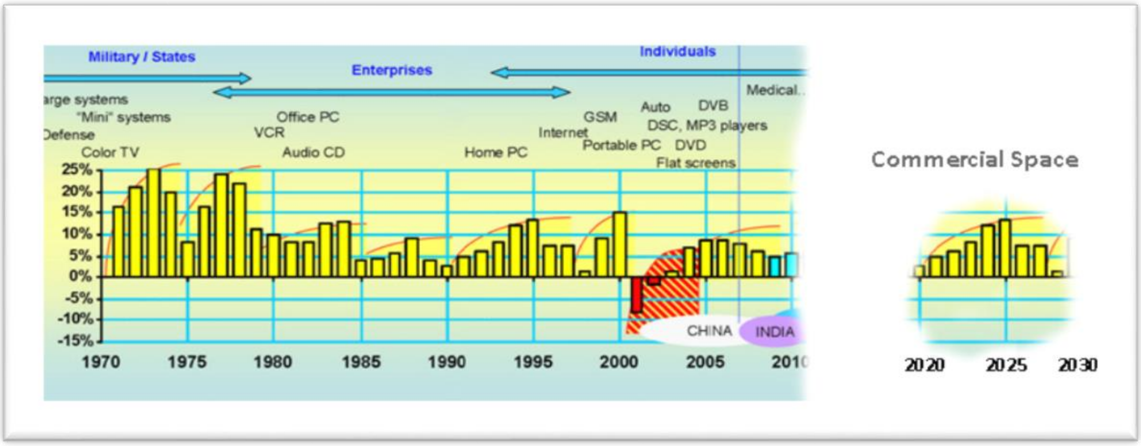


Fig.16. A vision of future commercial space business impact on electronic industry 2020-2030, EPCI

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