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宇宙航空研究開発機構特別資料
JAXA Special Publication

第19回 マイクロエレクトロニクスワークショップ
THE 19th MICROELECTRONICS WORKSHOP
<MEWS-19>

宇宙開発を支える部品材料の安定供給と品質の確保

平成20年1月

宇宙航空研究開発機構
Japan Aerospace Exploration Agency

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開催趣旨

JAXA は、宇宙用電子部品・材料及び機構部品の開発や調達に関して、世界の動向を注視しながら、我が国が進むべき方向、更に我が国に整備すべき宇宙用部品・材料技術を探るために、内外の宇宙機関、システムメーカ、部品メーカ及び部品輸入商社などの広範囲の参加を得て、各年度毎にふさわしいテーマを選び、活発に討議し、意見や情報の交換を行うことを目的にマイクロエレクトロニクスワークショップ（Microelectronics Workshop:略称 MEWS）を毎年開催しています。

またこのワークショップに併設して、国内外の企業による部品展示も行っております。この部品展示会は、部品メーカが内外のシステムメーカ参加者に直接その技術力をアピールしたり、具体的な商談のできる場であると同時に、ユーザーの要望を聞き、新製品開発・性能改善のきっかけの場となっています。一方、システムメーカは一同に会した宇宙用部品メーカ及び関連輸入商社等から最新の情報を得ると同時に、部品メーカに対する要望を投げかける場となり、部品メーカ、システムメーカ双方の情報交換の場として利用されています。

第 19 回マイクロエレクトロニクスワークショップ（以下、MEWS･19）は平成 18 年度 10 月 25 日から 27 日にかけて、筑波宇宙センターにおいて、開催されました。
MEWS-19 はそのメインテーマを「宇宙開発を支える部品材料の安定供給と品質の確保」とし、海外の宇宙機関 NASA、ESA、CNES の部品部門の代表者及び GEIA のチェアマンから、各機関の宇宙用部品の技術開状況や部品調達プログラムの状況や問題点などの報告をしていただきました。

さらに特別講演としてジョンズ・ホプキンス大学のオシアンダー博士による宇宙用 MEMS について、株式会社デンソーの大沢室長に車載用の電子部品の品質向上活動について講演していただき、好評を博しました。国内部品メーカ及び JAXA 職員による開発成果、開発状況などの論文発表も行われたことは言うまでもありません。詳細は次ページ以降に掲載する発表資料をご覧ください。

また MEWS-19 では従来の部品展示会に加え「MEMS＆ナノテク関連展示会」を開催し、新たな将来技術の利用及び参入の端緒を開きました。 MEWS-20 以降も宇宙用部品・材料・機構技術に「MEMS＆ナノテク」技術を取り入れ、実用化へ努力していきます。

このような活動がこれからの日本の宇宙開発の基盤を支えるものとして少しでもお役に立てれば幸いです。

NASA: Nationa1Aeronautics and Space Administration
ESA: European Space Agency
CNES:Centre National d'Etudes Spatiales
GEIA: Government Electronics and Information Technology Association
MEMS: Micro Electro Mechanica1 Systems

平成18年10月26日(木)ワークショップ第１日

10:00-10:10（10分）
開会の挨拶：坂田 公夫 理事・本部長（JAXA 総合技術研究本部）

基調講演

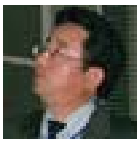
10:10-10:40（30分）「JAXA 基礎技術力の強化に関する現状と将来」
渡辺 篤太郎 執行役（JAXA）

特別講演・１

10:40-11:40（60分）「MEMS and Micro-structures in Aerospace Applications」
Dr. Robert Osiander : Assistant Group Supervisor, The Johns Hopkins University, Applied Physics Laboratories

11:40-11:45（５分）連絡事項（事務局）
11:45-13:15（90分）昼食及び部品展示会、MEMS＆ナノテク展示会の見学

特別講演・２



13:15-14:05（50分）「車載用電子部品の品質向上活動」
大沢 博昭 室長（(株) デンソー 電子品質保証部）

〔講演者の意志により、本誌には講演資料を掲載しておりません。〕

海外招待講演

14:05-14:45（40分）「NASA EEE Parts and Packaging Program (NEPP), An Overview of Current and Future Activities」
Michael Sampson：Program Manager, NASA Workmanship and EEEParts Assurance

14:45-15:25（40分）「GEIA G-12 Solid State Devices Committee Initiatives」
Mark Porter : Chairman-GEIA G-12Solid State Devices Committee

15:25-15:40（15分）休憩

15:40-16:20（40 分）Micro & Nano Technologies at the European Space Agency
Laurent Marchand : ESA/ESTEC

16:20-17:00（40 分）Status of main CNES activities with regard to strategic technologies and components in the domain of silicon ICs
Jean-Louis Venturin : CNES

宇宙用部品技術 委員会 分科会報告

17:00-17:15（15 分）電子部品分科会活動状況報告
大西 一功 教授（日本大学 理工学部、電子部品分科会長）

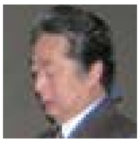
17:15-17:30（15 分）機構部品・材料分科会活動状況報告
本田 登志雄 部長（東京エレクトロニツクシステムズ（株）、機構部品・材料分科会長）

17:30-17:35（ 5 分）終了挨拶・連絡（事務局）
17:45-19:15（90 分）懇親会（会場：技術交流棟）

平成18年10月27日（金）ワークショップ 第2日

09:30-09:35（ 5 分）開始挨拶及び連絡（事務局）

論文発表：宇宙用電子部品 研究開発活動状況



09:35-10:00（25 分）電子部品の開発状況報告
久保山 智司 技術領域リーダ（JAXA 部品・材料・機構技術グループ）

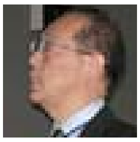
10:00-10:25（25 分）「COT を導入した宇宙用 LSI 生産システムの確立」
浦野 幹彦 副主任技師（高信頼性部品（株）技術部）

10:25-10:50（25 分）「耐放射線応用に向けた完全空乏型 SOI 技術」
井田 次郎 部長（沖電気（株）研究本部 SOI 技術研究部）

10:50-11:15（25 分）「LSI プロセス診断」
田中 大起 氏（沖エンジニアリング（株）信頼性技術事業部）

論文発表：宇宙用機構部品の研究活動状況

11:15-11:35（20 分）「宇宙用機構部品の研究」
小原 新吾 主幹開発員（JAXA 部品・材料・機構技術グループ）



11:35-11:55（20 分）「宇宙用波動歯車装置の開発」
上浦 啓次 マネージャー（(株）ハーモニック・ドライブ・システムズ 精機本部）

11:55-13:25（90 分）昼食 及び 部品展示会見学

論文発表：宇宙用材料の研究活動状況

13:25-13:45（20 分）宇宙用材料の研究
木本 雄吾 主任開発員（JAXA 部品・材料・機構技術グループ）

13:45-14:05（20 分）みどり 2 使用電線の材料評価
石澤 淳一郎 開発員（JAXA 部品・材料・機構技術グループ）

論文発表：海外部品関連報告

14:05-14:25（20 分）衛星搭載用 高信頼性コンデンサについて
山本 博章 代表取締役社長（ピーティーエム（株））

論文発表：安全・信頼性推進部関連報告 BGA 外観検査 RoHS 対応

14:25-14:45（20 分）X 線システムを用いた BGA の非破壊検査手法
中村 正夫 主任（日本アビオニクス（株）情報システム事業部 第 2 技術部）

14:45-15:15（30 分）JAXA RoHS 対応の動きと HSD の評価結果
根本 規生 主任開発員（JAXA 安全・信頼性推進部 技術開発室）

論文発表：宇宙用部品 DB の状況

15:15-15:45（30 分）プロジェクト承認部品データベースの紹介
松岡 毅 主任開発員（JAXA 部品・材料・機構技術グループ）

15:15-15:45（30 分）プロジェクト承認部品データベースの紹介

16:00-16:25（25 分）まとめ講演
田村 高志 グループ長（JAXA 部品・材料・機構技術グループ）

開催結果報告（概要）

Ⅰ　1 日目（平成 18 年 10 月 26 日（木）10：00～17：35）

１．開会挨拶　宇宙航空研究開発機構　総合技術研究本部本部長

理事　坂田　公夫

本日は、第 19 回マイクロエレクトロニクスワークショップに世界各国及び日本各地からお集まりいただき、大変ありがとうございます。

毎年この時期に開催していますこの種の会議は有意義な結果を得ていまして、私共の開発努力に貢献してきています。

本日も本会議において有益な議論や活発な意見交換が行われるものと期待していますし、そこから生じる成果を我々の次の開発研究に活かして参りたいと考えています。

また、近年宇宙用部品の分野における宇宙開発がいろいろと問題を抱えています。これは、宇宙用部品の安定的な供給や技術開発が困難になってきていることであり、ある意味では技術の曲がり角に来ているのではないでしょうか。

かかる観点から、マイクロとかナノは極めて重要な分野と位置づけています。私共、JAXA 総合技術研究本部としてはこのような分野を更に強化して、持続的な宇宙開発を推進してまいりたいと考えております。

このような分野における開発成果は宇宙に留まらず、他の分野にも波及するものと考えます。

この意味で、本日の会議の議論や意見交換の成果は今後有効に生きるものと確信している次第です。

本日はご参加いただき誠にありがとうございます。

（以　上）

２.　基調講演　「JAXA 基礎技術力の強化に関する現状と将来」

JAXA　執行役　渡辺　篤太郎

JAXA の基盤技術に対する取組みについて説明します。JAXA の組織は、大きくわけて 5 つの事業本部から成りたっています。その一つが総合技術研究本部で、その役割は残りの事業部の事業に対して成果を提供することです。即ち、JAXA の事業を支えていくことが重要な役割となっています。

この総合技術研究本部は 2 つの部署に分けられ、一つは航空の技術を支える部門、もう一つは宇宙活動を支える部門です。スタッフは 375 名で、その内宇宙部門は 183 名となっています。この人員で宇宙の基盤技術を支えている次第です。この宇宙部門は、更に 13 のグループに分かれ、3 ヶ所の事業所（角田、筑波、調布）に分散しています。

その主要な業務は、先行研究とその成果を研究開発に繋げていくこと、中には軌道上実証を行うこともあります。そのような研究開発がプロジェクトに反映されます。プロジェクト支援ということですが、実際は支援以上のことを行っていることもあります。そして、プロジェクトの支援を通じて、そのオペレーション及び評価に参加します。このような活動に参加することは、その結果として先行研究ないし研究開発に繋がります。

このようなサイクルを確立することが非常に重要な業務と考えています。この先行研究／研究開発／プロジェクト支援／運用・評価のサイクルの各レベルにおいては、JAXA 単独で実施するわけではなく、工業会、大学、政府系研究機関等との連携を行っているところです。

研究開発活動の具体例としては、宇宙機器を構成する重要なユニット、重要な部品・材料、プロジェクト支援技術としての解析・評価技術、ロケットエンジン等があります。また、研究開発を別な視点から、TRL (Technology Readiness Level)という指標を導入しています。1～3 が先行研究、4～6 のレベルがいわゆる研究開発の中心で、次のプロジェクトのユニットや部品開発に該当し、6～9 が現行のプロジェクト支援となります。

我々の研究開発の評価は、最近では、より綿密な形で行われております。まず、各センターレベルで行い（Peer Review）、それをまとめて各セグメントで

の評価になります。ここでは、JAXA のプロジェクト・マネジャーやユーザー及び外部の専門家よる詳細かつ重要な評価となります。その上に、本部レベルの評価があり、その後、理事長を長とする Board による JAXA 全体としての評価となり、最終的には政府レベルの評価となります。このような評価を受けて、次年度以降の研究開発業務に反映されることになります。

過去 5 年間に JAXA は衛星の打上げ失敗を経験してきております。そのたびに技術力の強化や組織の効率アップが大きな課題になってきており、総合技術研究本部としては、昨年 10 月組織改革を実施してプロジェクトと連携の深い専門グループを再編しました。

同時に業務の改革も進めまして、我々の関係する業務としては２点あるかと思います。一つは、研究部門としては異例の QMS (Quality Management System)を導入し、本年 3 月には ISO 9001 の 2000 年版の認証を受けております。この認証は TRL レベルの 3 ないし 4 以上を対象としました。2 点目は、NASA で開発され、国際的にも認知されつつある TRL という指標を導入して、研究のレベルをわかりやすく表示することになりました。

また、グループの再編ですが、各プロジェクトと 8 つのグループをマトリックス組織にして、プロジェクト毎に各グループの所掌分野についてはグループ自体で責任を持って遂行するということです。従来のプロジェクト内で全ての業務を完結する方法と比して、様々なプロジェクトを経験することで経験・知見の蓄積がそれぞれのグループで可能となります。これは、限られた人員で効率よく技術開発を遂行するために採られたシステムです。

我々の具体的な業務は、以下の 3 項目に分類されますが、時間の関係で項目のみの紹介とさせていただきます。

（1）現行プロジェクトへの支援

ロケット関係では、H-IIA ロケットの第 1 段エンジンである LE-7A、第 2 段エンジンである LE-5B、及び補助ロケットであります SRB(Solid Rocket Booster) への支援があります。国際的にみて、ロケットのトラブルではその 60%がエンジンに起因していると言われています。日本でも、過去 3 回の打上げ失敗では全てエンジンのトラブルでした。総合技術研究本部では、ロケット・プロジェクトの大部分はエンジンに関する研究開発や評価です。

衛星は対象が非常に多くあります。データ中継衛星の DRTS、地球観測衛星で現在定常段階にある ALOS、今年末打上げ予定の技術試験衛星 ETS-Ⅷ、通信・放送衛星の WINDS、月の観測ミッションである SELENE 等で担当部署が多岐にわたっていますが、ある衛星でコンポーネント等の改善が生じれば、他の衛星にもそれが反映されるという点でこのマトリックス方式は効率的だと思います。

次に宇宙ステーション関係では、日本の実験棟である JEM と軌道間輸送機である HTV の支援業務を実施しています。また、総合技術研究本部では各種のデータベースを構築しその充実を図っていますが、それぞれのデータベースは異なるアクセス・システムを有しているため使用しずらいという指摘もあります。従って、これらの異なるデータベースを有機的に結びつけて一つのシステムとして活用し、研究開発やプロジェクトの効率を図って参りたいと考えています。

（２）次世代プロジェクトの研究開発

これは、限られた資源を有効に活用するために、重点課題を定めてそこに集中することであります。具体的な部品開発例としては、”Guidance and Control Units” として、Star Sensor、Wheel、Fiber Optic Gyro、Next Generation GPS Receiver、”Electric Power System”として、High Efficiency Solar Cells、Lithium Ion Batteries、”Satellite Propulsion Units”としては、150mN-Class Ion Engine、The 20N Class Thruster Valve、その他”Telecommunications and Data Handling” 関連部品もあります。

更に宇宙環境計測装置の開発も重要な分野となっています。宇宙環境の正確な理解は、放射線の影響も含めて、衛星の運用にも重要なことですが、衛星自身のミッションから言うと必ずしも搭載しなければならない機器でもないのです。従って、装置の小型化と簡易な取扱に努め、原則として、全ての衛星にこの装置を搭載して、宇宙環境の正確な計測に取組んでいます。

もう一つ重要な点としましては、軌道上実証に重点を置いています。2002 年に打上げました MDS-1 に関連部品を搭載し、軌道上で実証しました。その実証の評価に基づき、必要な改善・改良を行いまして、現在の衛星の搭載部品に反映されています。同じ流れとして、50kg 級のミニ衛星を打上げて軌道上で実証を行っています。JAXA はロケットや衛星の生産・製造設備を有していませんが、この衛星は、例外で、JAXA 自身で設計・開発・製造したもので、衛星

に対する理解を深めながら人材の育成にも資するものです。

（３）将来の技術開発

詳細は配布資料を参考していただくことで、ここでは項目だけ述べますと、
ー宇宙エネルギーを利用した大規模な宇宙発電の検討、
ーロボティックス技術を利用した軌道上サービスの研究、
ー将来の再利用輸送機の研究
ー月・火星探査技術の研究、等
が挙げられます。以上で講演を終了します。ありがとうございました。

（以　上）

３． 特別講演－１

"MEMS and Micro-Structures in Aerospace Applications"

Dr. Robert Osiander
The Johns Hopkins University

自分はジョンズ・ホプキンス大学付属研究所の一研究機関である応用物理学研究所で、主として、MEMS の宇宙応用関係の研究に従事している。同大学の付属研究所は全体で 3,500 名程度、その内 60%が科学者である。ジョンズ・ホプキンス大学では数々の宇宙機を打上げており、最近では太陽や冥王星関係に科学ミッションの宇宙機を打上げた。

本日の講演は、MEMS に関する簡単な経緯、宇宙への応用にあたってなすべきこと、その具体事例、今後の展望、MEMS の宇宙利用に当たっての最大の関心事であります信頼性の問題等について、簡単に紹介します。

MEMS のはじまりは、1969 年に Westinghouse 社が resonant gate field-effect transistor に利用したのを皮切りに、1970 年代に入って bulk-etched silicon wafers に圧力センサーの生産用に利用、1980 年代にはディスク・ドライブのヘッド用に surface-micro machined polysilicon actuators の研究として、そして 1990 年代に空軍の科学研究室からの助成による材料研究の一環として MEMS の研究が行われ、1993 年には MEMS の飛躍的な発展がなされた。即ち、Defense Advanced Research Projects Agency (DARPA) によって Foundry がスタートし、MEMS の安価な製造が可能となった。我々のグループもここを利用して MEMS の製造を行ってきた。

その後、MEMS の宇宙利用が開始された。1998 年、スペースシャトルから MEMS 機器を搭載した Mighty Sat-1 が打上げられ、1999 年にはシャトル・オービタの micro/propulsion system の中に利用され、また、1995 年－2002 年には MEMS を利用した OPAL (Orbiting Pico satellite Automated Launcher)が打上げられた。

一般的な MEMS の利便性としては、
－アナログ・デジタル・機構対応の IC 機能、
－効率を向上させる精密性、
－製造コストや時間を削減させ均一性を保持した大量生産、

ー小型化を通じて、耐久性、低燃費、軽量化、多量配置、交換の容易性、及び環境への影響が小さいこと、
が挙げられる。

MEMS の商業的利用については、車のエアーバッグ用加速度計、ジャイロスコープ、RF スウィッチ、圧力センサー、マイクロホン、携帯電話、デジタル・ライト・プロセッサー等に及んでいる。

MEMS の商業市場への参入要因はコスト削減と大量生産であるが、宇宙はへの参入は技術的要因と少量生産であり、価格は製造コストというよりも宇宙への適用度によって決定される。宇宙において重要なことは、長期間にわたって機能するという信頼性の確保である。ただし、商業用の MEMS を厳しい宇宙環境に投入することは検討に値する。

MEMS を宇宙へ利用する利点としては、極めて軽量であること、消費電力が少ないこと、熱定数が小さいこと、振動や衝撃に強く、及び放射線に対しても耐久性があること、多機能でかつシステムの簡便性、そして伝統的な宇宙の要件ではないが、低価格・大量生産・大規模展開等が挙げられる。

NASA では MEMS 利用の技術開発を行っており、2001 年 59 件、2002 年 77 件、2003 年 111 件で、MEMS の部品として、"Stirling Cooler"、"Liquid Metal Micro Switches"、"Inertial Sensors"、"Microwave RF Switches and Phase Shifter"、"Thrusters"、"Deformable Mirrors"、"Pressure or Temperature Sensors"等が挙げられる。その他、MEMS 部品として代表的なものは"Accelerometers"、"Emissivity Control Shutter"、"Sun Sensors"、"Magnetometers"がある。

MEMS の宇宙での利用を推進する要因として、ユニークなプロトタイプの作成が可能となりますし、"Mirror Array"とか"Shutter Array"のように新機能を付加すること、"Accelerometer" や"Plasma Spectrometer"のように機器の小型化が可能となること、大量生産によって同時に 100 ヶ所以上の観測が可能となること、小型化や高次元コントロールによる性能のアップが挙げられる。

（MEMS 部品の具体的事例については、配布資料を参考願いたい）

MEMS の主要な利用分野としては小型衛星であり、特に 10kg クラスのナノ衛星乃至 1kg クラスのピコ衛星である。小型衛星は、コスト面、質量、搭載

機器、消費電力、多機能性等の観点から MEMS 部品は最適である。

MEMS 関連ミッションとしては､技術的立証としてはスペース･シャトル、観測衛星 (sounding rockets)､宇宙基地 (ISS)等があり､大学の衛星として Falcon Sat、MidStar、OPAL 等、また、ナノ／ピコ衛星が挙げられる。NASA によるこれらの技術立証は、60 年代は比較的小型の衛星で行われ、90 年代後半にはシャトルに実証も行われた。最初のシャトルによるフライトは、1998 年 7 月 23 日のコロンビア号であった｡最近の MEMS 関連小型衛星のミッションについては配布資料を参考願いたい。

MEMS の信頼性の問題ですが､MEMS 製品は今まで地上のみの試験を行ってきている。宇宙では極めて厳格な信頼性基準が要請されている。ある材質は宇宙用には向かない。特に単層のシリコン材質は宇宙では使えない。宇宙環境の特殊性に配慮する必要がある。また、MEMS の材質保護に特殊のパッケージ技術が要求される。

具体的に注意する点としては、一つは湿気の問題がある。湿気が高いと、MEMS 製品に静電気や電流漏れの問題が生じる恐れがある。二つ目としては埃や汚れがあると、ショートや障害、故障を引起す可能性がある。その他、打上げ時における激しい振動や衝撃は破損する場合がある。また、放射線、極小の宇宙塵との衝突､宇宙環境に特有な環境である無重力／高真空､極端な温度差、プラズマや放電等、更に材質疲労によって機能しなくなることが予想される。

結論を申し上げると､MEMS 機器は宇宙用に認定を受ける必要があること、いくつかの飛行実験を実施して、TRL のギャップを埋めることが重要であると考える。

（以　上）

４．　特別講演－２　「車載用電子部品の品質向上活動」

（株）デンソー　電子品質保証部

大沢　博昭　室長

（講演者の意志により､本誌には講演資料を掲載しておりません。）

５．　海外招待講演

（１）　初日の午後からは､｢海外招待講演｣として、４名の海外招待者(NASA、GEIA、ESA、CNES) による講演が行われた。最初に NASA/GSFC の Michael Sampson 氏から､｢NASA EEE Parts and Packing (NEPP) Program｣と題して、配布資料に基づいて、NASA の EEE（電気、電子、電気機械）部品と実装計画 (NEPP) について講演を行った。講演内容の概要としては、NEPP は TRL ４以上（R ＆ D ではなく、技術開発以上）であり、NEPP の枠内に NEPAG (NASA Electronic Parts Assurance Group) が活動していると説明。NEEP は 2005 年から特定の部品プロジェクト(FPGA's、Non-Volatile Memories、Advanced Mixed Signal、Scaled CMOS、Optoelectronics、Area Array Packages、Hybrids、Lead-free Assembly、Advanced Passives) に焦点を当てた開発を行っていること、予算規模としては約 1,000 万ドルで、内訳としては、放射線対策に 39%、信頼性関係に 33%、NEPAG 関係に 15%を費やし、部品分野では特定分野に 63%を割り当てていると述べた。また、特定の部品分野について、その開発状況等について説明を行うと共に（詳細は別紙参照）、NEAPAG について、NASA 関連センター、国防省、米国企業等と密接に協力した国内活動や JAXA、ESA、CSA 等を含む外国機関との国際活動について Lead-free や Tin Whisker 等をテーマに 2000 年から検討を行っている旨､及び Lead-free のための戦略について紹介を行った。結論として、NEPP としては、各フライト・プロジェクトに対して重要なガイダンスを提供し、費用便益に沿った開発に努め、ハイ・デマンド／ハイ・リターン技術に焦点を当てること、及び人材育成に努めることが強調された。

(Q) 何故 MMIC はカバーされないのですか？
(A) リストには載っていますが、短期的には優先度が低いので、別の優先事項に投資している。

（２） 次に GEIA の議長である Mark Porter 氏が､｢GEIA G-12 Solid State Devices Committee Initiatives｣と題して、GEIA は米国電子工業会 (EIA) の傘下にあり、米国政府と取引関係にある軍事・宇宙関連企業等を代表して活動する組織であること､その中で G-12 は半導体機器関係を担当している委員会であることの紹介を行った。その主要な業務は、受動部品の中の半導体機器（ハイブリッド、セミコン、IC）の利用、標準化、及び信頼性にかかわる問題点、及び放射線の影響について検討を行ってい

る。GEIA/G-12 は製造メーカーである JEDEC/JC-13 と緊密な関係にある。その他、NASA、DSCC、空軍、海軍等の米政府機関や JAXA、ESA、CNES、DLR 等の国際機関とも緊密な関係にあるとの説明が行われた。また、具体的な検討テーマとしては、鉛フリー問題、COTS の宇宙利用、偽造部品、部品の生産停止 (DMSMS) 問題等を挙げている。特に Lead-Free 小委員会では、鉛フリーにかかわる問題として、whisker の発生、鉛フリーのハンダに対する信頼性の問題、Joint Standard の作成等、及び偽造部品タスクフォースでは、半導体工業会 (SIA)と共同で多種多様な実例をピックアップして、製造過程、販売経路、ブラックマーケット等について莫大な経費と労力を費やして調査検討を行っている大きな問題であると紹介している。また、もう一つの大きな問題として、宇宙用部品のなかで生産の停止等で在庫減少に直面している部品の問題があるとして、宇宙用部品の特徴である、少量・高機能生産、短期間での陳腐化等の特徴で、部品メーカーの倒産、業種変更等供給サイドの脆弱性が指摘された。その他、残留ガス分析試験 (Residual Gas Analysis (RGA) Testing)が抱える問題点（試験機関によって結果が異なる等）についても言及された。結論として、GEIA/G-12 はシステムの信頼性を促進すること、陳腐化の部品を極力抑えること、使い易さと相互機能性を高めること、他の機関との協力を推進すること等を強調した。

(Q) PEMS のアプローチについて、もう少し詳細にお聞かせ願いますか？

(A) 個人的申し上げれば、自分の会社でもある種のハードウェアーには相当に使用していますが、宇宙への利用に関しては標準的な手法はありません。一番よいのは NASA のものではないかと思います。我々が認識しているのは、プラスチックでなくてはならない部品があります。今後とも、PEMS を使用しなければならない場合は、使用していくことになる。

（３） ３番目は ESA の Laurent Marchand 氏で、「Micro & Nano Technologies at the European Space Agency」と題して、ESA のマイクロ・ナノテクノロジーの活動概要について講演を行った。まず MEMS に係る主要な活動として、次の４分野を挙げてそれぞれ説明を行った。

- RF MEMS
- MOEMS（光学機器）
- AOCS MEMS Sensor
- Micro-Propulsion

RF MEMS のうち、テレコム用のスウィッチについては、2000 年からドイツの Daimler Chrysler 社、イタリアの Alenia Alcatel Space 社、及びベルギーの IMEC 社の３箇所で平行して開発が進めら、成功裏に終了した。また、非密閉性の RF MEMS スウィッチについては現在フランスの Alenia Alcatel Space 社とルーモジェ大学とので新材料・新デザイン等について研究開発を行っている。RF MEMS については、今後更に新たな技術開発が予定されていることである。MOEMS については主として光学望遠鏡の Mirros 部品の改善改良を目指すものであり、JWST ミッションに搭載する機器の開発についても説明を行った。その他、MEMS 内臓のマイクロ推進力の開発、圧力センサーの開発評価、角速度センサーの産業化、ジャイロ・速度計の開発・商業化等に関する活動概要が紹介された。その他、CRYOSAT-2、PRISMA、XEUS、JWST、GAIA の各ミッションにおけるマイクロ・ナノテクノロジーのかかわりについて、簡単に説明された。ナノテクノロジーについての活動概要については、終了プロジェクト、進行中のプロジェクト、今後予定されている計画等について紹介がなされたが、具体的内容については配布資料を参考願いたい。結論として、マイクロ・ナノテクノロジーは科学ミッションでは重要部品として成熟した技術となっているが、地球観測や通信分野においては信頼性や機能性から更なる努力が必要なこと、MEMS については信頼性の試験及び質的手法について JAXA との更なる協力が見込まれること、ナノテクノロジーの宇宙利用ついては､欧州では未だ R&D レベルであるも、着実に推進されていることが強調された。

(Q) MEMS 技術の宇宙実証のために、ペガサスクラスの小さいロケットで打上げる機会はありますか。
(A) 基本的にはそのような実証の機会を考えているが、TR４－５を経ないと技術実証ができない情況である。PICOSAT のような専門の衛星を打上げで実証することは可能かもしれないが、実際には、技術的実証のためだけの衛星打上げは困難と思われる。

（４） 海外講演の最後として、CNES の Jean-Louis Venturin 氏が「Status of main CNES activities with regard to strategic technologies and components in the domain of silicon ICs」というタイトルのもとで、まず、CNES の概要として 1961 年に設立された仏の宇宙機関で ESA との緊密な関係の下に宇宙計画を実施する機関であり、欧州以外にも米、ロシア、日、印、中国等とも協力関係を構築していること、JAXA とは宇宙部品に関する

４分野（商用部品政策、放射線環境、共同部品評価技術、及び戦略部品）について 協力していることを例示し、また、4 つのセンターと職員数2,400 名以上（内､約 1,800 名がエンジニアと管理職クラスで 35%が女性）、予算規模は 2010 年まで毎年 1%増の約 7 億ユーロ強（2007 年、約 1,050 億円）、宇宙へのアクセス確保、持続的発展、一般社会への還元、宇宙科学、国防／安全保障を政策目標に掲げていること、さらに、ESA への供出金はこの 3 年間で 6 億 8,500 万ユーロ（約 1,030 億円）であることを紹介した。

続いて、戦略的技術・部品に関して、宇宙用部品の外部依存を極力減らして自主開発を推進し、欧州部品産業の国際競争力の向上等を政策目標に掲げていることを説明した。具体的には、欧州部品イニシャティブフェーズ１に基づき、CNES と ESA は戦略的マイクロエレクトロニクス部品である耐放射線パワーMOSFET (Metal Oxide Semiconductor Effect Transistor) の開発状況について、その予算規模（4 百万ユーロ）、契約業者 (ATMEL)、作業パッケージ等を、また、0.18 μm CMOS (Complementary Metal Oxide Semiconductor) 技術についても予算規模（6 百万ユーロ）、開発業者 (ATMEL。但し 50%の参加)、耐法線技術の確立、製品開発状況、JAXA との協力状況等について説明がなされた。 最後に結論として、

－ 欧州としては、戦略的な技術や部品を外部に依存しないことは宇宙産業の競争力の確保する上で極めて重要であること。
－ 欧州の宇宙機関は部品産業に対して引続き財政支援を行う必要があること。
－ 最新部品技術の取得と適正価格の維持を奨励する必要があること、
－ ユーザーとの密接な協力体制を部品開発の初期の段階から構築することが重要であること。
－ コストのかかる部品開発に対して、更なる財政支援の財源をどこに求めるか、また、更なる重要戦略部品の選定方法を如何にするか、については新欧州部品イニシャティブフェーズ２に反映すること、また、外国の宇宙機関との協力が重要であること。

等が強調された。

(Q) SOI (Silicon on Insulator) 技術について、JAXA とのジョイントでは出てきていますが、それ以外で利用することはありますか。

(A) 我々としては現在のところ商用レベルではこのような技術を確立していませんので、大変興味がありますので、今後開発利用したいと考え

ています。

(Q) 貴機関では各種デバイスを開発していますが、これらデバイスを今後維持していくことは大変費用がかかると思いますが、どのような対策を講じていますか。

(A) 部品メーカーは市場で販売し続けるにはユーザーのニーズにどのように応えるかによります。我々としても必要なものは選択します。そういう部品が宇宙で利用されることになります。

（以　上）

６　宇宙用部品技術委員会　分科会報告

（１）　初日最後のセッションとして、宇宙用部品技術委員会の下にある２つの分科会報告が行われた。まず、電子部品分科会会長の大西一功 日大教授から、「電子部品分科会活動状況報告」と題して講演が行われた。同講演では、宇宙用部品にかかわる問題点として、かつては100%国産化していた時期があったが、その後状況の変化で国産化率が30%まで減少したことを受けて、2001年に当時のNASDAで部品プログラム検討タスクチームが設立され、2002年３月NASDA理事長（当時）あてに報告書が提出された。

同報告書では、各種広範な調査結果に基づいて、宇宙開発における部品技術の重要性を認識する一方、日本の宇宙用部品は危機的状況にあると訴え、各種問題点を提起した。その中で、NASDA認定部品の辞退者の増加や宇宙用部品の特殊性（高真空、放射線、微少重力という宇宙環境下と部品交換が不可能）を踏まえて、メーカー側では少量多品種、不具合による企業イメージの低下、製造ライン維持のコスト、専門技術者の減少、また、輸入部品については、納期の不確実性、輸出規制等の問題点が指摘され、宇宙用部品の確固たる供給体制の構築を訴えた。

これを受けて、2002年10月に宇宙用部品技術委員会が設立された。同委員会は産学官からの学識経験者からなり、技術的、管理的な視点も含めた幅広い観点から議論して、以下の項目を内容とする10の勧告をJAXA理事長に提出した。

－　宇宙開発における宇宙部品の重要性
－　宇宙用部品の安定した供給体制の維持・発展
－　部品の評価能力・データベースの充実・向上
－　重要部品の開発
－　開発した重要部品の供給と利用（プロジェクトへの優先利用）
－　高信頼性技術の研究（放射線の影響、民生用部品の宇宙への転用）
－　輸入部品の評価
－　先端技術の宇宙応用（MEMS等）、フロンティア部品の開発、
－　部品の軌道上実証
－　部品登録制度の見直し（QPL→QMLへ推進）

この中で、特に強調したのは、信頼性の確保と重要部品の開発及び民生用部品の宇宙への転用のであった、と述べた。

重要部品については、実態調査→優先付け→委員会での決定→

JAXA 理事長へ報告とのプロセスを通じて、2003 年に以下の電子部品を需要部品として認定したと説明。
高性能 64bit MPU、パワーMOSFETs、DC/DC コンバーター、SRAM、FPGA、オプト・カプラー等。

電子部品分科会として今後以下の項目について重点的に検討を行いたと述べ講演を了した。

ー　国際協力
ー　宇宙用部品のデータベース構築
ー　鉛フリーの問題
ー　民生用部品の宇宙への転用
ー　部品技術の継承という視点からの人材育成・教育

（２）　続いて、機構部品・材料分科会会長の本田 登志雄　東京エレクトロニクスシステムズ（株）部長による「機構部品・材料分科会活動状況報告」と題して、講演が行われた。講演内容は、先ず開発すべき機構部品として、フロンティア部品、高優先度部品、および基盤技術の３項目を挙げている。フロンティア部品とは、将来の衛星需要に見合う部品を R&D から始めることであり、高優先度部品とは重要部品で頻繁な不具合の発生、QPL からの撤退、シングルソース、ITAR の問題等の問題を抱え、しかも緊急性がありかつ長期間の使用と定義しているもの、基盤技術とは日本の宇宙開発にとって今後も保持すべき戦力的技術であると、説明。このうち、重要部品とフロンティア部品の相違は、利用状況、技術的観点、及び社会環境という視点から、開発フェーズ（２～４年）にあるものを重要部品と研究フェーズ（10 年規模）にあるものをフロンティア部品と区分けしたとのべた。

現在開発している部品として、遮断弁 (Latching Valve)、スラスタ弁、角度検出器、ハーモニック・ドライブ・ギア、があり、それぞれに開発状況を解説し、また第二期として、太陽電池パドルの駆動装置に使われるスリップリング、太陽電池パドルの保持開放に使用されている低衝撃保持開放機構の２点を共同で開発中とのこと。

材料関係については、宇宙環境に対する評価技術のレベルアップ、材料に関するデータベースのシステムの整備と公開を行っていること、また、今後は輸入品材料の適合性の評価を継続すること、高機能を持った材料の開発を行うこと、評価技術の改善、及び材料の性能に関するデータベース化を図ることを挙げている。

最後に、機構部品・材料分科会が抱える課題として、

－　機構部品の定義
　　多種多様な部品があるあるので減手する必要がある。
－　ISAS、NAL、NASDA の統合
　　ISAS の科学衛星、NAL の基礎研究をどこまで含めるのか。
－　機構部品の開発
　　長期ビジョンに基づくミッション達成のために新たな機構部品の開発が求められているも、システム体制が不十分
－　事務局の強化
　　事務局の現体制では不十分、
　　その他、開発した部品の維持の問題、予算の問題等が指摘された。

（以　上）

Ⅱ　２日目（平成 18 年 10 月 27 日（金）09：30〜16：30）

２日目は、JAXA 及び関係企業からの論文発表が１２件行われた。

１　「宇宙用電子部品の研究開発活動状況」

（１）　先ず最初は JAXA 久保山智司氏による「電子部品の開発状況報告」というタイトルで発表が行われた。発表内容は重要部品として、64bit MPU、DC/DC コンバーター、POL(Point of Load)タイプの DC/DC コンバーター、パワーMOSFET、32Mbit バースト SRAM、SOI ASIC、SOI FPGA の７部品を挙げ、それぞれについて、その開発状況を説明した（但し、2006 年に開発を了し、製品化中の 64bit MPU を除く）。

－　DC/DC コンバーター

この部品は非常に複雑な構造のため不具合が多い部品であったが、その原因となる巻き線を除去し、多層のプリント配線基板を巻き線の代わりとした。バスや電圧関連に関する部分を除き、昨年度中に一通りの試験を了した。

－　POL(Point of Load)タイプの DC/DC コンバーター

これは新しい部品で、LSI の微細化に伴い、１ボルトに近づく低電圧化の方向に進むため、基盤の負荷の近くに (point of load) 電源を設けるという発想で、今年から feasibility study を開始する。

－　パワーMOSFET

一応従前タイプのものは一区切りがついて認定試験を了した。この後は小型化の要求に基づき、表面実装型に入れた認定試験や 500 ボルトものの開発を予定している。

－　バースト SRAM

これは、同期式のもので 200MHz、340MIPS のマイクロプロセッサーに接続するために開発されたものである。高性能なマイクロプロセッサーを引き出すために製作。シングルチップは困難であるので、今回の開発は２段重ねて４チップで構成されている。今後、この形状で認定試験を受ける予定。

－　SOI ASIC

これは、沖電気だけが世界で商品化している唯一の会社で、対放射線 (SEU/SET) に大変優れている FD SOI/IC で、宇宙用に応用できないか検討してきた。これを利用した LSI の研究を開始した。

－　**SOI FPGA**

上記と同じ発想で、FPGA の開発を目指す。仏の ATMEL 社と共同で開発を予定している。

重要部品開発の第一フェーズはほぼ目途がつき、第二フェーズの議論を電子部品分科会等で開始した。

（２）　次に HIREC の浦野　幹彦氏が「COT を導入した宇宙用 LSI 生産システム確立」のタイトルで、発表した。本生産システムの確立作業を 2003 年から開始した背景として、JAXA 認定部品の急減した一方で、民生用の LSI 生産が迅速で、簡単かつ比較的安価で生産できるようになってきた（理由：wafer foundry の出現によりユーザー自身で LSI を生産する必要がなくなったこと、mask layout も CAD の出現によりユーザーができること等）ことを挙げ、COT (Customer Owned Tooling) を宇宙用に応用する LSI 生産システムの特徴として、SEU/SET 対策のための手法、１枚の wafer に２品種以上の LSI の焼付け、専門業者の活用、品質保証会社の設立、地震・火災等の災害からリスクを分散するための wafer banking の分散について、相関関係図等を利用して紹介を行った。また本システムの導入結果として、最初のターゲットである需要部品 320MIPS 64bit MPU は、昨年 JAXA の認定試験で良好な結果を得たとの報告がなされ、今後は、Burst SRAM や SOI ASIC の重要部品を同じシステムで開発する予定である旨、述べた。

(Q) wafer banking ではなぜ乾燥空気で保管しているのでしょうか。問題はありませんか。

(A) wafer を劣化させる要因として、温度，高湿による腐食が考えられますが、現在の保管状態である 30%以下の湿度では問題ないと思います。また、wafer 自身もあらかじめ専用の容器に入れて保管されていますので、二重に安全です。

(Q) QCI のコストが下がっていますが、どうしてですか。

(A) マルチプロジェクト・ラン方式を採用することによって、費用を圧縮することができます。

（３）３番目に沖電気（株）の井田　次郎氏から、「対放射線応用に向けた完全空乏型 SOI 技術」と題して、FD (Fully Depleted：完全空乏型) SOI について、低電圧、設計環境が良好、良好な温度特性、対放射線機能等により FD-SOI の開発を進めていること、また現在の開発状況として、PD-SOI (Partially Depleted SOI) は IBM 連合によるハイスピードのマイクロプロセッサーの応用、AMD は今後のプロセッサーは PD-SOI 方式への採用、ソニーや任天堂のゲーム機の開発等に利用されていること、他方で FD-SOI は沖電気のみが利用している技術で、例えば、太陽電池時計、低周波 RF デコーダーに利用していることについて紹介するとともに、FD-SOI の機能について配布資料に基づき説明を行った。また、0.15 SOI の開発状況、各種テスト結果等について紹介され、結論として FD-SOI は Latch-up フリーであり、耐放射線機能も有していること等から宇宙用にも適していることを強調した。

(Q)　0.15μの技術では最大周波数はどのくらいですか。

(A)　最大周波数は基本的にはデザインによって決まりますが、一般的には、モバイル系ですと、0.15μは 100 メガであると思います。

（３）　４番目は、沖エンジニアリング（株）の田中　大起氏で「LSI プロセ診断」と題して発表を行った。LSI プロセス診断の開発の背景としては、民生用半導体部品の宇宙用への転用に際し､LSI の微細化傾向のために、信頼性のテストだけでは欠陥の検出が困難でとなり、新たに欠陥を効果的に検出する手法が求められた結果であることが説明された。LSI プロセス診断のコンセプトとしては、高品質な部品の抽出の必要性、ウェハープロセスの効果的な評価、低コスト、短期間の解析、簡便性、拡張性、及び信頼性試験と DPA の情報源になることの七項目を挙げた。次に、その経緯として、1998 年から 0.6μm クラスのデバイスの配線に関する信頼性診断から始まり、その後 LSI チップの信頼性診断に移り、2004 年には 0.13μm のデバイス、そして 2006 年では 0.09μm についても実施したこと等経緯を資料に基づき説明を行った。また、検査内容としては、電気的に良品であるデバイスを使用して、その中のウェハーを評価することであること、5 種類の検査方法と検査手順、54 の欠陥項目、データベースシステムの利用を通じて効率的運用を行っていることが説明された。実際の検査例を配布資料に基づき解説し、今後の計画として、LSI プロ

セス診断の手法は確立されているが、プロセス自体にまだまだもんだいがあり、その評価の見直しを進めること、3 次元構造のデバイスへの対応、最終的にはアッセンブリ・プロセスとの融合の可能性について検討を行っていることが強調され、当面は 90 ナノ・プロセスのデバイスに対してデータの取得と検査項目の見直し、0.09μm のデバイスについてのデータベースの保管、プロセス診断そのものの回収作業、微細プロセスに対応した LSI プロセス診断の回収を検討している旨、説明した。

(Q) アクセレレーション・テストの温度を教えてくれませんか。
(A) 高温動作試験を 125 度の環境下で実施しています。ヒート・ショックを-55 度～125 度の範囲で行っています。

(Q) LSI プロセス診断にむいている半導体と向いていないものとがありますか。
(A) 適しているデバイスは、CMOS、ロジック、メモリー、適していないのは、バイポーラ・プロセス、シリコン半導体以外の加工物半導体が挙げられます。

２ 「宇宙用機構部品の研究開発活動状況」

（２） ５番目はJAXA部品・材料・機構グループの小原 新吾氏による「宇宙用機構部品研究」と題した発表が行われた。発表概要は、先ず機構グループの活動として、機構部品の開発、基盤技術の研究、成果の標準化、及び衛星等の評価を挙げ、また、機構関係の要求事項は高性能な精度と感知であり、かつ衛星の長寿命、機動性であるとしている。具体的な活動としては、第一期目はハーモニック・ドライブ・ギアと角度検出器、二期目として、低衝撃の分離機構及びスリップ・リングの開発を予定し、それを支える基盤技術として宇宙潤滑としての液体・固体潤滑剤、ベアリング、ギア、スリップ・リング等について研究を推進している旨述べた。さらに、これらの成果をガイドラインやハンドブック等にまとめている。次に、機構部品・材料分科会で選定された上記第一期目の部品の開発状況及び宇宙潤滑としての液体・固体潤滑剤の研究開発状況について、配布資料に基づき説明を行った。

（３） ６番目は、（株）ハーモニック・ドライブ・システムズの上浦 啓次氏から「宇宙用波動歯車装置の開発」について、発表された。英名”Strain Wave Gearing”は和名で「波動歯車装置」と訳しも、むしろ一般にはハーモニック・ドライブと呼ばれている旨及びこの名称は会社の商標になっている旨併せて説明があり、その後会社概要、取扱商品、特にハーモニック・ドライブの構造、機能、開発状況、EM 試験等について資料に基づき解説が行われ、ハーモニック・ドライブのテスト結果から、振動や熱の影響はなく、潤滑関係は真空中では厳しいこと、磨耗については更なる調査が必要であることが判明した、と述べた。

３　宇宙用材料の研究活動状況

（４） JAXA 宇宙用部品・材料・機構グループの木本　雄吾氏による「宇宙用材料の研究」について発表がなされた。宇宙用材料に関する研究活動として、耐宇宙環境性の材料の研究と新材料の研究に分けられ、前者は評価技術の向上に関する研究として、材料の暴露実験とその解析、照射試験とコンサルティング（次のスピーカーで説明)、今年の６月に開始された CNES との材料の相互評価があり、後者は宇宙環境に更なる耐性を有する新材料の研究活動が紹介された。また、試験設備として、複合環境試験設備の概要、試験照射装置や測定装置等が説明された。更に材料の暴露実験の内容や実験結果について、配布資料に基づき説明がなされた。さらに、ASTM595 の規格に基づきアウトガスの測定等を行ない、得られた成果は材料のデータベースに収録している旨、紹介された。

（５） 続いて、JAXA 宇宙用部品・材料・機構グループの石澤　淳一郎氏から、「みどり２使用電線の材料評価」と題して、みどり２の不具合原因と見なされている電源系の故障のうち、電線ハーネスの被服材料劣化の評価について発表が行われた。不具合にいたるシナリオとして、多層断熱材 (MLI) の帯電→電線の被服材の劣化→亀裂の発生→MLI とハーネス間でトリガー放電の発生→放電の継続→ハーネスの焼損→電流の停止を説明し、実際に利用した電線ハーネスの被服を使って、放電試験、熱サイクル試験、強度試験、引張試験等の各種試験を地上で再現し、特に熱サイクル試験でハーネスの表面にクラック（くぼみ）の発生を確認すると共に、宇宙環境での電線の使用可能温度としては 150 度で提案できると結論付けている。

４　海外部品関連報告

（６） 海外部品報告として、ピーティーエム（株）の山本　博章氏による「衛星搭載用高信頼性コンデンサについて」と題して発表が行われた。
マルチ・レイヤー・セラミック・キャパシター（コンデンサ）の電極構造として２種類ある PME (Precious Metal Electrode) と BME (Base Material Electrode)　について、それぞれの信頼性試験内容や結果、PME の宇宙・軍事への適正等の発表を行った。

(Q) BME の絶縁不良の原因は何でしょうか。
(A) 一番の原因は沢山の容量を確保するために、なかの金属及び誘電体の層を薄くしたためであると考えています。

５　　安全・信頼性推進部報告－BGA 外観検査、RoHS 対応

(10) 10 番目のスピーカーとして、日本アビオニクス（株）中村　正夫氏から「X 線システムを用いた BGA の非破壊検査手法」について、発表が行われた。これは、JAXA と共同で実施したもので、その背景としては、衛星の小型化に伴う高密度実装技術への要求の高まり及び BGA (Ball Grid Array) パッケージへの需要増、同パッケージへの目視検査の困難性、そのための X 線による検査の必要性が挙げられた。次に、BGA の主要な欠陥項目が指摘され、この欠陥に対する X 線を用いた検査内容、結果等について説明され、最後に、X 線検査は BGA 実装の故障解析又は品質確認のために効果的な検査手法であると、述べた。

(Q) 今後とも評価試験は予定していますか。
(A) JAXA と協議して参りたいと考えています。

（11）続いて、JAXA 安全・信頼性推進部の根本　規生氏から「JAXA RoHS 対応の動きと HSD の評価結果」と題して、発表が行われた。その概要は、EU の指令である RoHS（電子・電気機器における特定有害物の使用制限）の公布による電子機器での鉛の使用禁止（今年７月から実施）問題、鉛フリーによる Whisker の問題、信頼性の問題等について問題提起を行ない、RoHS へのシフト化に伴う課題等について指摘した。世界的な傾向

としては、EU 以外にも、米国では州にもよるがグリーン法により鉛が使用できないこと、中国においても RoHS 関連物質の使用が禁止されることにより、鉛フリー部品は避けて通れない傾向としている。ただし、宇宙は軍と同じで当面は対象外であり、むしろ、ESA、NASA、JAXA では鉛フリーの部品の宇宙機への利用は禁止されているが、今後は民生部品の宇宙への転用もあり、鉛フリーの部品との混在は予想される。JAXA としては、信頼性の問題等から当面は錫鉛のハンダ付けの部品を宇宙機の部品として使用の継続を述べると共に、市場が今後鉛フリーの部品へ代替される場合の対策を検討する必要性を強調した。次に鉛フリーの問題点、特に Whisker の評価試験結果について、配布資料に基づき説明を行った。Whisker についてはまだまだ不明点が多く更なる研究、試験が必要であることを強調した。最後に、今後、認定メーカーでは鉛フリーの部品しか供給できない事態への対処と鉛フリー化は避けて通れない問題であればその信頼性の検証との２つの議題を検討する場として、今年８月、システムメーカー、部品メーカー等からなるコミュニティーを立ち上げた旨、説明された。

(Q) Whisker の成長でどの程度までなら許容できるか、何か基準がありますか。
(A) 決めることは困難と思います。何故なら Whisker のメカニズムが判明していません。

６ 宇宙用部品－データベースの状況

(12) 発表論文の最後として、JAXA 部品・材料・機構技術グループの松岡 毅氏による「プロジェクト承認部品データベースの紹介」と題して、部品データベースの紹介が行われた。現状では部品データベースは JAXA 認定品に限定､他方で衛星の使用部品の内 70%は輸入品で､認定部品は 30%以下、そのため衛星で使用されている部品のデータベースが必要との認識で昨年度から本データベース (PAPDB) が構築されたと説明。PAPDB の目的としては､プロジェクト毎の部品データを一元化し､従来の紙ベースでの申請、審査、承認を Web 上で、総合的な部品情報を管理し、不具合発生後の一次評価を実施することを挙げている。その他配布資料に基づき、PAPDB の機能、特徴を解説すると共に、本データベースのデモンストレーションを実施し、今後の方針として、新規プロジェクトから PAPDB の利用を推進し、また､PAPDB の説明会をシステムメーカーに対して実施する予定と述べた。

(以 上)

7　総合質問

(Q) 重要部品として、第二フェーズで開発するリストにクリスタル・オシレータが候補として挙がっていますが、その理由・背景は何故ですか。

(A) 基本的には、部品技術委員会で勧告されたもので、そのクライテリアとしては、戦略部品として国産化し、継続して保持しなければ、わが国の宇宙における自在性を確保するために必要であるとして選定された部品と理解している。リストにクリスタル・オシレータはパワー・ヒューズとともに欧州でも同じ理由で挙げられている。欧州とはどの程度協力するかは、今後の検討課題であります。

（更なる質問がある場合は、Website 等を通じて、ご連絡願いたい旨、事務局より説明された。）

８　　まとめ

JAXA　部品・材料・機構技術グループ
グループ長　　田村　高志

２日間にわたる有意義なプレゼンテーションや活発なご意見、ご聴講どうもありがとうございました。ご発表いただいた内容すべてを網羅できませんが、自分なりの感じたことをまとめさせていただきます。

今回 MEWS-19 のテーマは「宇宙開発を支える部品材料の安定供給と品質の確保」であり、副題としては「航空宇宙・自動車業界の部品材料戦略」であります。昨日のデンソーの大沢室長からの講演でもお判りのことと思いますが、部品業界から見ると宇宙は極めてマイナーなシェアーしかありません。

他方、自動車産業は大きな力を持った業界でありますので、そこでの情報やノウハウを共有していきたいと考えます。また同様に航空機産業も視野に入れるべきと考えていますが、今回はエアバスを想定していましたが、多忙ということで参加が得られませんでした。日本国内では、航空機産業は、電子部品という観点から見ると、非常にマイナーな産業であります。

長期的には、航空機とか原子力とかといった大きな産業との協力関係を構築することによって、我々宇宙の自在性を確保しなければならないと考えています。

最近の宇宙用部品にまつわるバックグランドないし課題として、一つは部品の不具合であります。数は多くないのですが、１件起きますとその影響は甚大であります。特に LSI 関係は深刻です。それからシステムの複雑化や先端化に伴い信頼性が減少してきていることです。また、鉛フリー、whisker の問題は当面は大きな問題であると考えます。さらに、宇宙だけに限定せず、自動車産業やその他の産業からも学んでいこうという姿勢をもつことです。

このような課題に対して、日本としても戦略的な部品プログラムの策定

が必要となります。最低限必要なものを確保した上で、国際的な協力関係の構築が推進されることになります。それから MEMS やナノテクといった技術を今後どのように使いこなしていくか、そして最後にまとめという内容でご説明します。

宇宙用部品のバックグランドの中でおおきな特徴の一つとしては、JAXA 認定部品の品種数がここ５年間で劇的に減少したことです。それから、海外から輸入した重要部品のなかで、いくつかに不具合を経験したことです。その代表例が FPGA であります。最近、システムやデザインのソフトウェア化に伴い、この FPGA が大量に使用されています。例えば、ALOS クラスでは 100 品種を超える FPGA が使用されています。2004 年の衛星のトラブルはこの FPGA の不具合が原因となっています。

一般的には、民生用の部品の寿命は 3－10 年、特に家電関係では 3－5 年でありますが、他方宇宙用部品においては、通信衛星では 10－15 年、時には 18 年の稼動寿命を要求されています。このように宇宙用部品は民生用で開発されている部品と信頼性の点で相容れなくなってきていることは、重大な問題であると認識しています。

このような長期寿命の要求に逆らう問題として Tin Whisker があります。全世界的な問題として、これから取組まなければならない問題です。それから、数年前に ADEOS-2 という大型の地球観測衛星を失いましたが、これは太陽電池パドルから衛星に電力を供給しているケーブルに問題がありました。我々は当時その材質について十分な知識を有していませんでした。その材料の評価が十分でなかったわけで、やはりカタログの知識だけではなく、自らで取ったデータで理解する必要があります。また、不具合から故障にいたる物理法則を十分に理解する必要があります。このような自らの経験を蓄積し、標準化・データベース化することが重要になってきます。

先ほどデンソーの大沢室長からご講演をいただきましたが、トヨタグループでは”Good Design”、”Good Design Review”、”Good Discussion”の手法で知られています。ユーザー側と供給側とが一緒になってデザイン・レビューやリスクの理解及び議論をしあうことですが、これは非常に重要なことであると考えます。

米欧日の動向について概観しますと、米国では Military Standard をはじ

めとしたスペックの体系（例、MIL-STD-975）が 1975 年からはじまり、その後、MIL-STD の減少と調達を含めた各種改良がなされ、Perry Memo によって民生用の COTS 中心で進めるという動きが出てきました。それと平行して、”Faster, Better, Cheaper”という動きもありました。このような動きを通じて部品が民生用にシフトしていきました。その結果、米国の軍事用に納入していた主要部品メーカーが転業、海外移転し、コアとなる部品がアジア製等の外国製となり、米国にとって自在性の観点から問題となってきている。従って、2005 年に部品だけに限定はしませんが、”Back to Basic”という声明がだされ、原点に戻る動きが出てきました。この関連で、”Trusted Foundry”のもとに、ある一定レベル以上のウェハー・プラントは米国内に確保するとの指針が 2005 年にだされました。このように一度しぼんだミリタリーのシステムを復活させるというのが米国の現状であると理解しています。

他方、欧州では、1996 年に SCSB が設置、”Buy European”という標語を経て、2004 年から ITAR フリーを目標として”European Components Initiative”(Phase 1) を策定、現在 ECI の Phase 2 を検討している状況で、ヨーロッパの自在性確保に努めています。

日本では、H-II の国産化に伴って部品の開発も相当進展しましたが、コストダウンという要求により部品政策も変更し、その結果 JAXA 認定部品の市場も縮小しました。現時点において、半導体で認定されている部品はほとんどありません。このような事態は、自立性・自在性の観点から問題がありますので、最低限の宇宙活動を確保するためにも新しい部品計画を検討中であります。

我々としては、DC/DC Converter、200MIPS MPU、Power MOS FET 等機構部品を中心とした戦略的部品の開発を進める一方で、信頼性のデータを取得し、国内で安定した重要な部品供給源や高機能なシステム・デザインのツールを確保すること、そしてこのような活動を通じて技術の継承を図ることが重要であると考えます。

このようにコアとなる部品については各国とも国内で確保しようとする動きがありますが、他方で共有する部分については国際協力で推進することが重要であります。実際には、NEPAG を中心に JAXA、ESA 等が参加し国際コミュニティがあり、活発な情報交換が行われています。

将来の宇宙システムは、今後益々高機能かつ小型化されていくものと考えています。その中で、MEMS & Nano-Technology を積極的に導入していく必要があります。TRL7－9 レベルは既存技術ですが、これを今後安定的に利用すると共に TRL1－4 の技術を使いこなすことが必要になるかと思います。ただし、これを部品だけに限定せず、システムとして robust な設計を行うことがキーになるかと思います。今後は、部品サイドからもシステム側にマイクロとナノの技術を導入するので、robust なシステム設計を依頼する等積極的な働きかけを行って、両者の協調関係を確立することが重要であると考えます。

まとめますと、現在の宇宙システムの設計は、益々高度の技術を擁した部品に依存しているといえます。また、宇宙用部品のシェアは減少してきている中で、部品に対する長寿命化への要請は高まっています。このように、一見矛盾しているような状況に我々は置かれています。このような状況下において、国際間の協力のみならず、部品の製造メーカーとユーザー間の協力、蓄積した技術の標準化を推進し、その情報をみんなでシェアすること、そして異業種間のコミュニケーションを確立することが重要なことと考えます。

（以　上）

９　　閉会の挨拶

JAXA　部品・材料・機構技術グループ
グループ長　　田村　高志

　プログラムでは鈴木となっていますが、日程の都合で、自分が挨拶します。

　この 25 日から 3 日間にわたりまして開催された MEWS-19 では、積極的なご意見ご質問があり、また盛りだくさんなプレゼンテーションが行われ、我々としては普段ではなかなか聞けないような情報もありました。非常に成功裏に終了したと思います。

　因みに参加者数ですが、10 月 25 日の展示会では 71 名、10 月 26 日のワークショップ 1 日目が 144 名、27 日の 2 日目が 122 名と合計で 337 名の参加を得ました。

　今回発表のありましたハイテク関連のプレゼンテーションを来年以降も続けて、更に活発な意見交換を行い、このワークショップが皆様方のお役に立てればと念じています。

　本日は、どうもありがとうございました。

（以　上）

発表資料

ワークショップ１日目

平成18年10月26日（木）

Current Status and Future Prospect on the Reinforcement of Fundamental Technology in JAXA

October 26-27, 2006

Atsutaro Watanabe

Associate Executive Director

Institute of Aerospace Technology (IAT)

JAXA Institute of Aerospace Technology (IAT)

Legend: Aerospace Research Center / Tsukuba Space Center / Kakuda Space Center

Institute of Aerospace Technology — Staff:375

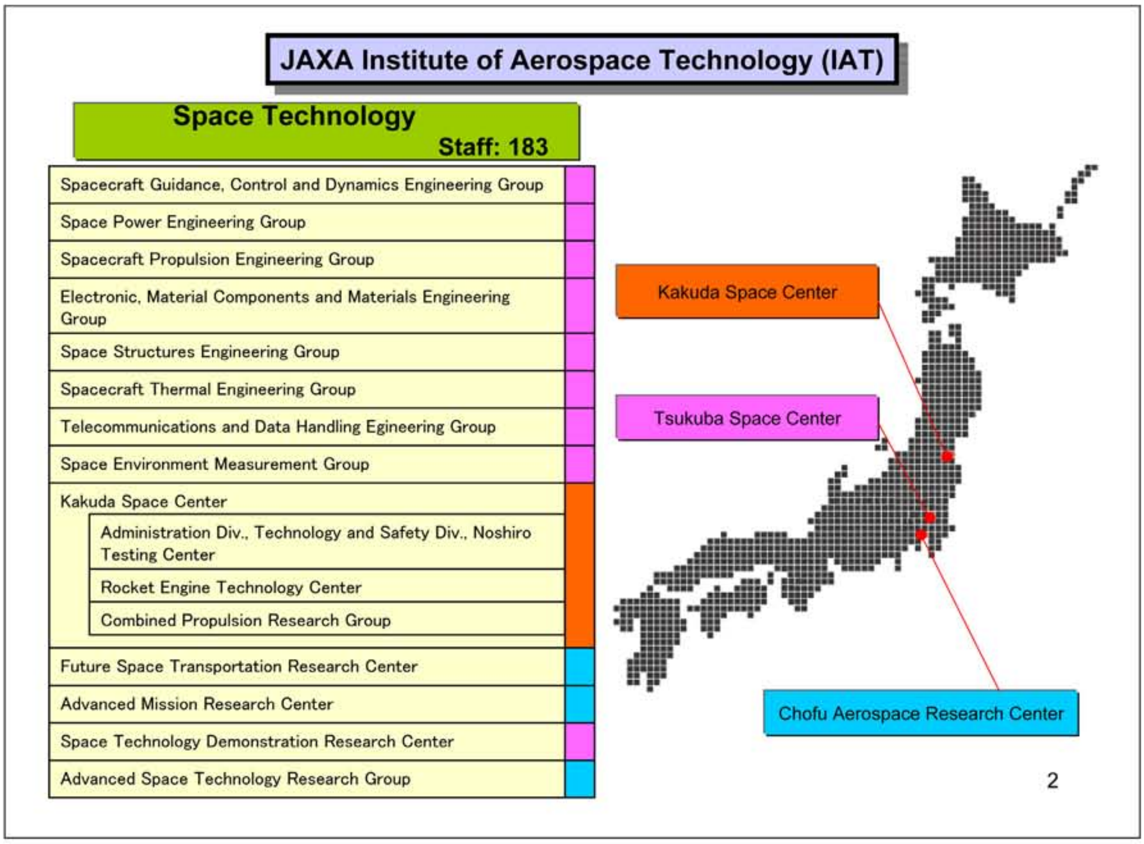
[ ]staff

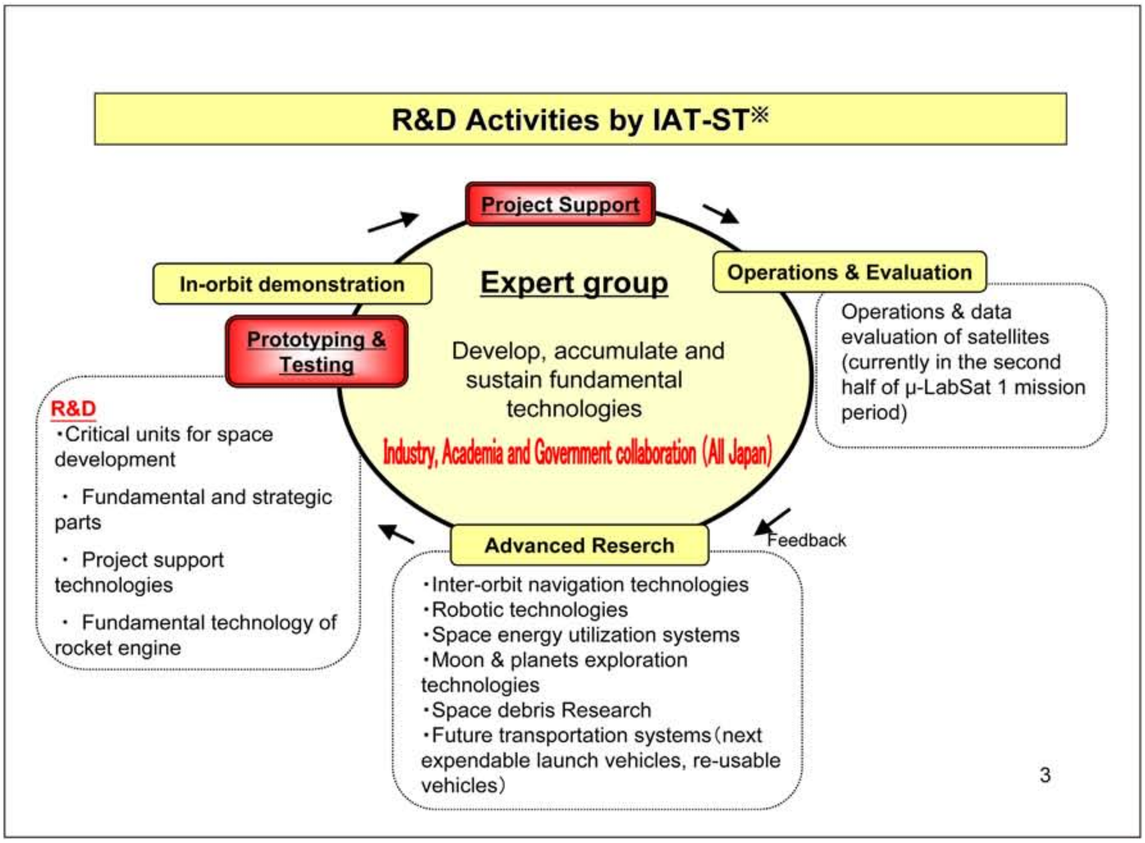
- Program Management and Integration Dept. — Staff:3
  - Staff:53
  - General Services Div., Program and Planning Office, Program Support Div.
  - Project Research Coordination Office, Project Project Promotion Div.
- Safety and Quality Assurance Office — Staff:4
- Aeronautical Technology — 1 — Staff:132

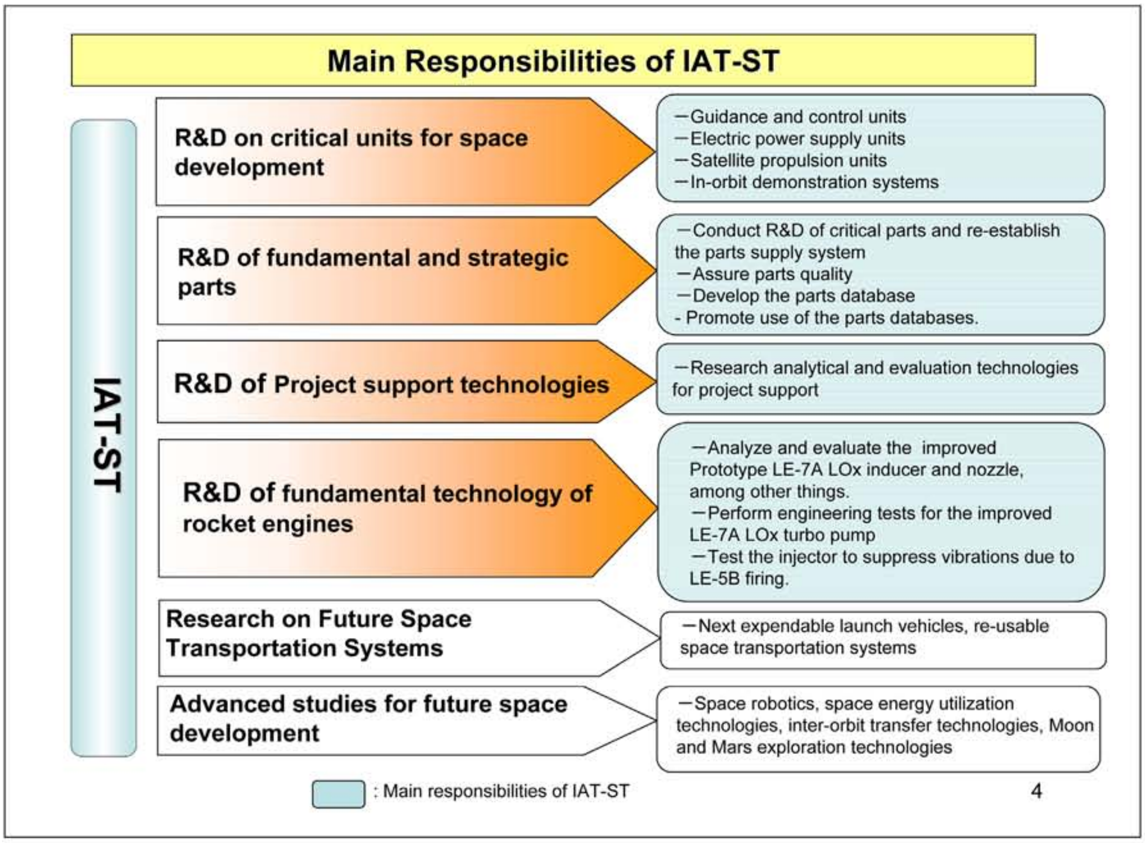
Aeronautical Technology	
Wind Tunnel Technology Center	[38]
Aerodynamics Research Group	[13]
Structure Technology Center	[13]
Advanced Composite Technology Center	[12]
Aeroengine Technology Center	[18]
Flight Systems Technology Center	[22]
Computational Science Research Group	[15]

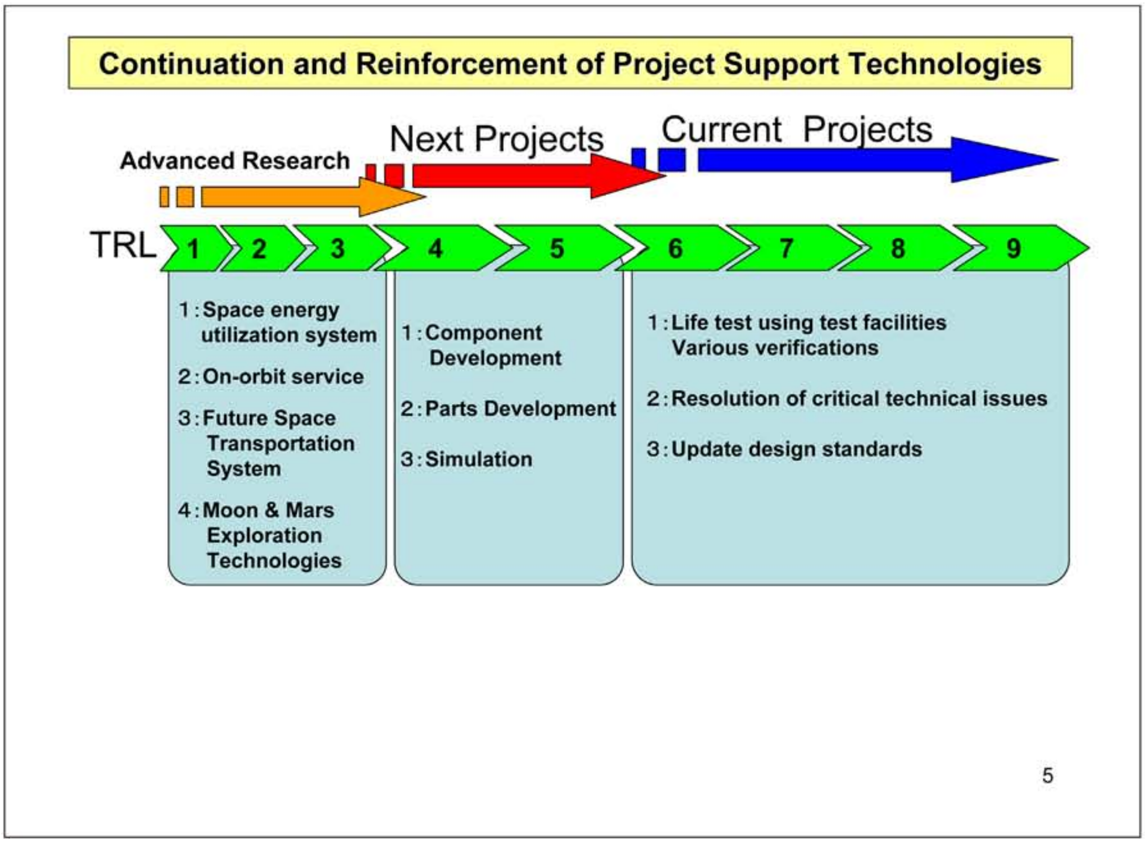
Space Technology — Staff:183

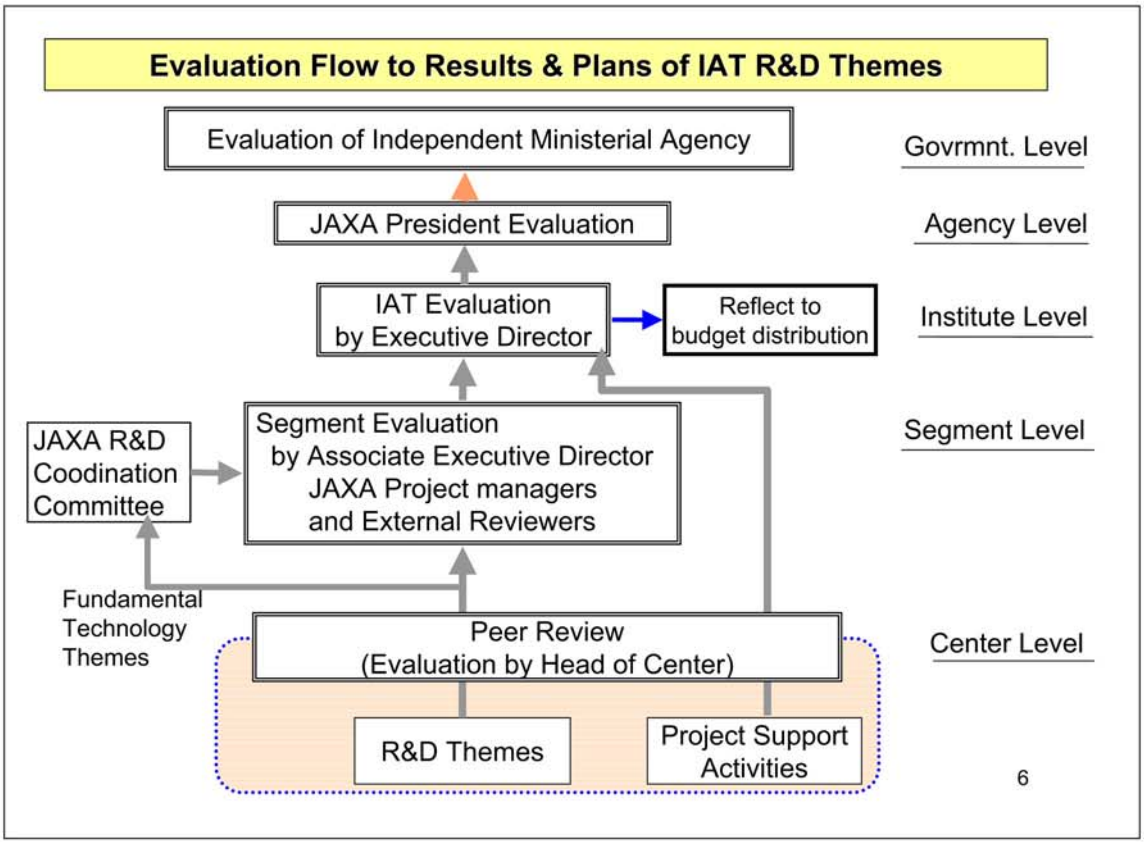
Space Technology	
Spacecraft Guidance, Control and Dynamics Engineering Group	[12]
Space Power Engineering Group	[11]
Spacecraft Propulsion Engineering Group	[10]
Electronic, Material Components and Materials Engineering Group	[19]
Space Structures Engineering Group	[4]
Spacecraft Thermal Engineering Group	[6]
Telecommunications and Data Handling Egineering Group	[7]
Space Environment Measurement Group	[4]
Kakuda Space Center	[70]
Administration Div., Technology and Safety Div., Noshiro Testing Center	
Rocket Engine Technology Center	
Combined Propulsion Research Group	
Future Space Transportation Research Center	[8]
Advanced Mission Research Center	[4]
Space Technology Demonstration Research Center	[9]
Advanced Space Technology Research Group	[19]


JAXA Institute of Aerospace Technology (IAT)
Space Technology
Staff: 183
Spacecraft Guidance, Control and Dynamics Engineering Group
Space Power Engineering Group
Spacecraft Propulsion Engineering Group
Electronic, Material Components and Materials Engineering Group
Space Structures Engineering Group
Spacecraft Thermal Engineering Group
Telecommunications and Data Handling Egineering Group
Space Environment Measurement Group
Kakuda Space Center
Administration Div., Technology and Safety Div., Noshiro Testing Center
Rocket Engine Technology Center
Combined Propulsion Research Group
Future Space Transportation Research Center
Advanced Mission Research Center
Space Technology Demonstration Research Center
Advanced Space Technology Research Group
Kakuda Space Center
Tsukuba Space Center
Chofu Aerospace Research Center
2


R&D Activities by IAT-ST※
Project Support
In-orbit demonstration
Operations & Evaluation
Expert group
Develop, accumulate and sustain fundamental technologies
Industry, Academia and Government collaboration (All Japan)
Prototyping & Testing
Operations & data evaluation of satellites (currently in the second half of μ-LabSat 1 mission period)
R&D
・Critical units for space development
・ Fundamental and strategic parts
・ Project support technologies
・ Fundamental technology of rocket engine
Advanced Reserch
Feedback
・Inter-orbit navigation technologies
・Robotic technologies
・Space energy utilization systems
・Moon & planets exploration technologies
・Space debris Research
・Future transportation systems (next expendable launch vehicles, re-usable vehicles)
3


Main Responsibilities of IAT-ST
IAT-ST
R&D on critical units for space development
－Guidance and control units
－Electric power supply units
－Satellite propulsion units
－In-orbit demonstration systems
R&D of fundamental and strategic parts
－Conduct R&D of critical parts and re-establish the parts supply system
－Assure parts quality
－Develop the parts database
- Promote use of the parts databases.
R&D of Project support technologies
－Research analytical and evaluation technologies for project support
R&D of fundamental technology of rocket engines
－Analyze and evaluate the improved Prototype LE-7A LOx inducer and nozzle, among other things.
－Perform engineering tests for the improved LE-7A LOx turbo pump
－Test the injector to suppress vibrations due to LE-5B firing.
Research on Future Space Transportation Systems
－Next expendable launch vehicles, re-usable space transportation systems
Advanced studies for future space development
－Space robotics, space energy utilization technologies, inter-orbit transfer technologies, Moon and Mars exploration technologies
: Main responsibilities of IAT-ST
4


Continuation and Reinforcement of Project Support Technologies
Advanced Research
Next Projects
Current Projects
TRL
1
2
3
4
5
6
7
8
9
1：Space energy utilization system
2：On-orbit service
3：Future Space Transportation System
4：Moon & Mars Exploration Technologies
1：Component Development
2：Parts Development
3：Simulation
1：Life test using test facilities Various verifications
2：Resolution of critical technical issues
3：Update design standards
5



New Approach at the IAT

To Establish DE groups and to participate in projects as the expert of each subsystem

Contribution to the Mission Success of satellite projects

Organization Revision in October 2005

To Apply Quality Management System to our R&D Activities

<Goal>

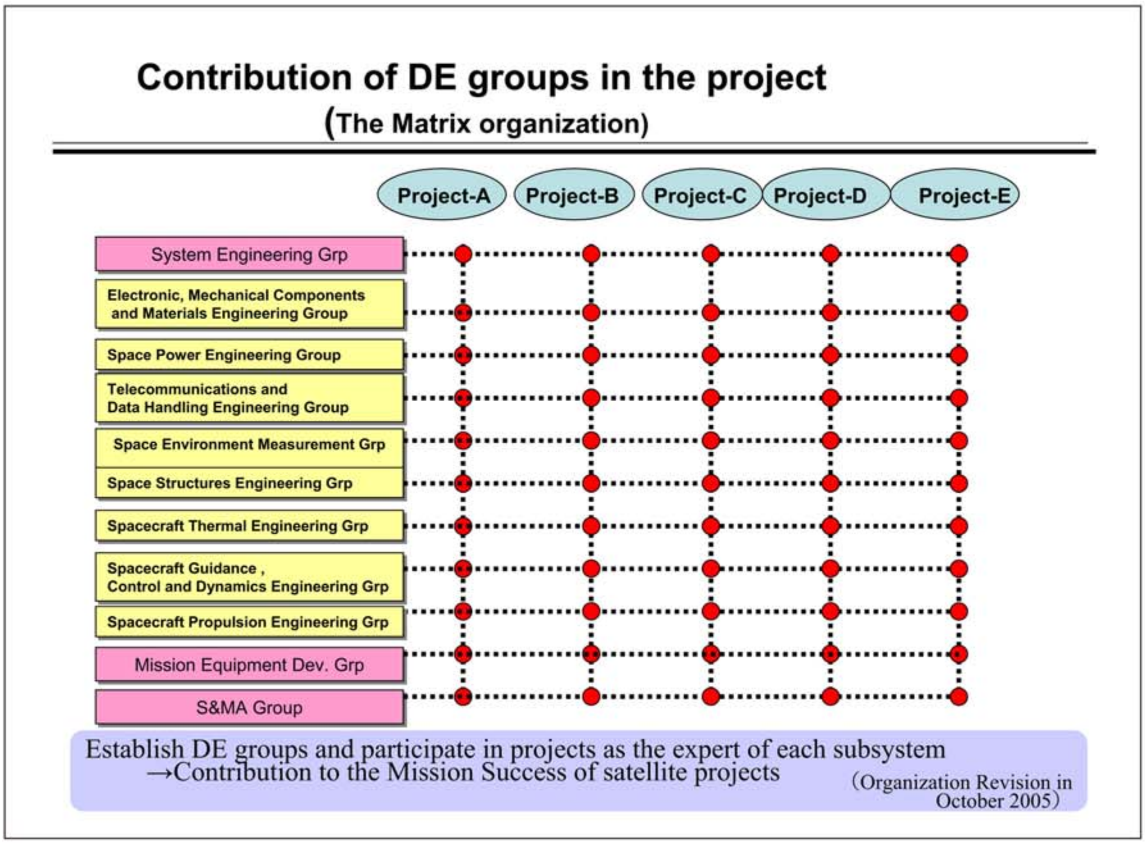
Contribution to our society by creating high-quality results in R&D
Continuous level up of the Quality Management System(QMS) across the organization

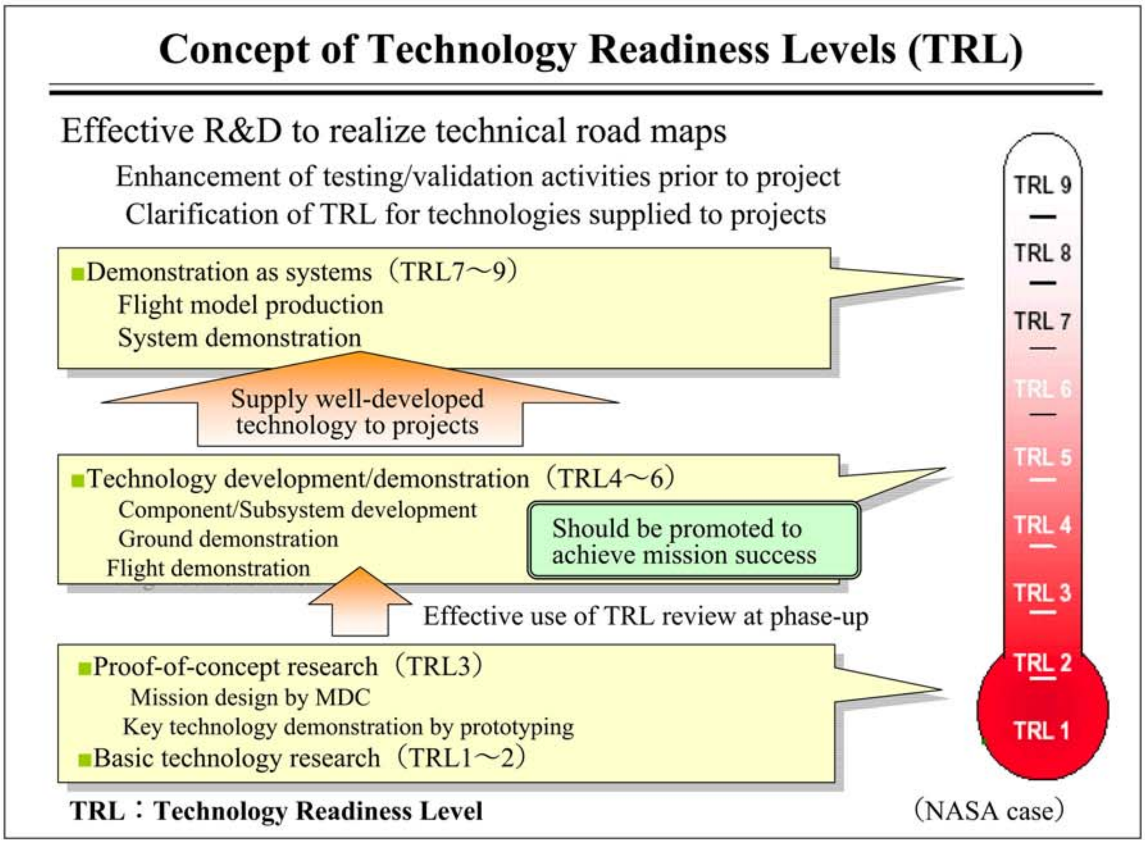
ISO9001：2000 Certification Since 6th March 2006

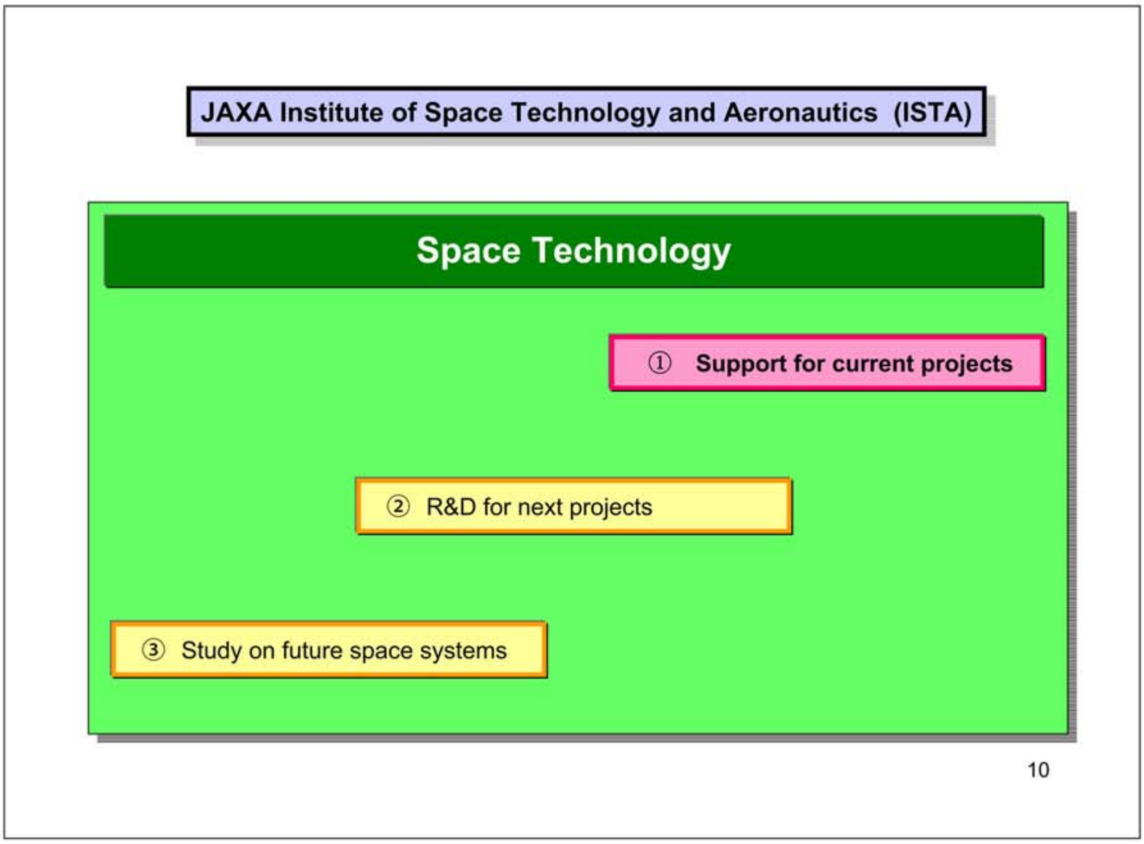
To Adopt the concept of Technology Readiness Levels (TRL) as an international standard for results in R&D

Setting TRL 6 or 7 for the R&D phase-up to the project

7


Contribution of DE groups in the project
(The Matrix organization)
Project-A
Project-B
Project-C
Project-D
Project-E
System Engineering Grp
Electronic, Mechanical Components and Materials Engineering Group
Space Power Engineering Group
Telecommunications and Data Handling Engineering Group
Space Environment Measurement Grp
Space Structures Engineering Grp
Spacecraft Thermal Engineering Grp
Spacecraft Guidance , Control and Dynamics Engineering Grp
Spacecraft Propulsion Engineering Grp
Mission Equipment Dev. Grp
S&MA Group
Establish DE groups and participate in projects as the expert of each subsystem
→Contribution to the Mission Success of satellite projects
（Organization Revision in October 2005）


Concept of Technology Readiness Levels (TRL)
Effective R&D to realize technical road maps
Enhancement of testing/validation activities prior to project
Clarification of TRL for technologies supplied to projects
■Demonstration as systems（TRL7～9）
Flight model production
System demonstration
Supply well-developed technology to projects
■Technology development/demonstration（TRL4～6）
Component/Subsystem development
Ground demonstration
Flight demonstration
Should be promoted to achieve mission success
Effective use of TRL review at phase-up
■Proof-of-concept research（TRL3）
Mission design by MDC
Key technology demonstration by prototyping
■Basic technology research（TRL1～2）
TRL 9
TRL 8
TRL 7
TRL 6
TRL 5
TRL 4
TRL 3
TRL 2
TRL 1
TRL：Technology Readiness Level
（NASA case）



Current Project Support Technologies

- Respond to urgent issues facing to the Japanese space community, support the project offices in developing common fundamental technologies to eliminate potential failures for on-going projects and improve reliability of future projects (i.e., remove potential failure causes).

- Support the project offices in improving reliability of launch vehicles and satellites and solve project-related technical issues.

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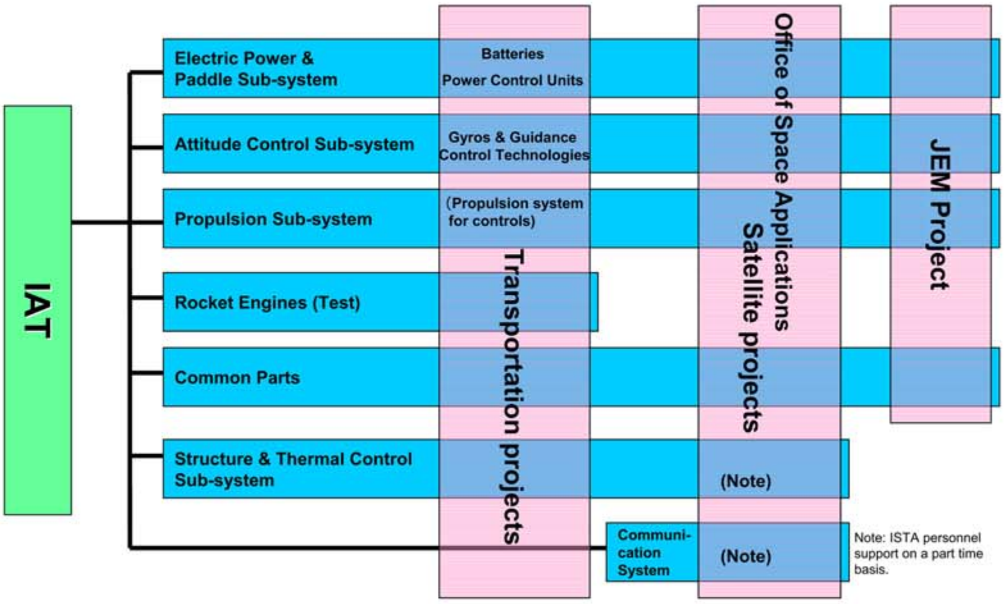
Current Project Support Technologies



➤Response to specific requests from projects such as component development and simulations (see details in later in this material).

12

Solutions by IAT for key technical issues

H-IIA Launch Vehicle H-IIA launch vehicle is the Japan's primary large rocket equipped with high performance engines that use liquid oxygen and hydrogen as propellants.

===== ======================= 【Support by ISTA】 =============================

- LE-7A
  - Inducer nozzle test and analysis.
  - Turbo pump engineering test and performance evaluation. Test and evaluation of vibration suppression performance during firing.
  - Developed a simulator to simulate non-steady state characteristics such as start and stop transient.
- LE-5B
  - Test and evaluation of vibration suppression performance during firing.
  - CFD analysis for engine mixer
- SRB
  - Analyzed uncertainty of ignition test and analytical data.
  - To understand a functional loss of ignition wires which could lead to a failure of SRB-A separation, gas diffusion 3-D CFD analysis was conducted for a period of two seconds starting the beginning of fuel gas leak in the aft-adaptor.
  - Stress analysis of the nozzle
- Element analysis
  - Flight analysis
  - Temperature prediction for the second stage electronics
  - In-orbit detail thermal analysis of DRE (Doppler Ranging Equipment) for VEP2 (Vehicle Evaluation Payload-2)
  - Analysis and evaluation of post-flight vibration data
  - Independent verification using a simplified vibration model and development of a mathematical model

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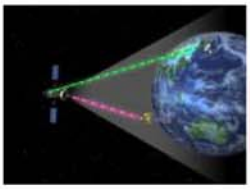
Summary of Project Supports (sheet 1 of 4)



DRTS DRTS is a data relay satellite, which is a GEO communication satellite and relays communications between medium to low altitude (300- 1,000 km) spacecrafts .

=====================【 Support by ISTA 】==========================

Telemetry evaluation (e.g., thermal, electric power system such as 50 Ah Ni-H2 batteries, Earth sensor and attitude control system such as wheels)

ALOS ALOS is one of the world largest earth observation satellite with higher performance than JERS-1 or ADEOS.

=====================【Support by ISTA】==========================

Experts from each discipline of the ISTA participated in the ALOS comprehensive review team. Charging and discharging tests as part of the ADEOS-II failure investigation and all necessary tests to prevent the same failure. IV&V of the flight software. Conducted radiation test for the heavy particle monitoring sensor and light particle monitoring sensor to calibrate these sensors. Test the star sensor and supported in the off-line attitude determination system.

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Summary of Project Supports (sheet 2 of 4)

ETS-Ⅷ ETS-VIII is an engineering test satellite designed to meet increasing communication demands such as cellular phones and mobile equipment. Two large, deployable antenna and two solar paddles are used. ETS-VIII is one of the largest GEO satellite.

=====================【Support by ISTA】==========================

Experts of each discipline of the ISTA participated in the ETS-VIII comprehensive review team. Evaluated the result of ion engine operation test. Calibrated sensors such as the charge sensor. Generated a mathematical thermal model of the deployable radiator using a loop heat pipe. Analyzed and evaluated flexible structures. Develop 100 Ah Ni-H_2 battery.

WINDS R&D of WINDS is being implemented under the e-Japan Priority Policy Program established by the IT Strategy Office. This is a joint project between JAXA and National Institute of Information and Communications Technology to develop the most advanced information network.

=====================【Support by ISTA】==========================

Thermal and structure analyses of satellite system. Communication, thermal and structural analyses of mission equipment. Supported solar cell evaluation and electric power system design.

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Summary of Project Supports (sheet 3 of 4)

SELENE SELENE is the Japan's first, large lunar explorer and stands for SELenological and Engineering Explorer. This is the largest lunar exploration project since U.S. Apollo project and has drawn attention from the world. (ISAS project)

======================【Support by ISTA】========================

Supported analysis of the landing, navigation, guidance and control system and procurement of 35AhNi-Cd batteries and 13AhNi-MH batteries. Consulted on space-use parts applications. Supported the propulsion subsystem design and subsystem ignition tests. Supported analysis of materials and mechanical parts.

GOSAT This is a joint project between JAXA and Ministry of the Environment. GOSAT is a Japan's contribution to the Kyoto Protocol created at the third session of the Conference of the Parties to the U.N. Framework Convention on Climate Change (COP3) and to Global Climate Observation System. GOSAT will measure CO_2 distribution from the space. CO_2 worsens greenhouse effect.

======================【Support by ISTA】========================

R&D of onboard equipment such as space environment measurement equipment and newly–developed components and parts (e.g., high speed wheel, 200MIPS 64bitMPU and DC/DC converter). Thermal evaluation of high-efficiency solar cells.

GPM／DPR GPM and DPR stand for Global Precipitation Measurement and Dual-frequency Precipitation Radar, respectively. GPM mission is composed of Core Spacecraft and some 8 constellation satellites. Core Spacecraft is equipped with DPR, which measures precipitation using two radio frequencies, and GPM Microwave Imager .

======================【Support by ISTA】========================

Supported parts program, thermal design of radiator, and material technology. Analysis of heat balance and structure.

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Summary of Project Supports (sheet 4 of 4)

JEM Pressurized Module/Exposed Module/Manipulator, Space Experiment Equipment

JEM "Kibo" is the Japanese contribution to the International Space Station. JEM includes two experiment elements; the pressurized laboratory and the exposed platform. JEM also includes the pressurized stowage as part of the pressurized laboratory and the exposed pallet as part of the exposed platform, the robotic manipulator for experiments and other tasks, and the communication system with satellites.

======================【Support by ISTA】========================

・Offgassing test, flammability test and odor test. Measurement and evaluation of noises.
・Supported MATOF platform development and outgas measurement from organic materials (e.g., FRP).
・Evaluated long-term accuracy of harmonic drive dumper used for the small manipulator joint. Provided technical support on PCS (Parallel Computer System) which is used as part of the backup computer for the manipulator controller. PCS was mounted on MDS-1.
・Safety evaluation of batteries embedded in the small, portable equipment.

HTV HTV(H-II Transfer Vehicle)is a re-supply vehicle for the ISS. HTV is an unmanned vehicle designed to be attached on top of the augmented H-IIA launch vehicle, delivers a maximum of 4 tons of foods, clothes and various experiment equipment to the ISS and brings back used experiment equipment and clothes to the atmosphere. HTV will be burnt during the re-entry.

======================【Support by ISTA】========================

R&D of rendezvous sensor. Evaluated the lubrication segments for friction characteristics and lifetime. Evaluated imported mechanical parts (low impact separation mechanism). Supported rendezvous docking testing. Supported in the area of batteries and electric power system. Support in the operational phase using the distributed simulator.

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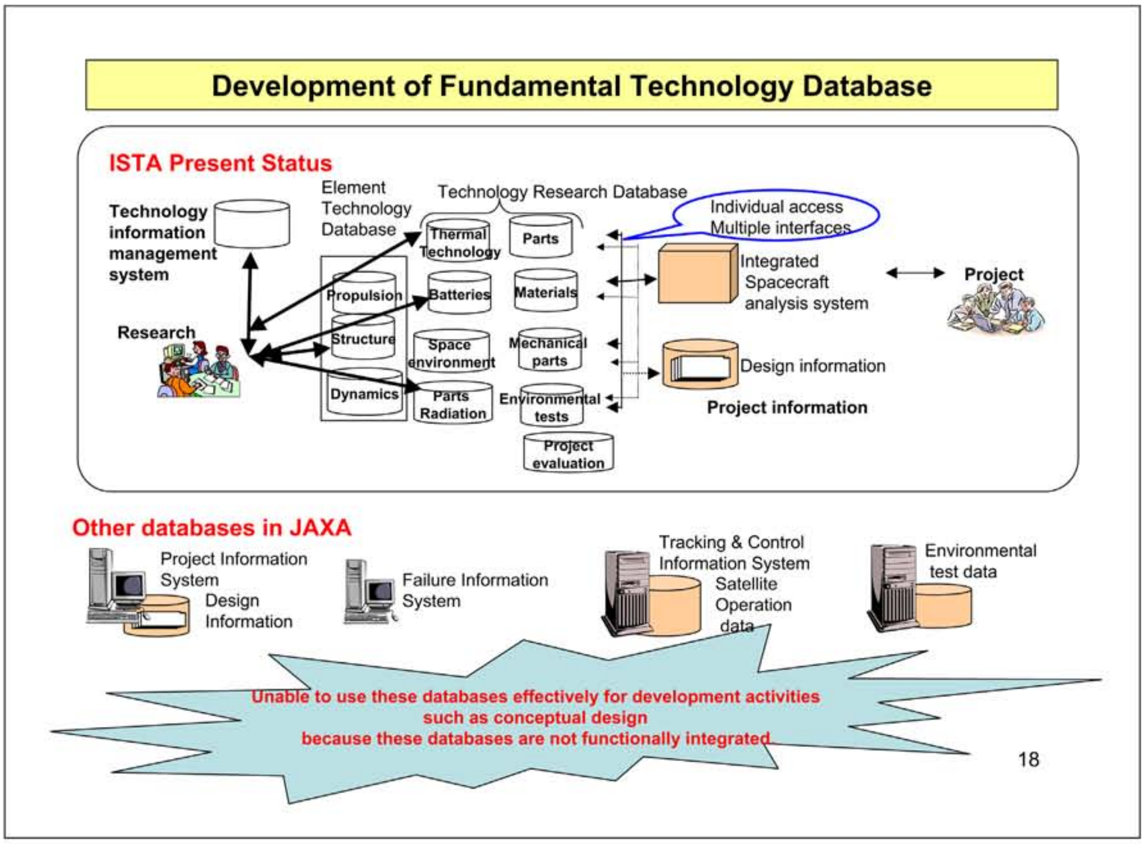

Enhance existing technical databases

Database	Summary	Status
Common Parts Database	Database integrated to provide information on JAXA (former NASDA) qualified parts.	Open to Public/Restricted
Parts Test Data Analysis System	Database of solar cells including data such as radiation test data, flight heritage and failures. This database also provides search and retrieval capabilities of test and analytical results.	Open to Public/Restricted
Guidance Control Information System	Database of dynamics, navigation and guidance, results on robotics research such as materials, numerical data and evaluation results.	In Group Only
Mechanisms & Parts Database	Database of space-use mechanical parts and systems including research results and design standards related to mechanical parts and systems.	In Group Only
Structure Information Database	Database of results of structural system researches such as materials, numerical data and evaluation results.	Under construction
Space Environments Measurement Information System	This database has radiation environment simulation function including satellite anomaly warning notification function and satellite environmental information supply function. This database also has a function to utilize stored data.	Open to Public/Restricted
Battery Life Database	Added a capability to register past data and to compare in-orbit operational data and ground-based test data for batteries that are used for satellites to be operational in the future. Converted "Collection of Battery Cleaning Test Base Data" into an electronic file, which was distributed to related parties and added to the database.	In house Only
Material Database	Database of outgassing test, safety demonstration test, material evaluation test and space demonstration data.	Open to Public/Restricted
Thermal Design Analysis Information System	Database of thermal design technology such as design materials, mathematical thermal models, chamber test data, in-orbit data and other thermal-related data.	In house Only

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JAXA Institute of Space Technology and Aeronautics (ISTA)

Space Technology

① Support for current projects

② **R&D for next projects**

③ Study on future space systems

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R&D for Next Projects －Components & Parts－

➢Continue enhancing the fundamental parts technologies to prevent potential spacecraft mission failure due to increasing imported items of space equipment and parts and decreasing domestic high-reliability parts.

➢Enhance R&D to sustain and grow domestic technologies for design, fabrication and quality assurance of the following critical units and parts in order to assure independence of Japan's space development.

Star sensors

High torque and low disturbance wheels

Fiber gyros（FOG）

Next generation GPS receivers

Guidance and Control Units

Units or parts critical to performance and design of satellites and space transportation systems such as attitude control system.

Lithium Ion Battery Assembly

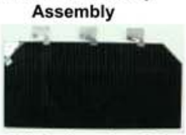
150mN Class Ion Engine

Electrical Power Supply Units

Units and parts that Japan has sufficient experiences and international competitiveness such as electric power supply system.

Satellite Propulsion Units

Units and parts critical for mission assurance. Technologies for these items must be sustained and accumulated in Japan.



Triple-Junction Solar Cells

Satellite propulsion parts (e.g., valve)

Toward establishment of Japan's independence for space development

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Guidance and Control Units

➢ Advance the attitude control technology, which is the brain of spacecraft, in accuracy, weight and reliability and strengthen international competitiveness.

Star Sensor（SST）：

The next generation star sensor, which can autonomously determine the attitude, is being developed. Utilizing the high performance MPU, the high accuracy and the small size are achieved. A prototype has been built and evaluated.

Star sensor

Wheel：

Developing new two type Reaction Wheels, High Torque Reaction Wheel (HTRW) and High Speed Reaction Wheel(HSRW). HTRW is for a future observation mission and has characteristics of high torque and low disturbances. HSRW is for general missions and has characteristics of small/light and low disturbances. HSRW will be launched on GOSAT in 2008.

High Speed Reaction Wheel(HSRW)

Fiber Optic Gyro（FOG）：

Aiming for the application to the future spacecraft attitude control system, high performance Fiber Optic Gyro, which employs the high power erbium-doped fiber light source and long fiber coil (3km) are now under development. A prototype has been built and evaluated.

Fiber optic gyro（FOG）

Next Generation GPS Receiver：

The new space borne GPS receiver, which can track 24 satellite signals including the L2 new civil code was under investigation. Because of dual frequency utilization, the ionospheric delay error is dramatically reduced. A functional model has been built and evaluated.

Next generation GPS receiver

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Electric Power System

➢ **Reducing the power system mass and cost by improving their life, performance and reliability in order to increase spacecraft competitiveness.**

High Efficiency Solar Cells：

Triple-junction (3J) solar cells were developed and demonstrated a conversion efficiency of greater than 28%. The 3J cells have been qualified and utilized for WINDS, GOSAT and other GEO/LEO satellites. A thin-film flexible dual-junction solar cell is now under development to reduce the cell-weight by 1/10 or less.

Triple-junction Solar cell

Lithium Ion Batteries：

The life of Lithium Ion Batteries has been investigated. Long cycle-life tests under LEO and GEO operation conditions have been achieved over 35,000 and 1,500 cycles, which are equivalent to over 6 years and 15 years, respectively. The Lithium Ion Batteries have an advantage of 50% weight reduction compared to existing alkaline batteries and will be used for future spacecrafts.

100Ah-10 series Lithium Ion Battery Assembly

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Satellite Propulsion Units

➢**For supplying reliable satellite propulsion subsystem**

- **150mN class Ion engine and electric propulsion mission concept.**
  ⇒Lengthening the grid lifetime and improving the durable grid design against the launch vibration. Conceptual mission study for using the advantage of the large thrust and high Isp.

- **The 20N class thruster valve**
  ⇒Development the reliable 20N class thruster valve. Reliable technology of COTS components.

- **Continuous improvement activity of propulsion components and systems**
  ⇒Thrusters, engines, valves, tanks, material, propellant, ...etc.

150mN Class Ion Engine

Thruster Valve

Monopropellant Thruster

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Telecommunications and Data Handling

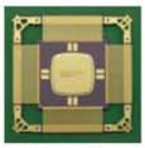
➢**Telemetry, tracking and command (TT&C) is key system for spacecraft operations. High performance and multifunctional transponder are required. Data recorder is indispensable for massive data processing required for advanced space missions with higher precision.**

- **Multi-mode Integrated Transponder (MTP)**
  New S-band transponder for TT&C operation is under development. MTP integrates four radio transmission modes: USB, SSA, QPSK, and CDMA. MTP capability will be demonstrated on the SDS-1.

- **The third generation Solid State Recorder (SSR)**
  SSR prototype with rad-hard 64-bit MPU, stacked ultra-high-density SDRAM technology achieved the performance of 2.5Gbps recording/playback speed. The environmental tests (VT, TVT, EMC, long-term operation test) were successfully finished.

- **The development of 200MIPS 64bit MPU is successfully finished at the end of JFY 2005.**

Multi-mode Integrated Transponder (TBD)



200MIPS 64bitMPU

3rd generation Solid state recorder

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Space Environment Measuring Instruments 1/2

➢These instruments measure space radiation environments that may induce satellite failures and contribute to improving space environmental models that are used to optimize satellite design and operation planning, which enhances the fundamental technologies.

- **Conduct R&D of instruments such as the small and light weight "light particle monitor*.**

*Currently flight-types of this instrument are under evaluation. This instrument will be used for GOSAT, Jason-2, SmartSat.

- **Collected data is used to develop space environment models which are used for spacecraft design.**

- **Further, space environment data is made available in various manners such as for high energy electron prediction and warning system.**

French Satellite
Jason-2 (CNES)

Light Particle Monitors

※This is an instrument to count electrons, protons and α-particles, and measure distribution of energy and moving directions of these particles accurately.

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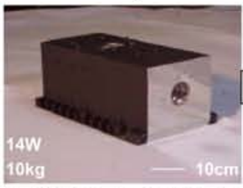
Space Environments Measuring Instruments 2/2

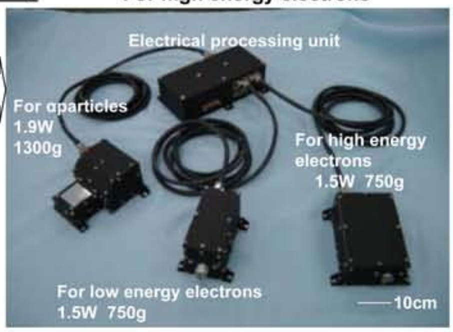
Radiation (electrons, protons and α particles)



For Tsubasa, Kodama, Kibou
Electronics (0.4～9MeV)
Protons (0.9～210MeV)
A particles (6.5～140MeV)

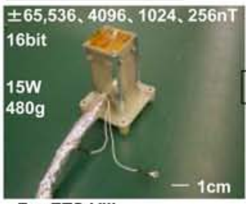
For Daiti
Electrons (0.3～10MeV)
Protons (1.5～250MeV)
A particles (6～250MeV)

For high energy electrons



New development for GOSAT, Jason-2,& SmartSat
Electrons (0.03～20MeV)
Protons (0.4～500MeV)
A particles (3～2000MeV)

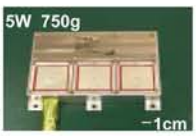
Magnetometer



For ETS-VIII

New development

Electric charge monitor



For ETS-VIII

Contribute to satellite design and operation planning in JAXA

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Basic Approach for In-Orbit Demonstration

Continue providing timely space demonstration opportunities

- ➢**Avail space equipment developed by the R&D group or industry to space demonstration missions, projects and markets in a timely manner.**
- ➢**Currently opportunities of timely and cost-effective space demonstration are short of demands.**

Benefits of In-Orbit Demonstration

①In-orbit demonstration is indispensable before actual use in the space.
（e.g.：Flight proved equipment for commercial satellite）

②Verify technologies that cannot be verified on the ground.
（e.g. LDREX）

③Enhance the fundamental technologies by comparison between ground-based tests and in-orbit demonstration.
（e.g. MDS-1/μ-LabSat）

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Achievements of In-Orbit Demonstration

MDS-1 Tsubasa

Use of results for next generation satellites

（1）New satellite development method：
－Short duration (3 years) and low cost development

（2）Use of COTS for space applications：
－Tested COTS in-orbit using parts of the same lot used for ground-based tests. The result was used to establish ground-based evaluation technology and develop a guideline for test methods.

（3）Collection of new space radiation data and revision of the models：
－Revise radiation hardened design standards.
－Influence the space environment design standards.

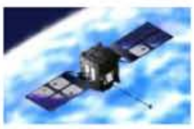
μ-LabSat-1

Use of results：

（1）Establish small satellite bus technologies：
－Acquire spin-stabilized satellite bus technology and three axis attitude control technology.
－Acquire remote inspection technology.

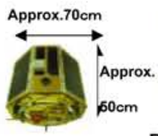
（2）Increase space demonstration opportunities：
－Expect to serve as a vehicle for space. demonstration to evaluate future space equipment. Expect to continue μ-LabSat project as a series.

（3）Train young engineers：
－Contribute to training JAXA's young engineers to learn design, fabrication and testing technologies.



Commercial Semiconductor Device

In-house satellite development by JAXA's young engineers



Remote inspection technology experiment

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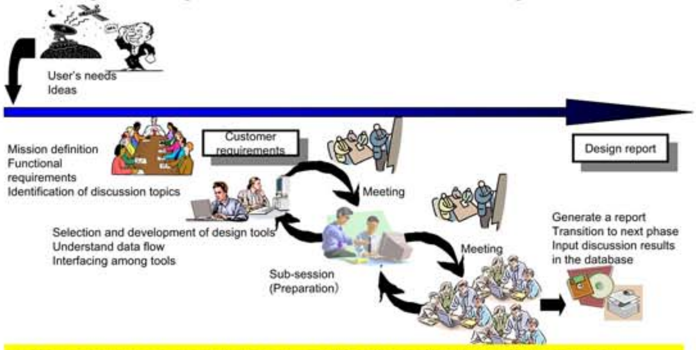
R&D for Next Project －Design Center－

Study on conceptual design method

CoA (computer-aided group designing method) is under way to enable a joint designing session by experts where each expert uses his or her own analytical tools and interacts with other experts through a network. CoA is a conceptual designing method that takes advantage of information technologies, concurrent engineering and collaboration technologies.



In the beginning of conceptual design, define discussion topics, initiate design activities and develop a system that supports the entire design. In the rest of the design period, the system is used repeatedly until the design comes to satisfy the requirements.

Example: Spacecraft designing session in a collaborative environment

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JAXA Institute of Space Technology and Aeronautics (ISTA)

Space Technology

① Support for current projects

② R&D for next projects

③ **Study on future space systems**

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Policy for Advanced Research

■**Objectives**

- ➢**Serve as the front runner to meet future needs.**
- ➢**Enhance and progress technology base through challenges to advance technologies.**

■**Approach**

- ➢**Programmatic approach based on a roadmap**
- ➢**Assess technical feasibility. Move forward steadily one step at a time.**

■**Themes**

- ➢**Expand space utilization and develop infrastructure to reach frontiers by manned mission.**
  - **Space robotics, rendezvous docking technology**
- ➢**Future space utilization missions**
  - **E.g. Space energy (space solar lights) utilization system**

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Major Advanced Research 1/2

Research on space energy (space solar lights) utilization systems

Space Solar Power Plant System (Concept)

➢This is a system to collect unlimited solar energy efficiently in the geostationary orbit and transfer the energy to ground in the form of microwave or laser.

Research to develop the system:
e.g. Plan in-orbit technology demonstration such as a technology demonstration plan near ISS*.

Research on element technologies:
e.g. Optimal design and element tests of high power transmission technology, high performance magnetron and microwave transmission system.

※ISS：International Space Station

Research on In-orbit Services

➢Reduce operational costs for future space systems through in-orbit assembly and re-supply using robotics and rendezvous/ docking technology.

Research to develop autonomous systems:
e.g. System concept studies on in-orbit work machines (e.g. re-fueling), assembly robots and inspection robots.

Research on element technologies:
e.g. Space robotics technology, rendezvous/ docking technology, capture technology, image recognition/ automated and autonomous technology and remote manipulation technology.

Autonomous assembly robot

Satellite capture experiment

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Major Advanced Research 2/2

Study of re-usable space transportation systems

Concept of Raflex

- Development of design and evaluation tools for trade-off of re-usable transportation concepts:
  - Tools that compare various re-usable transportation system concepts on the same criteria.
  - → Feed-back the results to the development scenario and R&D guideline
- Study on major fundamental technologies and flight demonstration of those technologies
  - Structures using composite materials, advanced avionics and abort guidance, among other things.
  - Flight demonstrator (Raflex)

Ground test of the air-breathing engine

Study on improving performance of re-usable transportation system

- Air-breathing engine
  - High-speed type (Composite engine based on Scramjet engine)
  - Low-speed type (Turbo engine with pre-cooling function)
- Advanced TPS
  - TPS better than that of Space Shuttle in areas such as maintainability, reliability and resistance to high temperature

Study on Moon and Mars Exploration Technologies

- Study toward Moon & Mars exploration
  - Navigation, guidance, control and collision avoidance for soft landing
  - Study on rovers

Lunar surface running test

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MEMS and Micro-Structures in Aerospace Applications

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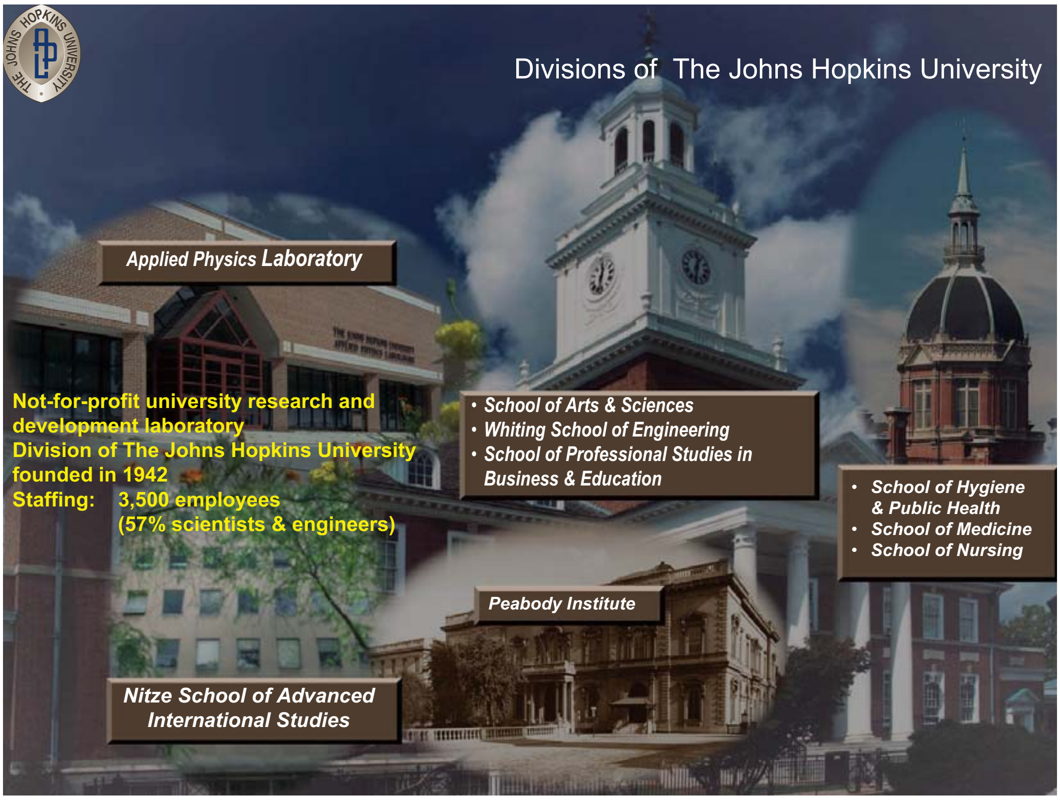
19th Microelectronics Workshop - October 25 – 27, 2006
JAXA Tsukuba Space Center (TKSC), Tsukuba, Japan



Applied Physics Laboratory
Space Department

Recent Missions

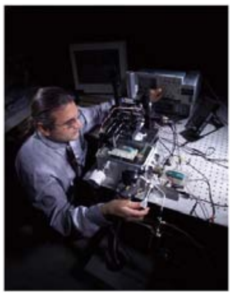
- New Horizons - Pluto
- MESSENGER - Mercury
- STEREO – Solar Terrestrial Observer
- Magnetospheric Imager on Cassini – Saturn
- TIMED – Ionospheric Dynamics

3

Applied Physics Laboratory
Research and Technology Development Center

Areas of Expertise

- Systems & Information Sciences
- Chemical & Biological Sensors
- THz Technology
- Wave Scattering & Propagation
- Quantum Information
- High-Speed / Micro- Propulsion
- Bioinformatics
- MEMS and Nanotechnology



4

Outline

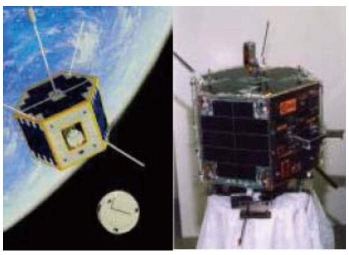
- Introduction- MEMS
- MEMS in Space Applications
- Missions and Visions for MEMS Space Applications
- MEMS Reliability
- MEMS Shutters on ST5 - From TRL3 to Space
- Summary

5

History of MEMS and MEMS in Space

- 1969 Resonant gate field-effect transistor(Westinghouse)
- 1970s Bulk-etched silicon wafers for produce pressure sensors
- 1980s Surface-micromachined polysilicon actuators for in disc drive heads.
- 1990s Air Force Office of Scientific Research (AFOSR) Materials Research
- 1993s Defense Advanced Research Projects Agency (DARPA) Foundry

- *1998 Mighty Sat 1, STS 88*
- *1999 Shuttle Orbiter STS 93*
- *1995 - 2002 OPAL (orbiting pico-satellite automated launcher)*



6

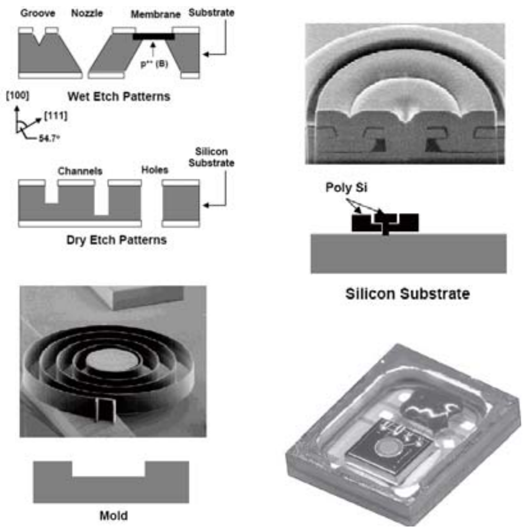
(Non-Space) Advantages of MEMS

- IC Technology
  - Integrated multiple (also analog and digital) functions
- Precision
  - Improved performance
- Batch Production
  - Reduced Manufacturing Cost and Time,
  - Mass Production with maintained performance
- Miniaturization
  - Ruggedness
  - Low power Consumption
  - Lightweight
  - Massive Deployment
  - Easy replacement
  - Low environmental impact

7

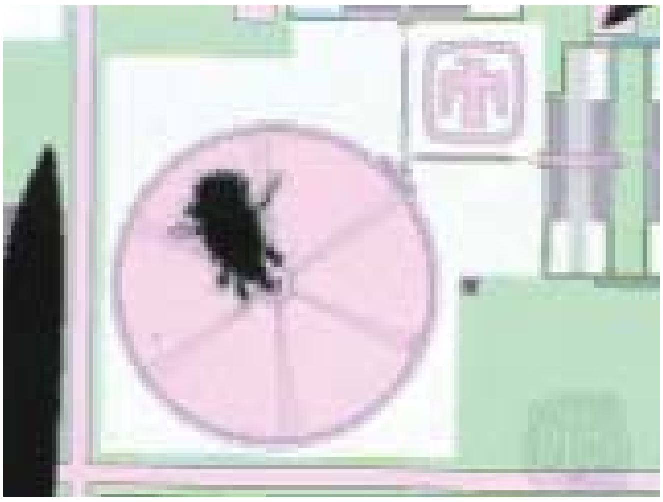
MEMS Fabrication

- Design
- Photolithography
- Fabrication
  - Bulk (wet etch, DRIE)
  - Surface micromachining
  - LIGA
- Wafer assembly/bonding
- Electronic integration
  - Hybrid
  - On die, MEMS first, MEMS last, CMOS MEMS
- Packaging, wire-bonding



8

MEMS and Mites (SNL)



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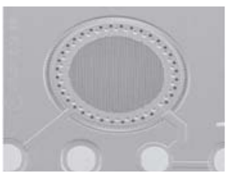
Commercial MEMS Applications

- Accelerometers (Analog Devices, Airbags)
- Gyroscopes (Segway)
- RF Switches
- Pressure Sensors
- Microphones (Knowles Acoustic)
- Moveable Mirrors (Texas Instruments -DLP)



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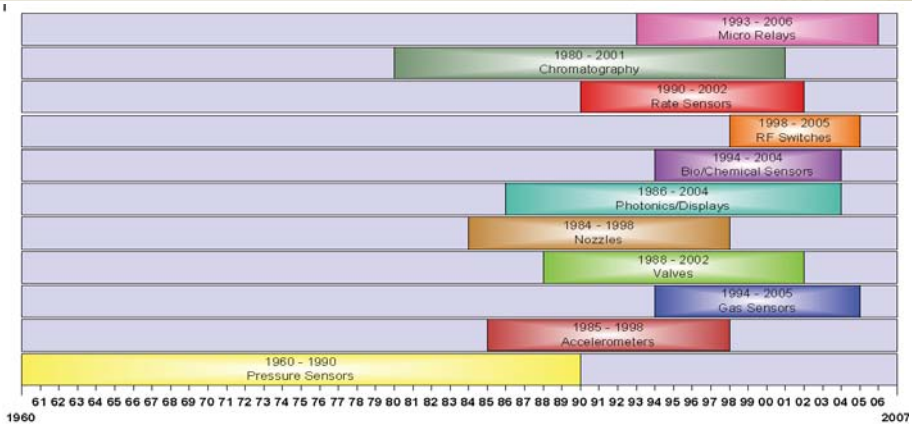
MEMS Commercialization Timeline



Commercialization times (from beginning of product evolution to full commercial production) for various MEMS technologies.

(***"International MEMS, MicroSystems, Top Down Nano Roadmap,"*** **Micro and Nanotechnology Commercialization Education Foundation (MANCEF), Albuquerque, New Mexico, 2002, p.53**.)

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Outline

- **Introduction- MEMS**
- **MEMS in Space Applications**
- **Missions and Visions for MEMS Space Applications**
- **MEMS Reliability**
- **MEMS Shutters on ST5 - From TRL3 to Space**
- **Summary**

12

Drivers for Miniaturization- Space

- Driver in the commercial market is cost reduction (Accelerometer for airbag < 0.1 $) via mass production
- Traditionally Space has been the driver for technology
- Space is a niche market looking for small number of instruments or devices
- Price is typically determined by the space qualification more than by fabrication cost
- Reliability is main issue for space, work without failure for extended period
- Infusion of commercial MEMS into harsh space environment non trivial

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Advantages of MEMS for Space

- Very low mass and volume
  - Low launch mass (~$10,000/kg for LEO)
- Low power consumption
  - most devices are electrostatic
- Small thermal constant
  - Low power to maintain temperature
- Resistance to vibration, shock, and radiation
  - Design dependent
  - Mechanical devices, e.g. switch, could be radiation hard
  - Low inertial mass makes them shock/vibration resistant
- High integration
  - Multiple Functionality
  - Simplified systems
- Batch fabrication
  - low-cost, mass production (no traditional space requirements)
  - large arrays or repetitive tasks

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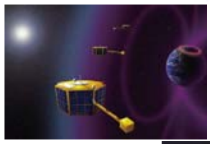
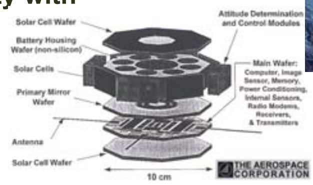
Space Applications for MEMS



- Components for traditional satellites
- New or improved instruments for satellites
  - Typically MEMS is an enabling technology, e.g. mirror array for JWST
  - Size reduction makes MEMS instruments applicable for nano-sats
  - New functionality, mass production of instruments
- Systems for Nano – and Pico Satellites
  - MEMS components are enabling technology, weight, size, and power reduction, mass production for constellation, compatibility with micropropulsion
- MEMS satellites
  - The ultimate picosat



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MEMS Applications for Space

NASA Technology Inventory on MEMS based technology developments
2001 : 59; 2002 : 77; 2003 : 111
Technologies include:

- MEMS Stirling Cooler
- MEMS liquid metal micro switches
- MEMS inertial sensors
- MEMS microwave RF switches and phase shifters
- MEMS thrusters
- MEMS deformable mirrors
- MEMS pressure or temperature sensors
- MEMS power supplies

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Drivers
MEMS Components for Space Applications

- Part of traditional Satellite systems
- Can be directly transitioned from COTS or Prototypes
- Require Space Qualification
- Replace mechanical / electrical Components (e.g. RF switches)
- Radiation Hardness (e.g. RF switches)
- Lower Power
- Cost
- New Functionality (e.g. accelerometer, gyroscope)
- Lower Weight and Smaller Size for same (or new) functionality

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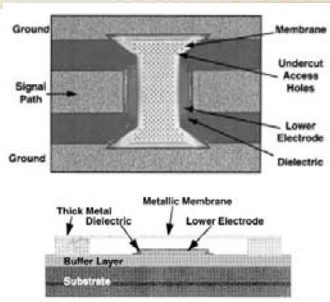
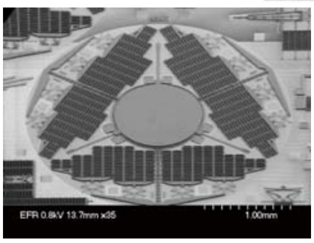
Examples
MEMS Components for Space Applications

- RF – Switches
- Accelerometers
- Gyroscopes
- Micro-Mirrors
- Emissivity Control Shutters
- Sun Sensors
- Magnetometers
- Thrusters





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Drivers
MEMS Instruments for Space Applications

- Typically unique prototypes
- New functionalities e.g. mirror arrays, shutter arrays
- Size reduction of instruments (accelerometer, plasma spectrometer)
- Mass production allows use in mapping with constellation
- Better performance due to smaller dimensions and higher dimension control

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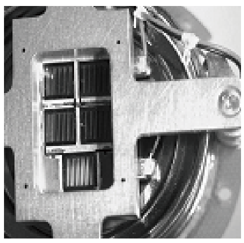
Examples
MEMS Instruments for Space Applications

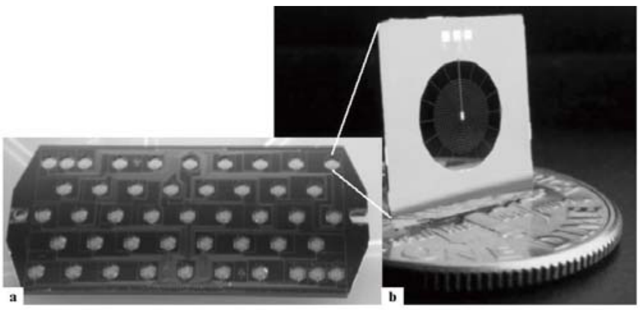
- JWST – Shutter array
- Flat plasma spectrometer
- Miniature mass spectrometer
- Switch configurable array antennas
- Tunable Fabry Perot Etalons
- Fine-pointing micromirrors



20

MICRO TECHNOLOGIES FOR SPACE SYSTEMS

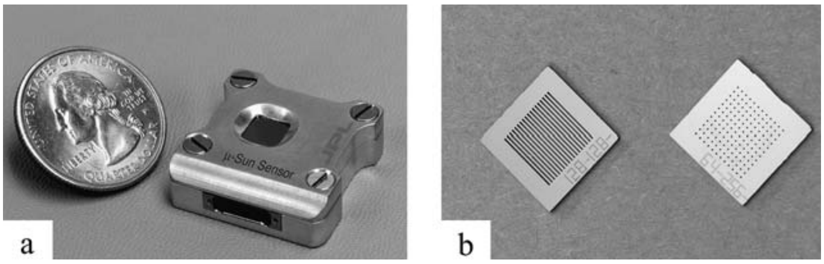
"Spider Web Bolometers" for Herschel Space Observatory and Planck Surveyor Missions



- To be flown on PLANCK Surveyor Mission (2007)
- The High Frequency Instrument (HFI) will map the entire sky in six frequency bands ranging from 100 GHz to 857 GHz to probe cosmic background anisotropy
- NEP 10^{-18} W/rt-Hz at 100 mK

22

MEMS based Sun Sensor



- Part of the attitude control systems of spacecraft
- JPL's miniaturized sun sensor to be flown on Mars Surface Laboratory (2009)
- Mass less than 30 g, power consumption less than 20 mW
- Microfabricated silicon mask (b) mounted on FPA

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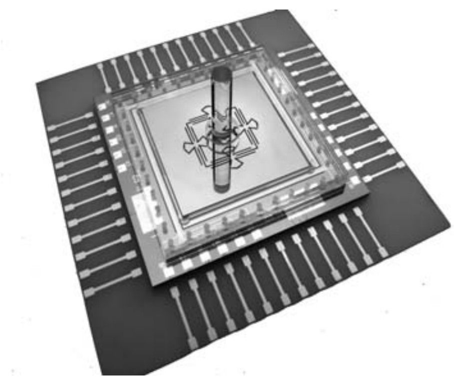
MEMS Vibratory Gyroscope



- The JPL-developed Post Resonator Gyroscope (PRG) holds the world record for the performance of MEMS Gyroscopes, at 0.1 degree/hour angular bias drift
- The PRG consists essentially of a two degree-of-freedom, planar resonator arrangement, which is "rocked" about an in-plane axis using capacitive actuation electrodes

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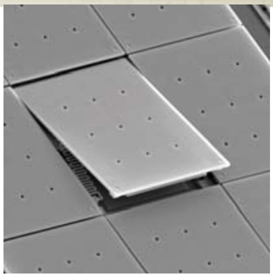
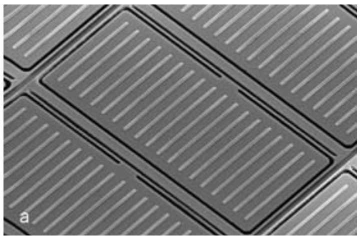
The James Webb Space Telescope Near IR Spectrograph

- NIRSpec provides users of JWST with the ability to obtain simultaneous spectra of more than 100 objects
- The European Space Agency (ESA) will be providing the NIRSpec instrument, NASA will provide the detectors and the MEMS aperture mask
- Two approaches initially proposed in 1996
  - MEMS micro-mirror array (SNL)
  - MEMS shutter array (NASA GSFC)
- Requirements
  - Pixel size 100 μm x 100 μm
  - Fill factor better than 80%
  - Contrast better than 2000:1
  - Array size 1800x1800 square elements
  - Operation at 40K





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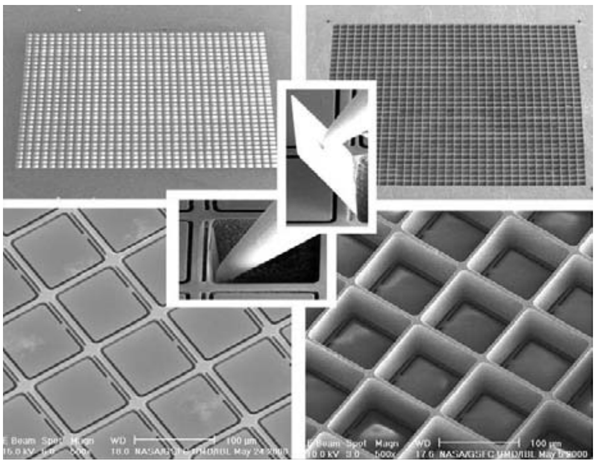
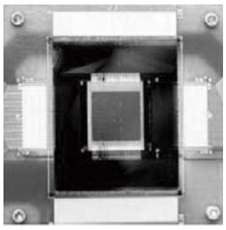
MEMS Micro-Shutter Arrays for the James Webb Space Telescope





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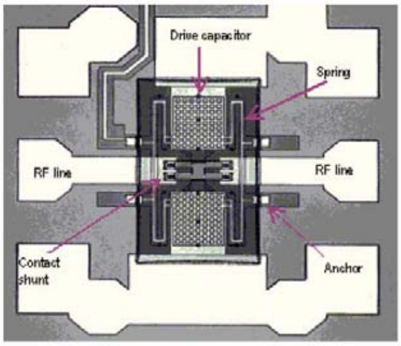
RF MEMS Switch



Rockwell Science Center)

- RF MEMS switches are an exciting alternative to the conventional semiconductor field effect transistor-based switches
- Applications in Communications, Phased-Array antennas
- Advantages
  - low mass, low power and small size
  - low RF insertion loss
  - high isolation
  - high intermodulation product
- Disadvantages
  - Low switching power
  - reliability

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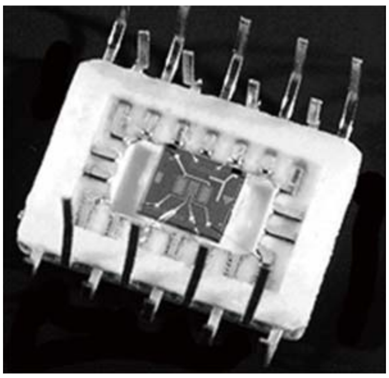
Micro Chemical Sensors

- Demonstrated on STS-95 and STS-96
- Baselined for use in the water processing and oxygen generator on the International Space Station
- GRC hydrogen sensor remains highly sensitive in inert, and oxygen-bearing environments
- Can operate over a wide concentration range of hydrogen
- Pd-alloy based hydrogen sensors with MEMS heater and temperature sensor



NASA Glenn Research Center (GRC) Hydrogen Sensor

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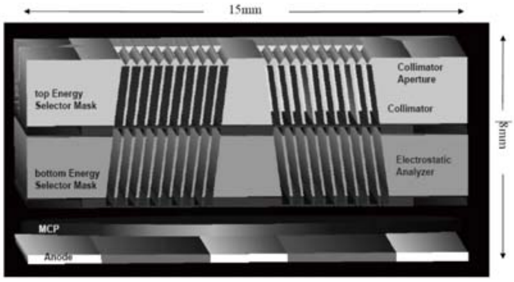
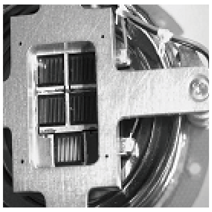
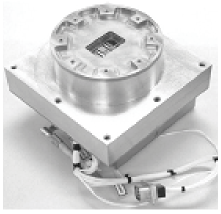
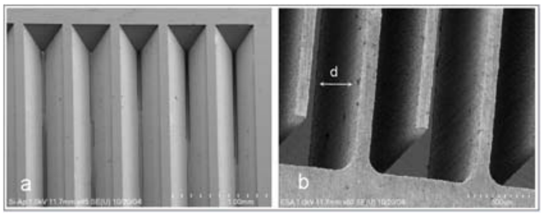
JHU/APL/NASA/USAFA Flat Plasma Spectrometer (FlaPS)

- Less than 500 g including power conversion
- Directionality given by (16) angle in deflector electrodes (flat)
- Entrance and exit slits DRIE in SI
- To be flown on USAFA FalconSat 3, 2007









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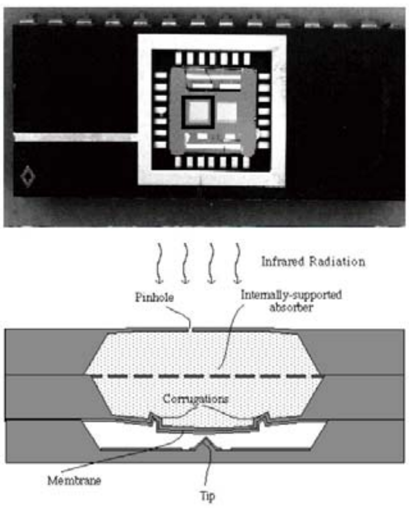
Micromachined Bolometers



- Tunneling Infrared Sensor (JPL, Stanford University) used as a horizon detector on Sapphire
- Golay-cell using quantum mechanical electron tunneling as the displacement transducer
- Application as imaging array possible
- Other Examples: uncooled IR imagers (Honeywell, Sarnoff)

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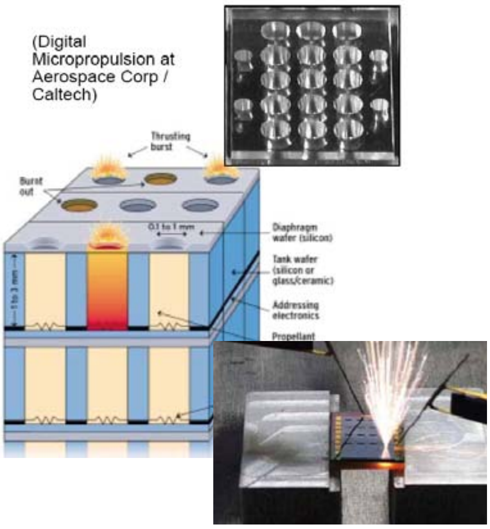
Digital Propulsion

(Digital Micropropulsion at Aerospace Corp / Caltech)



- Demonstrated on STS-93 (1999)
- Large array of sealed plenums filled wit fuel (e.g lead styphnate)
- A thin diaphragm as the sealant
- By igniting the fuel with small resistive (digital) lines, the pressure inside the plenum is increased sufficiently causing the diaphragm to rupture and release the propellant, producing an impulse
- Impulse bits range from 1 to 100μN-s

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Nano- and Pico Satellites

- Small satellites with mass less than 10 kg (nano) or 1 kg (pico)
- MEMS is enabling technology and are poised to have the greatest impact
- Smaller satellites require much tighter integration, and ideally multi-functional components (e.g. a structural skin that is also and antenna and a panel)
- Cost is a serious and driving issue, no longer a race to the moon mentality, but lighter means cheaper to put into orbit
- Mass production allows to make more (constellations) cheaper

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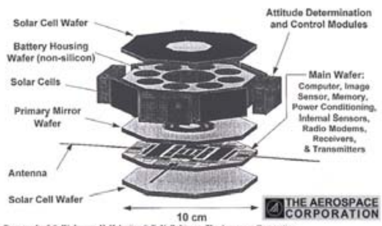
MEMS as Enabling Technology in Nano- and Pico Satellites

- Micro propulsion – low thrust and impulse bit only applicable for small satellites
- Thermal Control – low power availability and thermal mass requires active (non-heating) thermal control
- Guidance – low weight attitude detectors, gyroscope

- Solar energy ~ r^2
- Radiated energy ~ r^2
- Thermal mass ~ r^3



From work of S. W. Janson, H. Helvajian & E. Y. Robinson, The Aerospace Corporation

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Applications of Nano- and Pico Satellites

- Inspector" satellites piggy-backed on larger satellites for Repair and Inspection.
- Arrays of pico-satellites for weather prediction, communication.
- Constellations for large aperture antennas
- Large constellations for mapping missions (spatial resolution at identical times)
- Small lander probes

Miniature Autonomous Extravehicular Robotic Camera (Mini AERCam, NASA JSC)

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Recent Microspacecraft Designs

Table 1: Examples of Some Recent Microspacecraft Designs

Designation	Mission Purpose/Status	Lead	Mass (kg)	Size (cm)	Power (W)	Voltage (V)	Ref
MightySat	Technology Demonstrator, Launched Dec. 1998	USAir Force	64	48x69	≤32	-	8
Micro-Bus 70	Misc. Missions 14 Launches prior to April 1999	Surrey Space Centre, U. of Surrey, England	40-70	35x35x65	21-43	12	9
Orsted	Magnetic Field and Charged Particle Mapping, Launched Feb. 1999	Danish Space Research Inst.	60.7	68x45x34	54 (EOL)	-	10
SNAP-1	Technology Demonstrator, Inspection of other Spacecraft Launched June 28, 2000	Surrey Space Centre, U. of Surrey, England	6.5	34 x 23	4 (avg.) 7 (peak)	7-9	5
New Millennium ST-5	Magnetic Field Mapping Design Phase	NASA Goddard Space Flight Center	20	42x20 (Flat-to-Flat)	7.5-8.5	5/0.25	4
PROBA	Autonomy Demonstrator, In Design Phase	ESA	100	60x60x80	9	28	11
Falconsat	S/C Charging, In Design Phase	US Air Force Academy	50	46x46x43	24	12	12

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Recent Microspacecraft Designs

Designation	Mission Purpose/Status	Lead	Mass (kg)	Size (cm)	Power (W)	Voltage (V)	Ref
ASU Sat 1	Awaiting Launch	Arizona State U	5	31x24	8.5-10	13	13
		University Nanosat Program					
3-Corner Sat	3 Spacecraft, Formation Flying Demo, Stereo Imaging, Cell-Phone Comm. In Design Phase	Arizona State U., U. of Colorado, New Mexico State U.	10	45x25	33	3.3-5	13, 14, 15
ION-F	3 Spacecraft, Formation Flying Demo, Ionospheric Studies, micro-PPT Exp. In Design Phase	Utah State U., U. of Washington, Virginia Polytech. Inst.	10/13	45x12/ 45x25	18	28	14, 16, 17
Emerald	2 Spacecraft, Ionospheric Studies, Formation Flying, Micro-Colloid Thruster Experiment. In Design Phase	Stanford U., Santa Clara U.	15	45x30	7	5/12	14, 18, 19
Constellation Pathfinder	3 Spacecraft, Formation Flying Demo, Demo 1-kg S/C Fab. and Flight Operations In Design Phase	Boston U.	1	20x14	1	-	14, 20
Solar Blade Heliogyro	Solar Sail Demo, In Design Phase	Carnegie Mellon	5	-	28	-	21

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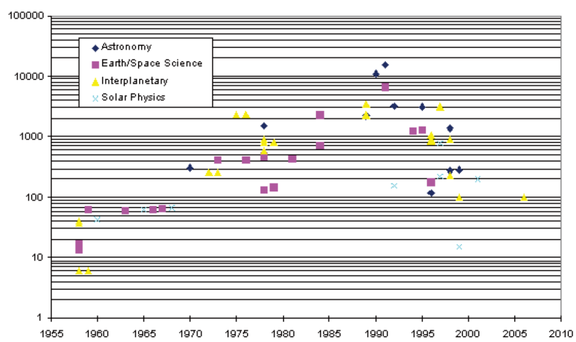
Missions for MEMS in Space

- Technology Demonstration
  - Space Shuttle
  - Sounding Rockets
  - ISS, Space Shuttle
- University Satellites
  - Falcon Sat, MidStar, OPAL
- Nano - /Pico – Satellites
  - ST5, Picosat1,



Mass of unmanned spacecraft / NASA

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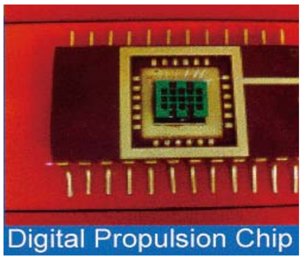
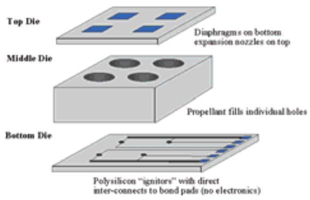
Digital Micro-Propulsion Program STS-93

- One of the first flights recorded for a MEMS device July 23rd, 1999, on NASA flight STS-93 with the Space-Shuttle Columbia
- TRW/Aerospace/Caltech MEMS Digital Micro-Thruster (inert, water)
- Succesfull suborrbital Space Flight Test on Microcosm Scorpius SR-S, January 27, 1999
- Thruster fired more than 20 times



The Aerospace Corporation



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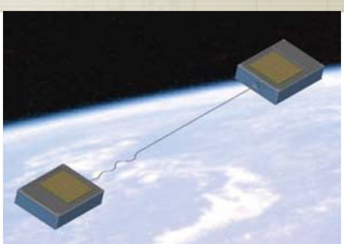
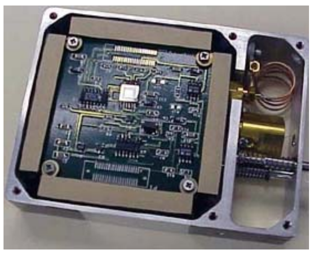
Pico-Sat Mission

- Jan 26, 2000 OSP1/Minotaur launch from VAFB
- JAWSAT - Successful deployment of OPAL, ASUSat1, FalconSAT
- Feb 6 deployment of PICOSATs from OPAL
    - Two tethered PICOSATs: 1 x 3 x 4 in., 270 gms each
    - Successful tracking and acquisition strategy
    - MEMS switch operation data returned to Earth





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MEPSI

- Microelectromechanical System-based (MEMS) PICOSAT Inspector (MEPSI)
- MEPSi1 – STS-113, Endeavour, December 2, 2002
- IMU, MEMS Transmit/Receive (T/R) switch.
- Demonstrate a completely new capability to provide active, on-board companions for use on future DoD space assets
- Provide active on-board imaging capability to assess spacecraft damages
- Monitor launch operations and augment servicing operations.

MEPSI 1A & Picosat launcher assembly (PLA) & MEPSI 1B [USAF]

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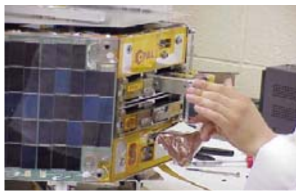
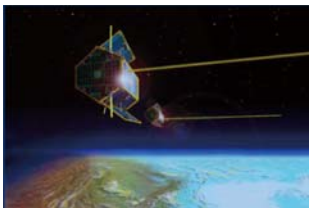
Opal, Sapphire, & Emerald

- Satellite quick research Testbed (SQUIRT)
  - Stanford University
  - Test micro and nanotechnologies for space applications
- OPAL (Orbiting PicoSat Launcher)
  - RF switch
  - MEMS accelerometers
- Sapphire
  - MEMS tunneling IR horizon detector
- Emerald
  - Colloid micro-thruster
  - Two Micro-sats, Virtual bus technology





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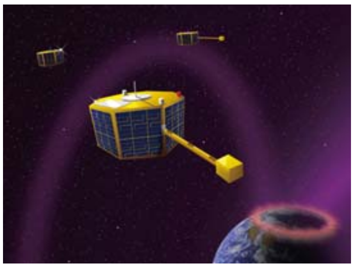
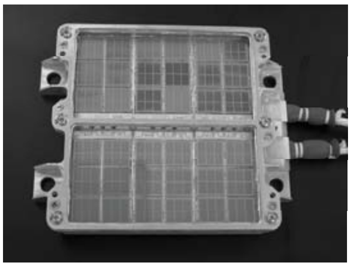
New Millenium St5





- 3 Nano-Satellites
- NASA Trailblazer for Nanosats, Constellations
- 25 kg, 50.8 cm Diam x 28.3 cm High
- Launch Pegasus, March 2006
- Mission ended June 2006
- Objective: Validate 7 Technologies
- Ultra Low Power
- Fractal Antenna
- Lithium-Ion Battery
- 5-V Spacecraft bus
- Variable Emittance Coatings (VEC) for Thermal Control
  - Electrostatic
  - MEMS

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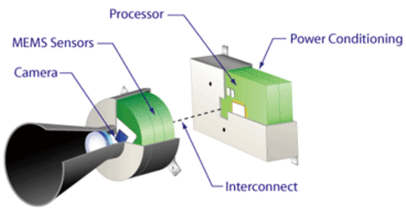
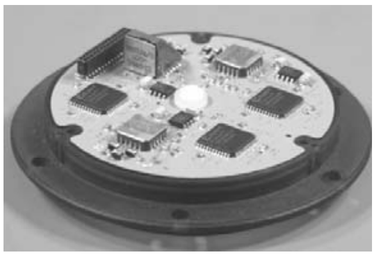
New Millenium ST6

- Autonomous Sciencecraft Experiment:

  Sciencecraft technology will equip radically different future missions with significant onboard decision-making
- The Inertial Stellar Compass (Compass) provides the capability of low-power, low-mass, and high-precision attitude determination for long duration space science missions
- Use of MEMS Gyroscopes for the IMU system



COMPASS Packaging Concept



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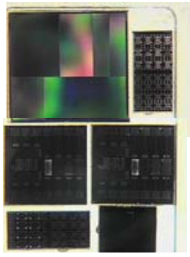
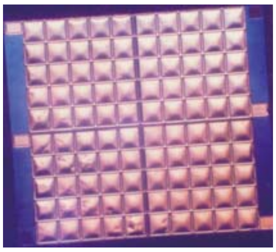
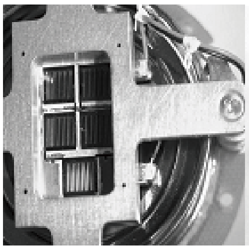
Other Opportunities

- Materials in Space Station Experiment (MISSE)
- Missiles, Munitions
- USNA MidStar – MEMS Thermal Switch (2007)
- USAF Falconsat 3 – Flat Plasma Spectrometer
- International examples



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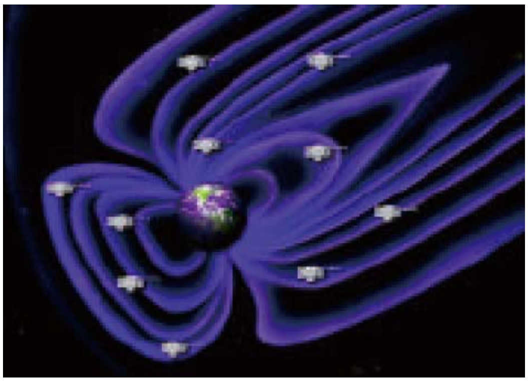
Missions for Nano-Satellites NASA Magnetosperic Constellation Mission

- MAGCON mission is part of the Sun-Earth Connection Program
- The launch date for this mission is 2010
- The primary mission campaign objective is the Earth's Space Environment : How does the earths magneto-tail store, transport and release matter and energy
- A secondary mission campaign objective is providing Impacts of Space Weather



NASA MagCon Mission Concept based on New Millennium ST-5 20-kg Micro-spacecraft to study the magnetic fields and plasma fields around Earth

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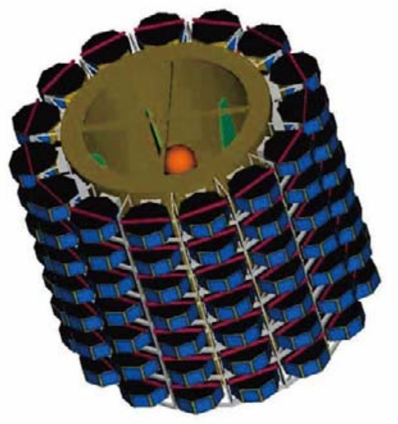
NASA Magnetosperic Constellation Mission

- Instrument Technologies
  - Miniature Instruments
  - Lightweight, miniaturized particles and fields instruments
  - Magnetometer
  - Plasma Analyzer
  - Energetic Particle Detector
  - Miniature, sensitive analog electronics
  - Rad-hard durable instruments
- Spacecraft Technologies
  - Miniature autonomous spacecraft
  - Li-metal batteries
  - Micro-Avionics
  - Rad hard processors
  - Data acquisition from constellations



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Environmental Concerns

Pre-Launch

- High humidity
  - Can cause stiction, leakage currents
- Particulates, Dust
  - Can cause shorts, jamming, failure

Launch

- Vibration and Shock
  - Can cause breakage of devices (not only packages)
- Particulates

Space Environment

- Radiation and Charged Particles
- Micro-meteorites
- Zero gravity
- Vacuum
- Temperature swings, Thermo-mechanical Stress
- Plasma, Electric discharge
- Atomic oxygen
- Fatigue

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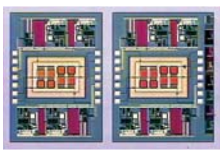
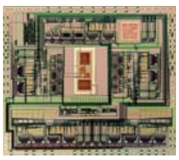
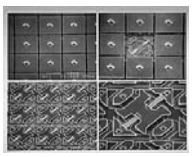
Taxonomy of MEMS Devices

No Moving parts	*Moving Parts, No Rubbing or Impacting Surfaces*	*Moving Parts, Impacting Surfaces*	*Moving Parts, Impacting and Rubbing Surfaces*
			
Accelerometers Pressure Sensors Ink Jet Print Heads Strain Gauge	Gyros Comb Drives Resonators Filters Shutters	TI DMD ($ 1B) Relays Valves Pumps Optical Switches RF Switches	Optical Switches Corner Cube Refl. Shutters Scanners Locks Discriminators

Commercial Devices

Danelle M. Tanner, MEMS Reliability Methods and Results, Sandia National Laboratories

Sandia National Laboratories

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Failure Modes for different MEMS Devices

	No Moving parts	*Moving Parts, No Rubbing or Impacting Surfaces*	*Moving Parts, Impacting Surfaces*	*Moving Parts, Impacting and Rubbing Surfaces*
Stiction		x	x	x
Wear			x	x
Vibration		x	x	x
Shock		x	x	x
Humidity	x	x	x	x
Radiation	x	x	x	x
Thermal Stress	x	x	x	x

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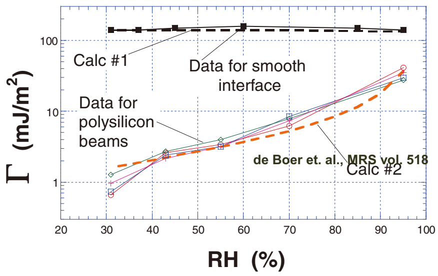
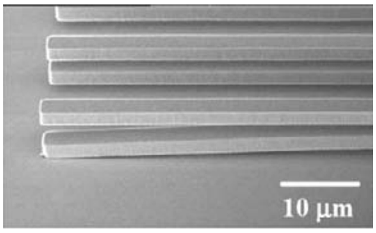
Adhesion / Stiction

- Caused by van der Waals forces
- Surface contact causes failure
- Can be caused by condensation in high rh environments
- Can be caused by electric fields during operation
- Can be caused by shock and vibration
- Some mitigating design features such as dimples which reduce contact area

Adhesion vs. RH





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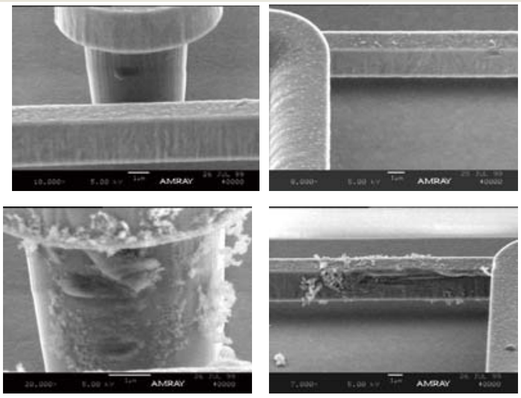
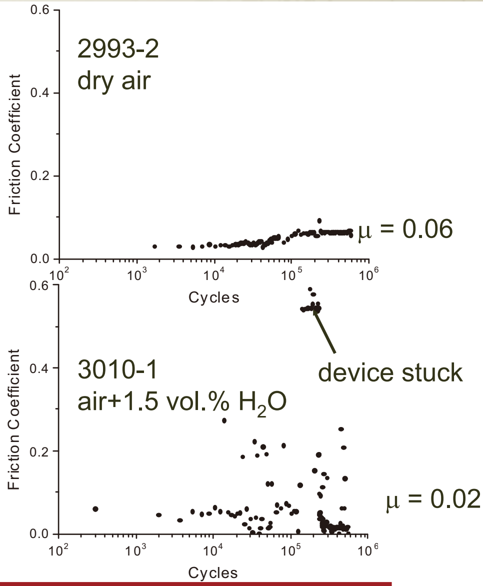
Friction and Wear





- Example FDTS-coated polysilicon (Tanner et al., SNL)
- debris generation begins before sticking - monolayer coating gone?
- Friction coefficient smaller at higher rh

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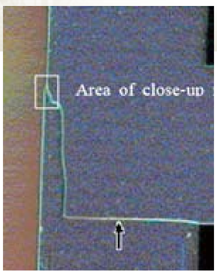
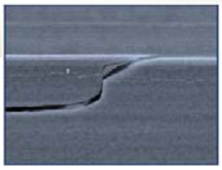
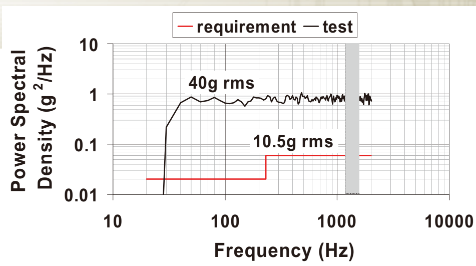
Vibration

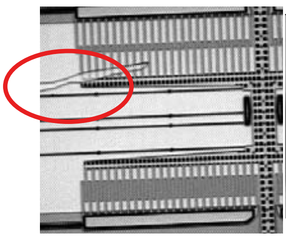




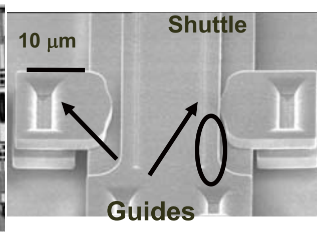
Cracks in single silicon support beams caused by vibration from launch test (Stark et al., JPL-D15753, 1997



- Can produce adhesion failure
- Can cause debris movement
- At launch up to 10 g at 2 kHz
- MEMS devices have higher resonance frequencies
- Modeling needs to include also device resonance frequencies
- Presently only components such as PCB are modeled



Vibration caused debris movement



Vibration caused adhesion to shuttle guides (*D. Tanner et.al., IRPS 2000)*

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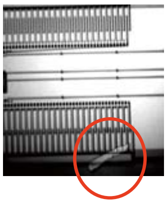
Shock

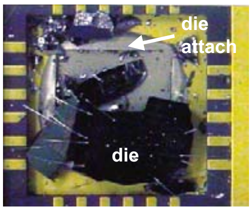
shock level:
G →

500 4000 10000 20000 40000

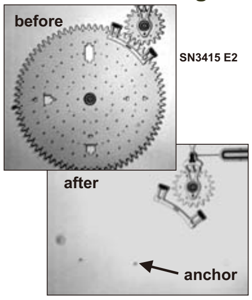
debris movement



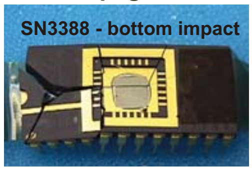
die attach failure



structural damage



ceramic pkg fracture



D. Tanner et.al., IRPS 2000

- Micromachines are extremely robust in shock environments
- working devices found out to 40 kG
- design/process modifications can allow survival beyond 20,000 G

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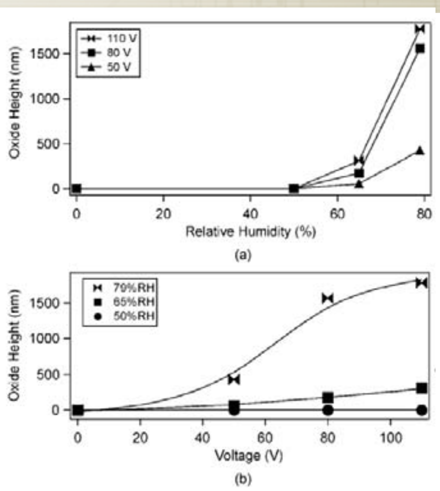
Humidity Effects

- Processing makes surface-micro-machined devices hydrophilic
- Condensation in small cracks and pores
- Increased residual Stress
- Bending moments in structures
- Adhesion due to capillary pressure between surfaces
- Corrosion
- Oxide Growth
- Electrical leakage currents
- Packaged devices are hermetically sealed (<5000 ppm) to shield against moisture
- Environmentally open devices must be able to withstand 50% humidity (testing, pre-launch, launch)



Growth of anodic oxide on poly-Si electrodes after 24 h under various relative humidity and voltage conditions at 23 C.

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Radiation Effects

Levels of radiation exposure orders of magnitude to small (even on Jupiter) to have effect on bulk material properties

- Typical radiation effect is charge generated in insulator
  - mechanical displacement
  - change resonant characteristics
  - alter output of many sensors
- Charge generation as radiation effects experimentally observed on 4 different MEMS devices

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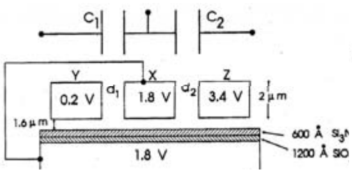
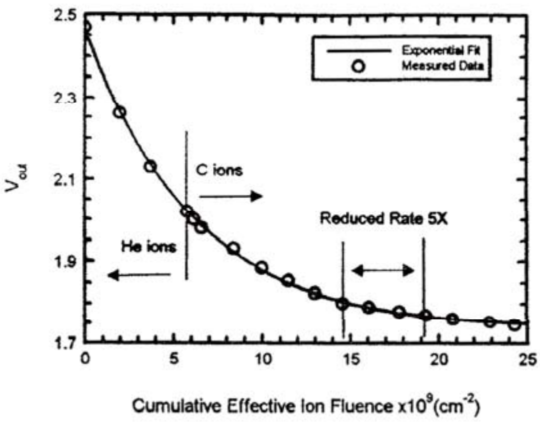
Radiation and Accelerometer





Cross-section of ADXL50 accelerometer, and output Voltage as function of particle flux (Knudsen et. Al., IEEE 1996)

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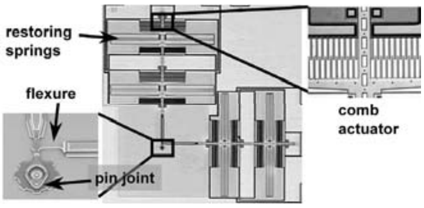
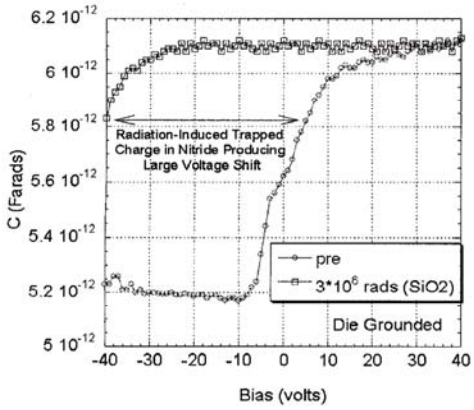
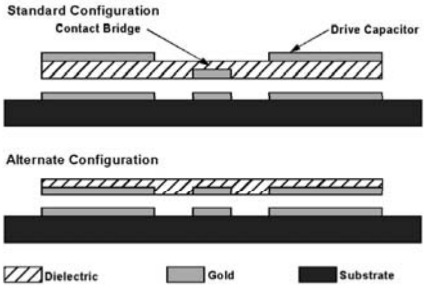
Radiation and Micro-Engine with Comb-Drive and Gear

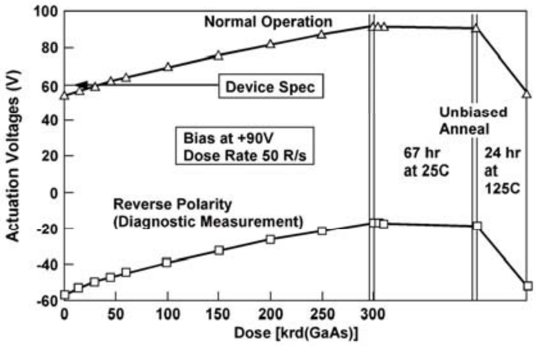




MEMS comb drive and Capacitance as a function of voltage before and after radiation exposure (L.P. Schanwald et al., IEEE 1999)

Radiation and RF Relay





Schematic of standard RF switches and actuation voltage as a function of dose (L.P. Schanwald, IEEE, 1998)

Reliability Concerns

- MEMS devices have been tested for reliability in terrestrial applications only
- Reliability is the critical issues for MEMS in Space Applications, Space requires stricter reliability standards
- Some materials are not compatible with the space environment (e.g. self-assembled mono-layers)
- Special packaging requirements (e.g. hermetic, conducting surface, open to environment)
- Modeling and Design can improve the reliability
- Acceptance testing early in the path, at the part and device level, required

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Outline

- Introduction- MEMS
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- MEMS Shutters on ST5 - From TRL3 to Space
- Summary

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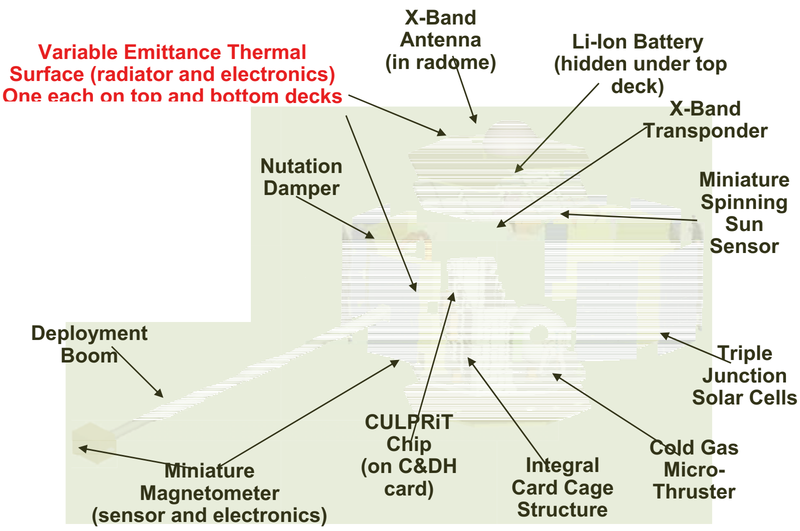
ST-5 Spacecraft Overview / Technologies



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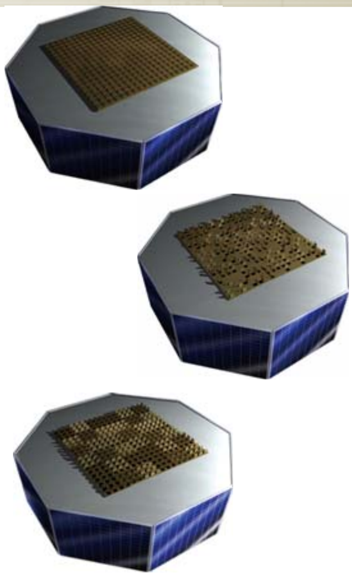
ST5 MEMS Variable Emittance Control (VEC) Objectives

- Micro-Electro Mechanical Systems (MEMS) Approach for thermal control:
  - Many small shutters vary the emittance of the surface of the radiator.
  - Emittance will be remotely controlled with low power electrostatic drive.
- To demonstrate that MEMS Shutter Arrays can be utilized as a variable emittance device for thermal control
- To test and flight-validate a MEMS instrument in the harsh space environment of the Earth's magnetosphere



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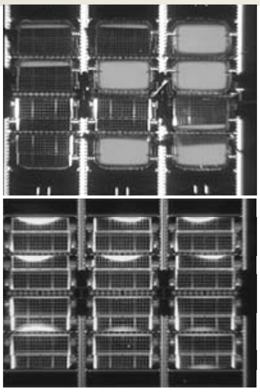
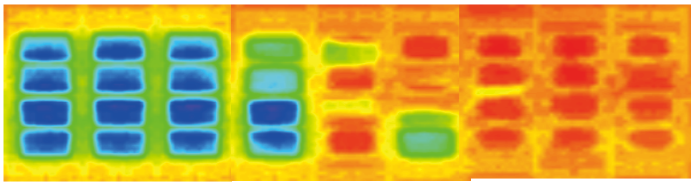
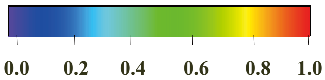
Initial Prototypes - MUMPs Louvers

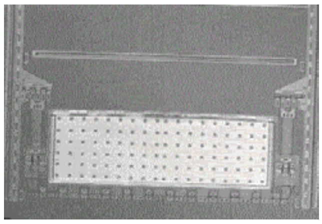


Optical image of louvers with etched openings, with open louvers (top) and all closed (bottom).



Closed ----------------------------Partially Open----------------------------------
Open





Infrared images (3-5 mm) of louver array in different states, effective emissivity over entire area is 0.5 / 0.75 / 0.88.

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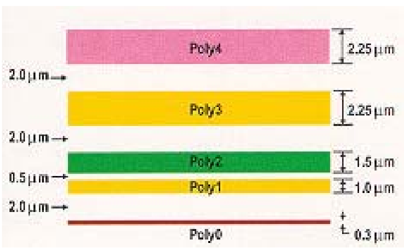
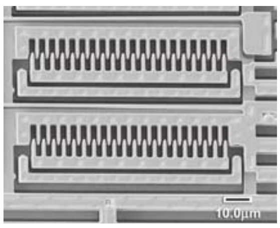
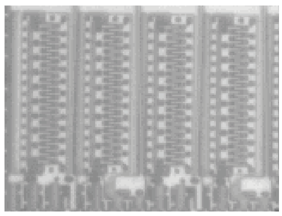
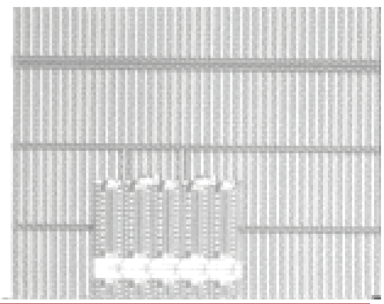
Sandia Ultra-Planar Multi-Level MEMS Technology V (SUMMiT)







- 4 (3) Mechanical Polysilicon Layers
- Oxide Below Poly3 and Poly 4 Is Planarized
- Comb Drive Motor Performance Scales Linear With Area and Thickness -> Same Force, Less Area



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MEMS Shutters - Reliability Issues

- Charge Built-up (2pA Ion Current Max)
  - Ground design
- Friction degradation in low RH environment
  - No rubbing parts, shutters suspended with springs
- Stiction caused by high humidity levels during pre-launch
  - Appropriate packaging
  - All Building Blocks connected to a single Bus with 20 μA Fuse to disconnect shorted areas
  - Cover Plate to be removed before launch
  - IR transparent, conductive cover (ITO-coated CP1)

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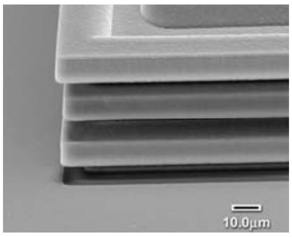
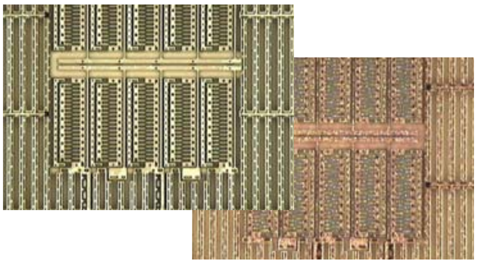
MEMS Shutter Arrays – Gold Coating





- SNL Does Not Offer Metal Layer in Summit V
- Metal deposition before release: 300 Å CR, 5 mm Gold on bondpads only
- Metal Deposition after release: 600 Å Au
- Design Precautions:
  - Buried Interconnects under Building Blocks
  - Self-shadowing Architecture (See SEM of Bondpad)
- Concerns
  - Residual Stress in Metal Layer
  - Adhesion
  - Electrical Shorts
  - Mechanical Shorts
  - Au-Si Eutectic (see pic)
  - Gold Emissivity seems higher

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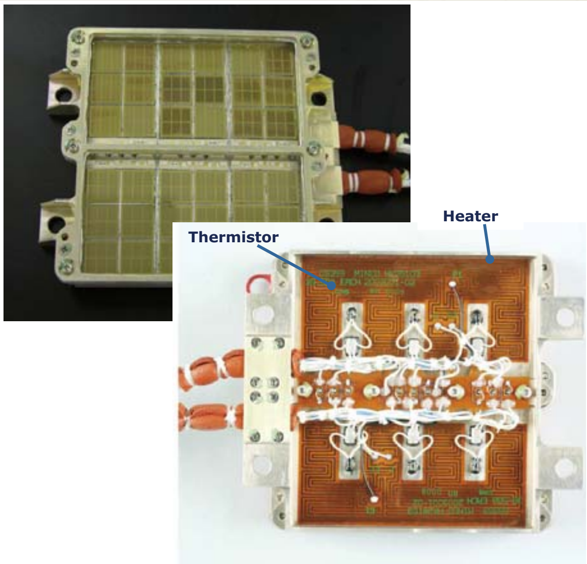
MEMS Radiator, final design

MEMS Shutter Array Radiator contains the following:

- **Top Side**
  - **36 Shutter arrays die, 12.65 mm x 13.03 mm, 72 Building Blocks each, entire area actuated**
  - **CP1 Polymer Cover**
- **Back Side**
  - **2 Heaters, 1.5 W total**
  - **6 Thermistors (3/section)**



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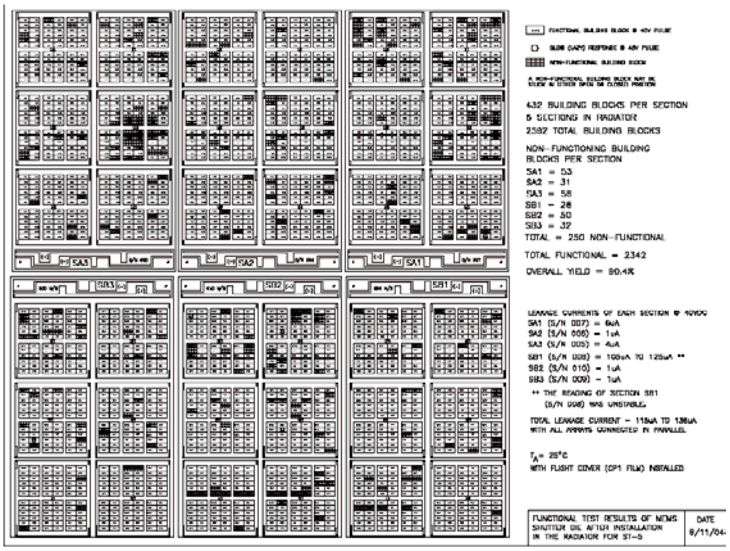
Final Assembly Yield



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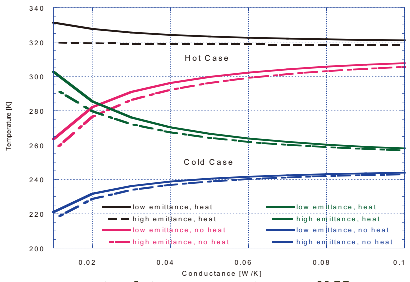
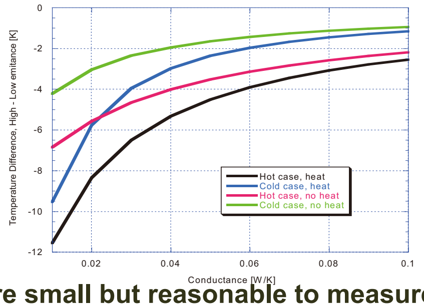
Thermal Analysis / Results





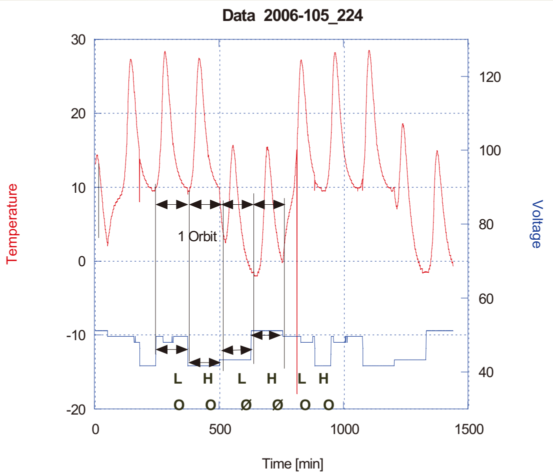
The expected temperature differences are small but reasonable to measure. The numbers for a conductance of 0.05 W/K are shown below.

	Heat, Hot case	No heat, Hot case	Heat, Cold Case	No heat, Cold Case
ΔT	4.5	2.3	3.5	1.6
T Low ε	324	296	266	240
T High ε	319	292	264	239

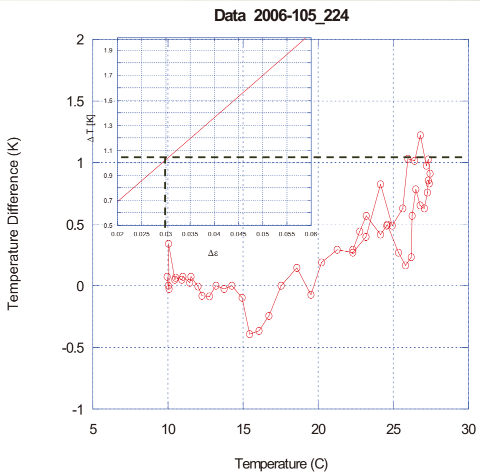
TV measurements in the hot case with heater:

ΔT=4 K

On-Orbit Performance Results



MEMS VEC On-Orbit Performance (~ 10 Orbits)



Temperature difference between the Hi-E vs. Lo-E state in the Autonomous w/ heater mode.

Nested Image reflects the temperature change as a function of the radiator emissivity for 300 K spacecraft temperature.

Summary MEMS Shutters

- Yield much lower than expected, testing before assembly important
- Thermal performance of Variable Emittance (MEMS) Technology limited by overall design, materials, and engineering constraints
- Results:
  - Assessment of flight data reveals a dynamic range of 0.03
  - MEMS devices have been shown to switch properly and survive for the entire 3 month mission
  - The VEC technology (i.e. ECU and MSA radiator) met the mission requirements for packaging and power consumption
- MEMS technology shows potential for future use in Space, provided design is optimized
- First moving MEMS device fully space qualified

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Summary

- MEMS have applications in space, but technology needs maturation to achieve the reliability required
- There is a challenge transitioning from low TRL to high TRL
- MEMS insertion requires increased reliability, testing, and flight time to overcome the "TRL Gap"
- New missions (ST5, ST6) need to allow to fly MNT-based devices at the low TRL stage of development
- This generates the necessary space heritage required for future NASA, Military and Commercial spacecraft
- Allows to screen" the technology for space-worthiness
- Allows building in the requisite robustness far more cheaply and cost-effectively than at higher TRLs

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Acknowledgements

- JHU-APL: Ann Darrin, Keith Rebello, Dawnielle Farrar, Danielle Wesolek, John Champion, Patricia Prettyman
- NASA: Donya Douglas, Ted Swanson, Fred Herrero, Cornelius Dennehy, Stephen Buchner, Brian Jamieson, Phil Chen
- JPL: Thomas George, David Gerke
- LLNL: Jochen Schein
- USAF: Samara Firebaugh
- All the Authors which contributed with their articles, books and publications: H. Helvetian, S. Janson, D. Tanner, S. Kayali, R. Lawton, J. Muller, H. Shea, and many others

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NASA EEE Parts and Packaging (NEPP) Program

An Overview of Current and Future Activities

Presentation to 19th Annual Microelectronics Workshop (MEWS 19)

JAXA, Tsukuba, Japan, October 26, 2006

CO-MANAGERS

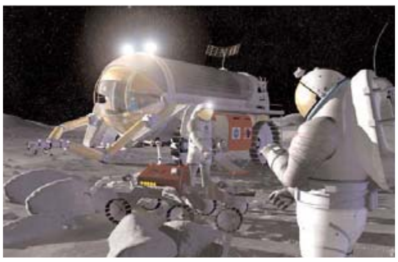
Kenneth A. LaBel
NASA/GSFC
Applied Engineering and Technology Directorate

Michael J. Sampson
NASA/GSFC
Office of System Safety and Mission Assurance

NASA EEE Parts & Packaging Program

Overview

- The NASA EEE Parts and Packaging Program (NEPP)
  - NEPP and NEPAG
- Current NEPP Focus Areas
  - Field Programmable Gate Arrays (FPGA's)
  - Memories, particularly non-volatile
  - Advanced Mixed Signal
  - Scaled CMOS
  - Optoelectronics
  - Area Array Packages
  - Hybrids
  - Lead-free Assembly
  - Advanced Passives
- NASA EEE Parts Assurance Group (NEPAG)
- Information Management and Dissemination (IMD)
- Summary and Comments

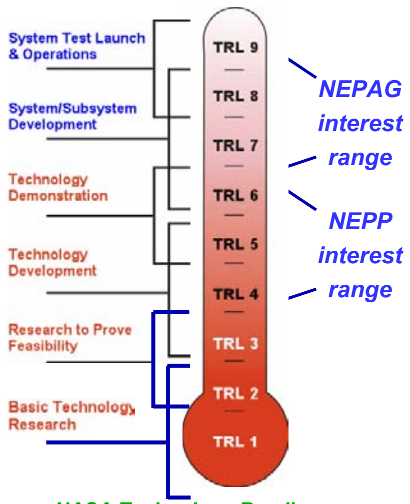


MEWS 19 10/26/06 (2)

NASA EEE Parts & Packaging Program

NEPP Mission and Focus

- The NEPP mission is to provide guidance to NASA for the selection and application of microelectronics technologies, to improve understanding of the risks related to the use of these technologies in the space environment and to ensure that appropriate research is performed to meet NASA mission assurance needs.
- NEPP subset: NASA Electronic Parts Assurance Group (NEPAG)
  - *Focuses on daily needs of parts assurance knowledge-base*



NASA Technology Readiness Levels (TRLs)

NASA EEE Parts & Packaging Program

NEPP Project Assistance

- MAP
  - Single Event Transients (SETs) – NASA alert
- TERRA
  - Optocouplers, Solid State Recorders (SSR), High Gain Antenna anomaly
- AURA
  - Oscillators
- AQUA
  - Interpoint DC-DC converters
- TRMM, XTE
  - SSRs, Fiber Optics
- TOPEX/Poseidon
  - Optocouplers
- SeaStar
  - SSRs
- Launch Vehicles
  - Optocouplers
- Suborbital
  - Parts screening
- LWS
  - FPGAs, memories
- Hubble Space Telescope
  - Optocouplers, Capacitors, SSRs, Fiber Optic Data Bus (FODB), Xilinx FPGAs, detector technologies
- Hubble Robotic Servicing
  - Processors, memories, FPGAs, packaging
- JWST
  - Detector technologies, memories
- Cassini
  - Interpoint DC-DC converters, optocouplers, processors
- AXAF/Chandra
  - Optics
- SWIFT
  - ACTEL FPGAs
- MER, MRO
  - ELDRS, Processors, Memories, Packaging, FPGAs
- ISS
  - Fiber optics, wire/cable
- Shuttle
  - ACTEL FPGAs, capacitors
- GLAST
  - Lasers

NASA EEE Parts & Packaging Program

NEPP Collaborations

Government partners

- Department of Defense
  - Defense Threat Reduction Agency (DTRA)
  - Air Force Research Laboratory (AFRL)
  - Air Force Space and Missile Command (AFSMC)
  - Missile Defense Agency (MDA)
  - Defense Advanced Research Projects Agency (DARPA)
  - NAVSEA
  - NAVAIR
  - Naval Research Laboratory
  - US Army Strategic and Missile Defense Command (USASMDC)
  - OGA
- Department of Energy
  - Sandia National Laboratories
  - Lawrence Livermore National Laboratories
  - Brookhaven National Laboratories
  - Los Alamos National Laboratories
- National Science Foundation
  - National Superconducting Cyclotron Laboratory
- ESA
- JAXA
- CNES

Industry partners

- Actel
- Lambda/International Rectifier
- Interpoint
- Vishay
- Presidio
- BAE Systems
- Honeywell
- Aeroflex
- Intersil
- Xilinx
- IBM
- Freescale (formerly Motorola)
- Cardinal
- LSI Logic
- Ball Aerospace
- ATK
- Micro RDC
- Seakr
- Maxwell
- Texas Instruments
- SAIC
- Boeing

MEWS 19 10/26/06 (5)

NASA EEE Parts & Packaging Program

NEPP Focus Areas

- Starting in FY05, the NEPP Program was organized around these high demand focus areas:
  - Field Programmable Gate Arrays (FPGA's)
  - Memories, particularly non-volatile
  - Advanced Mixed Signal
  - Scaled CMOS
  - Optoelectronics
  - Area Array Packages
  - Hybrids
  - Lead-free Assembly
  - Advanced Passives

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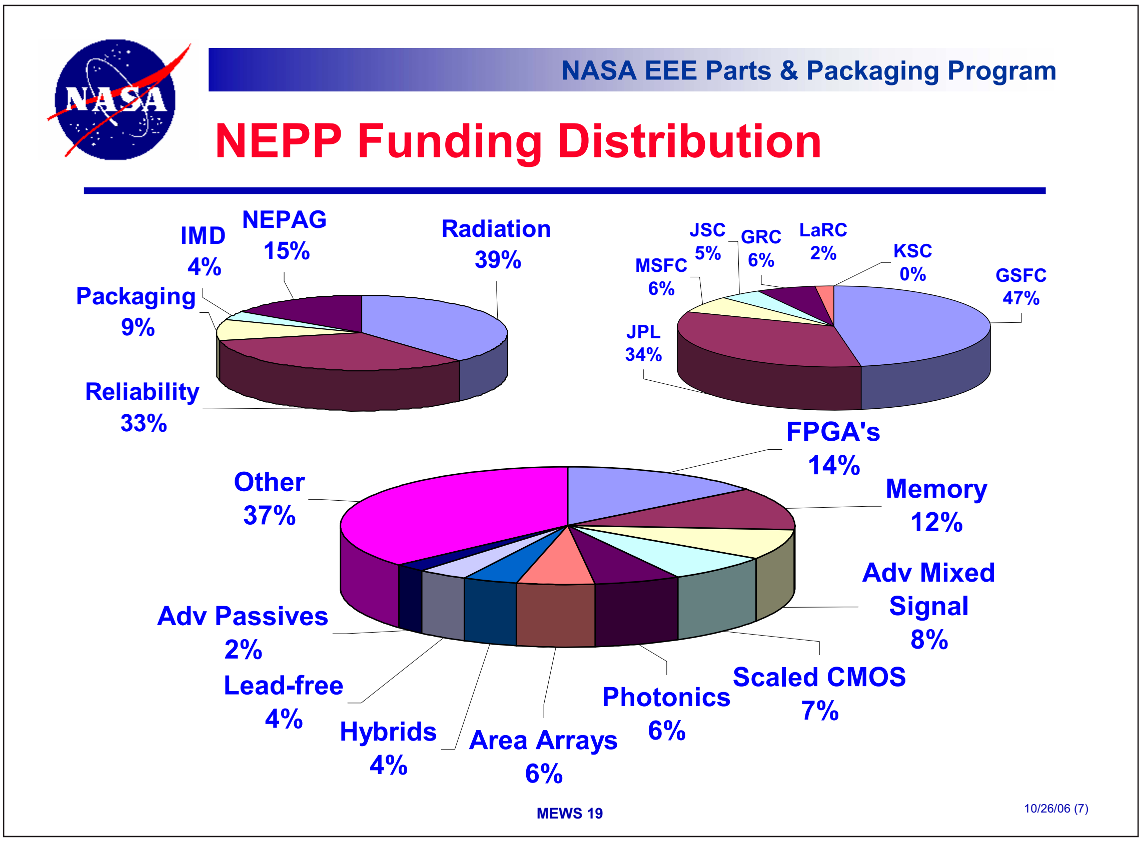
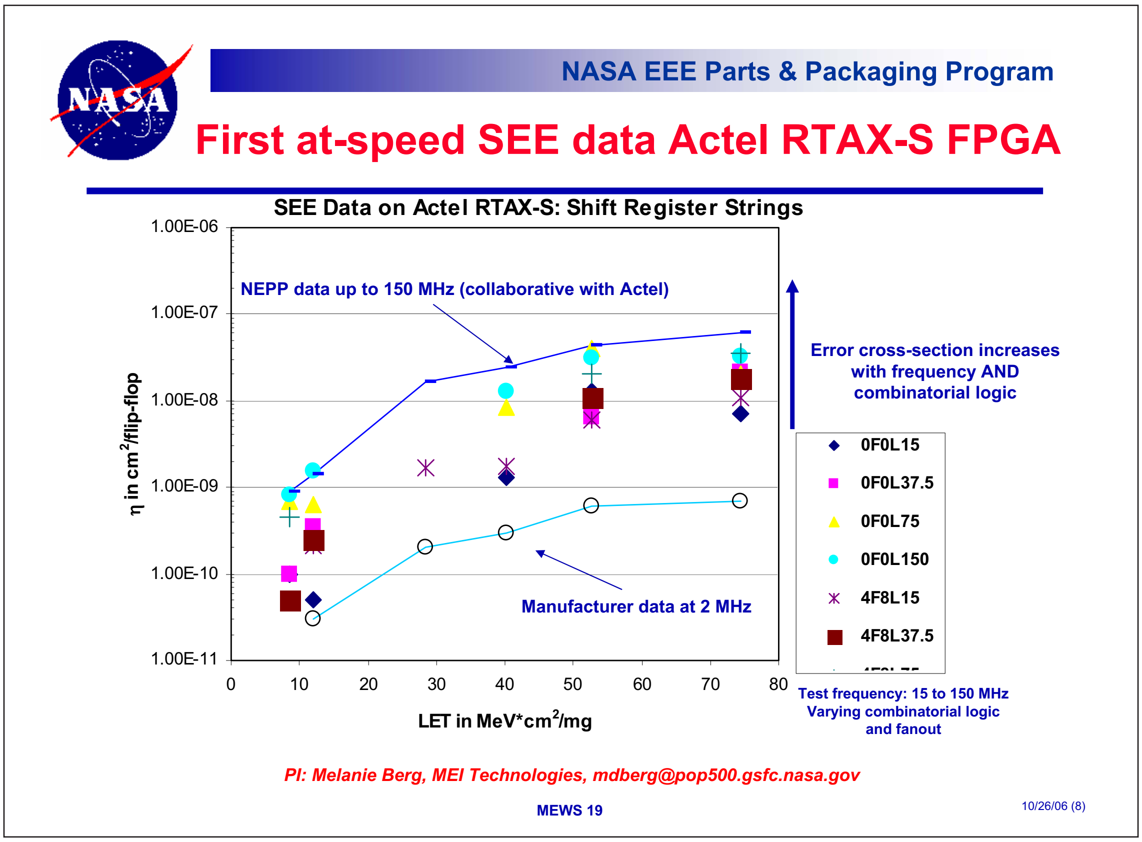
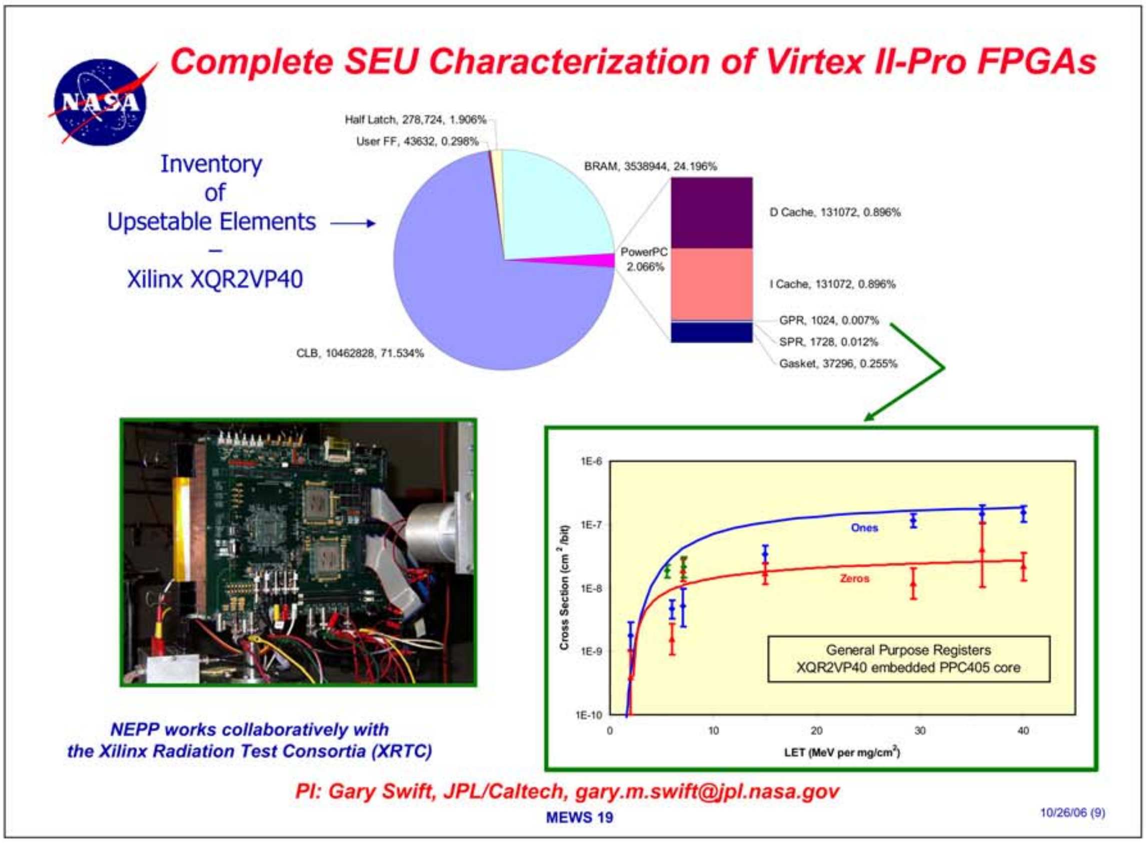
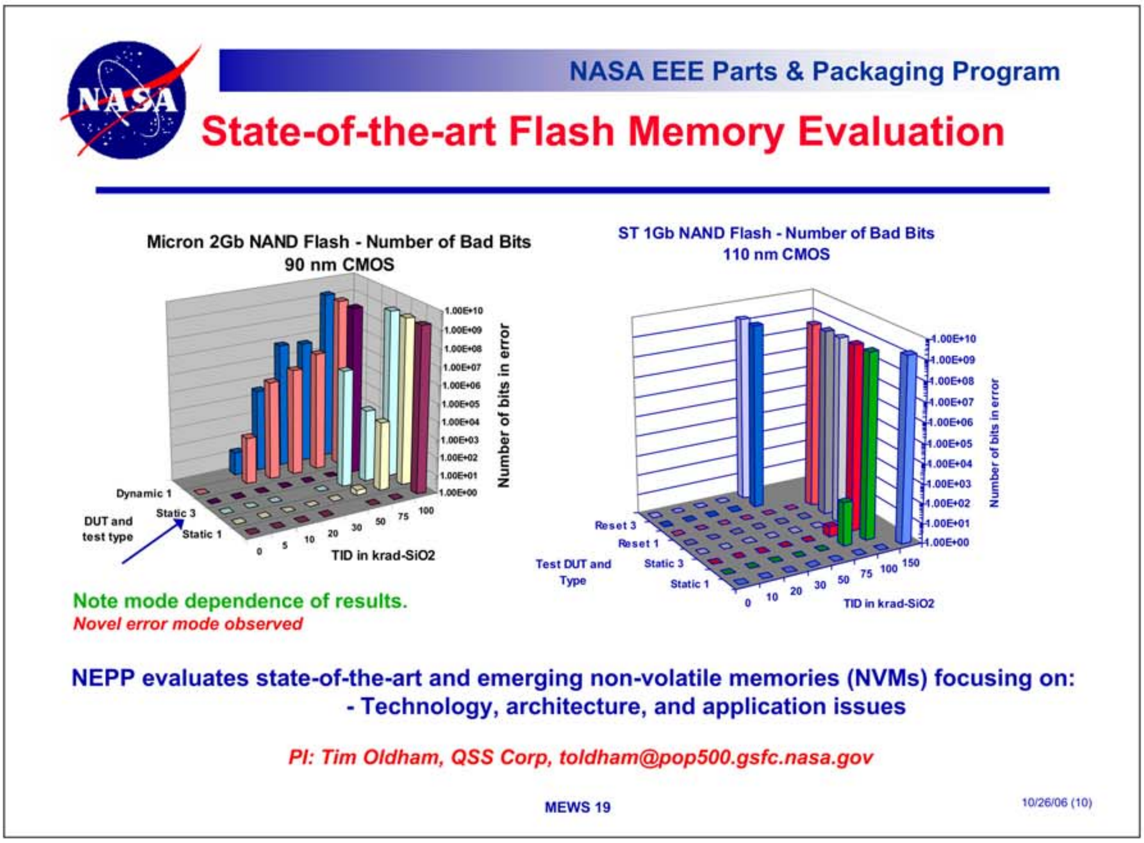

NASA EEE Parts & Packaging Program
NEPP Funding Distribution
IMD 4%
NEPAG 15%
Radiation 39%
Packaging 9%
Reliability 33%
JSC 5%
GRC 6%
LaRC 2%
KSC 0%
MSFC 6%
GSFC 47%
JPL 34%
FPGA's 14%
Memory 12%
Other 37%
Adv Mixed Signal 8%
Adv Passives 2%
Lead-free 4%
Scaled CMOS 7%
Photonics 6%
Hybrids 4%
Area Arrays 6%
MEWS 19
10/26/06 (7)


NASA EEE Parts & Packaging Program
First at-speed SEE data Actel RTAX-S FPGA
SEE Data on Actel RTAX-S: Shift Register Strings
NEPP data up to 150 MHz (collaborative with Actel)
Error cross-section increases with frequency AND combinatorial logic
Manufacturer data at 2 MHz
η in cm²/flip-flop
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
0
10
20
30
40
50
60
70
80
LET in MeV*cm²/mg
0F0L15
0F0L37.5
0F0L75
0F0L150
4F8L15
4F8L37.5
Test frequency: 15 to 150 MHz
Varying combinatorial logic and fanout
PI: Melanie Berg, MEI Technologies, mdberg@pop500.gsfc.nasa.gov
MEWS 19
10/26/06 (8)

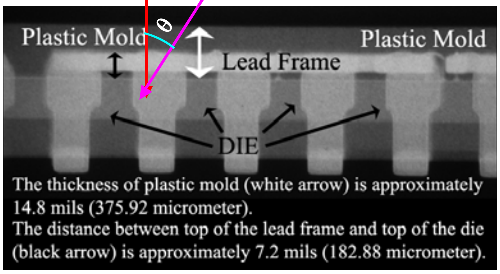

Complete SEU Characterization of Virtex II-Pro FPGAs
Inventory of Upsetable Elements – Xilinx XQR2VP40
Half Latch, 278,724, 1.906%
User FF, 43632, 0.298%
BRAM, 3538944, 24.196%
PowerPC 2.066%
D Cache, 131072, 0.896%
I Cache, 131072, 0.896%
GPR, 1024, 0.007%
SPR, 1728, 0.012%
Gasket, 37296, 0.255%
CLB, 10462828, 71.534%
Cross Section (cm²/bit)
Ones
Zeros
General Purpose Registers
XQR2VP40 embedded PPC405 core
LET (MeV per mg/cm²)
NEPP works collaboratively with the Xilinx Radiation Test Consortia (XRTC)
PI: Gary Swift, JPL/Caltech, gary.m.swift@jpl.nasa.gov
MEWS 19
10/26/06 (9)


NASA EEE Parts & Packaging Program
State-of-the-art Flash Memory Evaluation
Micron 2Gb NAND Flash - Number of Bad Bits
90 nm CMOS
Number of bits in error
DUT and test type
Dynamic 1
Static 3
Static 1
TID in krad-SiO2
ST 1Gb NAND Flash - Number of Bad Bits
110 nm CMOS
Reset 3
Reset 1
Static 3
Static 1
Test DUT and Type
Note mode dependence of results.
Novel error mode observed
NEPP evaluates state-of-the-art and emerging non-volatile memories (NVMs) focusing on:
- Technology, architecture, and application issues
PI: Tim Oldham, QSS Corp, toldham@pop500.gsfc.nasa.gov
MEWS 19
10/26/06 (10)

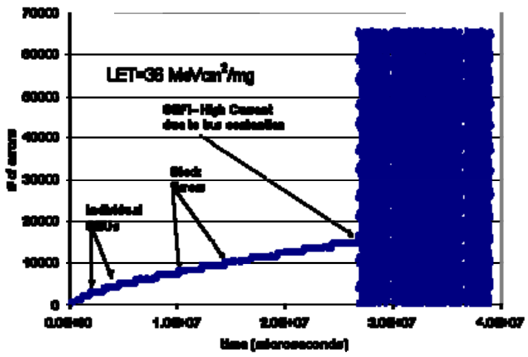
NASA EEE Parts & Packaging Program

State-of-the-art SDRAM Memory Evaluation –

Challenges for test preparation and data collection/analysis



X-Ray Photo of a DUT



Determining effective LET as a function of angle requires correcting for the energy lost by the ion as it traverses overburden to the sensitive volume, as well the usual 1/cosθ dependence.

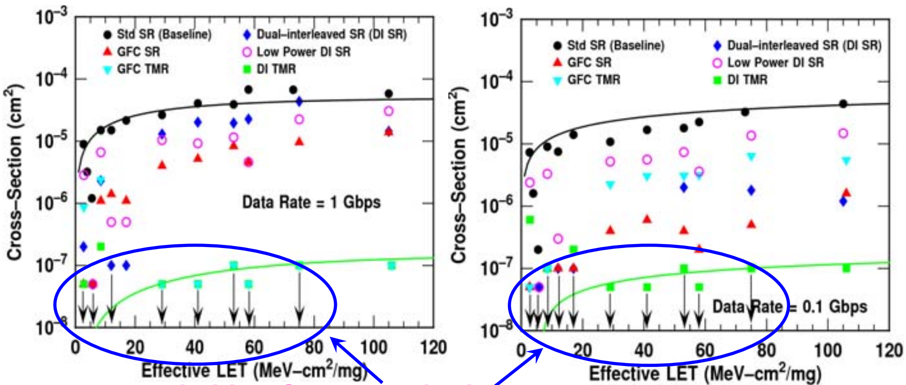
NEPP evaluates state-of-the-art and emerging SDRAMs focusing on:
- Technology, architecture, and test methodology issues

PI: Ray Ladbury, NASA-GSFC, rladbury@pop500.gsfc.nasa.gov

MEWS 19 10/26/06 (11)

SiGe Radiation Evaluation and Modeling –

Working collaboratively with technology development programs



Limiting Cross-section!

Evaluating SEE Rad Hard by Design (RHBD) Approaches:
Dramatic SEE improvements in SEE sensitivity on 8HP HBT

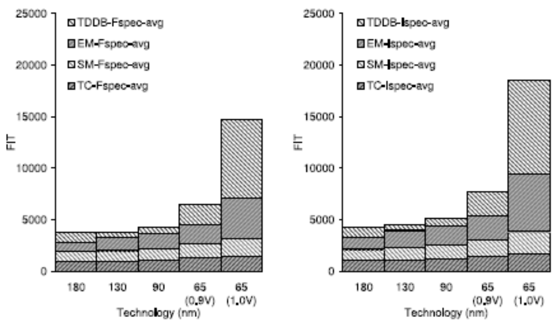
PI: Paul Marshall: pwmarshall@aol.com

MEWS 19

NASA EEE Parts & Packaging Program

Scaled CMOS Reliability

Modeling Trends



(a) Average SpecFP (b) Average SpecInt

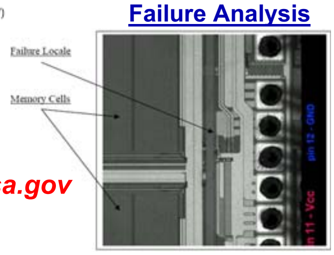
Impact of Technology Scaling on Lifetime Reliability – Processor modeling predictions from various failure mechanisms as a function of technology. (U of I, IBM)

Accelerated Stress Testing

Tech. Node (um)	Vratio (Vapp/Vnom)	Temp C	Time to 0.1% Device-Bit Failures (Hrs)
0.13	1.4	165/155	588
	1.5		
0.15	1.6	165	528
0.25	1.7	165	768

SRAM time to failure as a result of step stress testing_125*C to 165*C (10*C steps) and high voltage ramp stress (0.1Vdd) at constant frequency. (JPL)

Failure Analysis



Decapsulated optical overview - Post stress test 0.15um, 4M SRAM. (JPL)

PI: Mark White, JPL, Mark.White@jpl.nasa.gov

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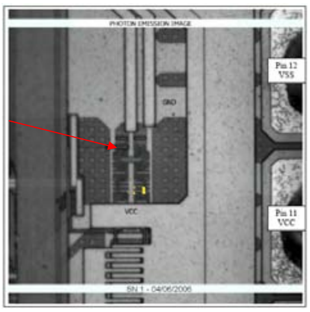
NASA EEE Parts & Packaging Program

Scaled CMOS Reliability - 2

Failure Analysis

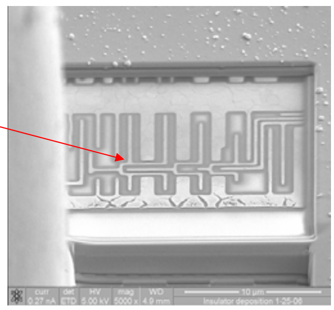
Leakage Site



Photon emissions between Vcc and Vss. Characteristic failure site across technologies (JPL).

Buffer/voltage regulation circuitry protects the actual memory cells and damage is concentrated on the input transistors of the devices (regardless of technology scaling).

Stress Migration



Focused Ion Beam close-up of a failure site (0.15um 4M SRAM) post accelerated stress test. Failure Mechanism: Stress migration in the input transistors - buffer/voltage regulation circuitry, not in the memory cells (JPL).

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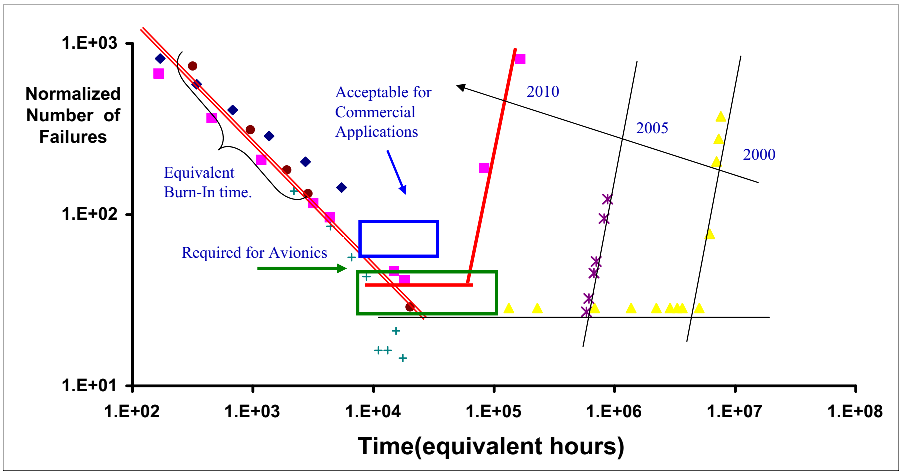
NASA EEE Parts & Packaging Program

Scaled CMOS Reliability - 3

Reliability Trends and Early Wearout: Normalized Commercial Manufacturer's data



Industry data showing both increasing failure rate and decreasing product lifetime with progressive commercial technologies (UMD).

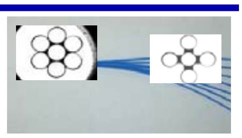
MEWS 19 10/26/06 (15)

NASA EEE Parts & Packaging Program

Optoelectronics for Space Environments

- **Provide guidelines for qualification and application of flight critical photonic components**
- **Disseminate lessons learned**
- **Enhance TRL of fiber laser and semiconductor laser components**
- **FY06 focus: commercial parts for space with emphasis on high power laser diode arrays, fiber amplifier components, optical fiber cable, and optical fiber array interconnection**

Vibration Test; MTP Connector



Fiber array in AVIM evaluations

fiber cable in moving gimbal test

FY06 Highlights

- ***ESA/NASA Workshop 2005 & 2006,*** **Web access to presentations;** ***included participation from JAXA.***
- ***High Power Laser Diode Array Qualification and Guidelines for Space Environments*** **Draft coordinated with GSFC, LaRC and Laser Risk Reduction Prgm.**
- ***Qualification and Issues with Space Flight Laser Systems and Components, SPIE Solid State Lasers, Vol. 6100, Jan. 2006,***
- ***Space Requirements for Fiber Optic Components Testing and Lessons Learned*****, SPIE Europe Vol. 6193, April 2006.**
- ***Space Qualification of a Multi-Fiber Ribbon Cable and Connector Array Assembly*****, SPIE Photonics for Space Environments XI, Vol. 6308, Aug 2006.**
- ***Photonic Component Qualification and Implementation Activities at NASA,*** **SPIE Vol. 6308, Aug 2006.**

PI: Melanie Ott,, NASA-GSFC, Melanie.N.Ott@nasa.gov

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NASA EEE Parts & Packaging Program

Optoelectronics - The ESA-NASA Workshops

Workshop 1

Fiber Optic Technologies for Space-Lessons Learned, October 2005.

Co-Chairs: Dr. Nikos Karafolas, ESTEC-ESA, Melanie N. Ott, NASA-NEPP

Workshop 2

Qualification of Technologies and Lessons Learned from LIDAR and Altimetry Missions

June 2006

Mission Presentations Included:

MESSENGER
Mercury Laser Altimeter
NASA GSFC

ADM-Aeolus
Wind LIDAR
ESA

LRO
Laser Ranging/LOLA
NASA GSFC

Hayabusa
LIDAR at
Itokawa Asteroid
JAXA

ICESAT
Geoscience Laser
Altimeter
NASA GSFC

Calipso
Ball/Fibertek
NASA LaRC

URL for Websites with Presentations:

http://misspiggy.gsfc.nasa.gov/photonics

https://escies.org/public/conferences/photonics/1/index.xml

http://nepp.nasa.gov

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NASA EEE Parts & Packaging Program

Reliability of High I/O Area Array Packages

Objective:

- Qualification guidelines for high I/O area array packages Testing to develop guidelines:
  - Thermal cycles-to-failure using:
    - NASA thermal profile (-55/100°C)
    - and military cycle (-55/125°C)
    - for > 1,000 thermal cycles
  - ~ 50 packages 700-1200 I/O
  - Also for a few samples:
    - -65/150°C
    - Mars profile -120/85°C
  - Data analysis plus literature review for key design and process controls.
  - Body of knowledge and test matrix developed for High I/O packages
  - Designed experiment and test matrix for low pitch/High I/Os

Highlights:

- Publications, IPC APEC, IEEE CPMT, Microelectronic Reliability Journal (in print- Dec 2006)
- Book chapter-2006
- Papers on NEPP web site

Various CCGA >1000 I/Os. Have been thermal cycled under various regimes

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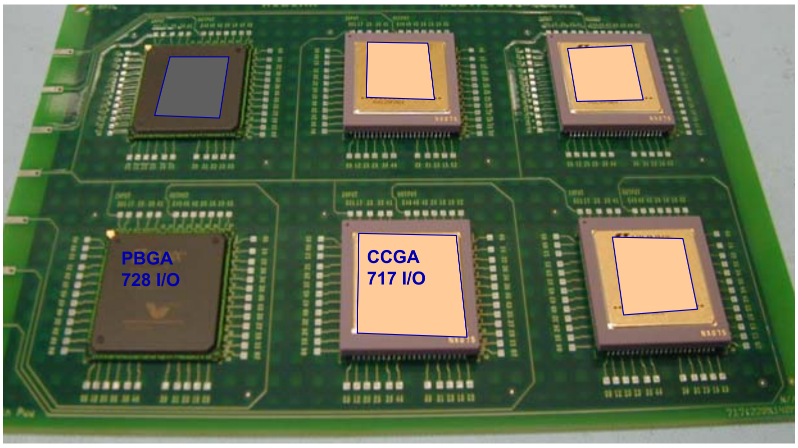
NASA EEE Parts & Packaging Program

CCGA 717 & PBGA 728 I/Os TV



PI: Reza Ghaffarian, JPL, Reza.Ghaffarian@jpl.nasa.gov

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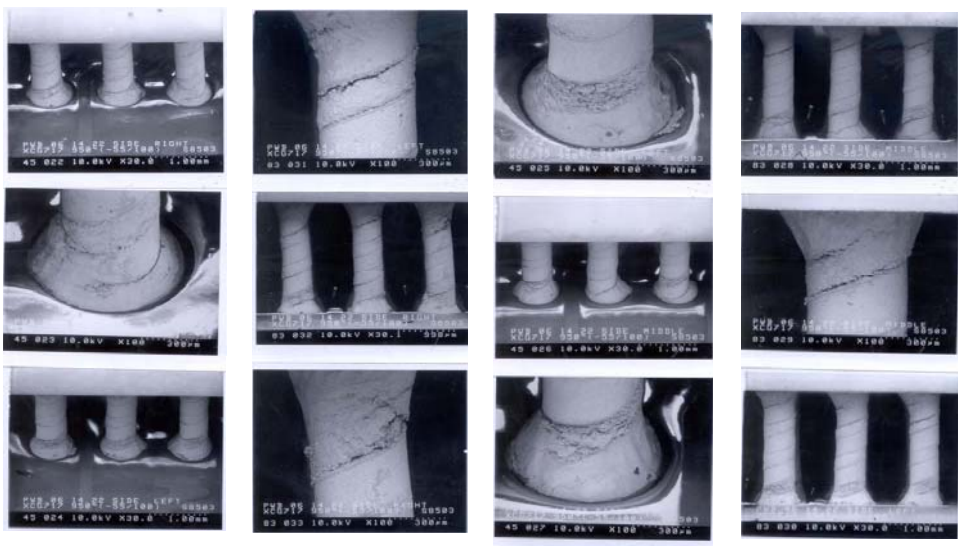
950 Thermal Cycles (-55°/100°C)

Copper Spiral Wrapped Columns – SIX SIGMA

Copper provides reinforcement and redundant conductive path



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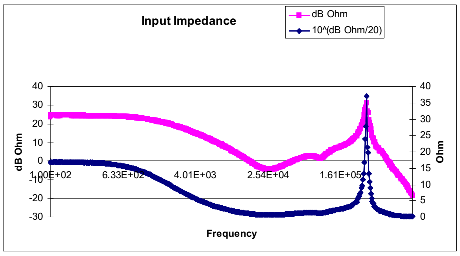
NASA EEE Parts & Packaging Program

DC/DC Converter Risk Mitigation

Failures in spacecraft range from:

- Manufacturer installed defects
  - Workmanship
  - Inconsistent magnetics design/control
  - Unqualified replacement of elements
  - Incorrect screening of elements
  - Application errors
    - Under-loading
    - Impedance mismatching
    - Incorrect synchronization
  - Confusion about how
    - Far outside of the nominal operating conditions the part can be safely used
    - Load derating actually adds risk

Incomplete information has directly contributed to failures



Using Zin measurements to find safe operating zone

NEPP is developing:

- Test and evaluation guidelines
- Application guidelines
- Databases for information exchange

http://nepp.nasa.gov/dcdc

PI: Jeannette Plante, Dynamic Range, Jeannette.F.Plante@gsfc.nasa.gov

MEWS 19 10/26/06 (21)

NASA EEE Parts & Packaging Program

JG-PP Lead-free Program Summary

Tests:

Thermal Shock

Vibration

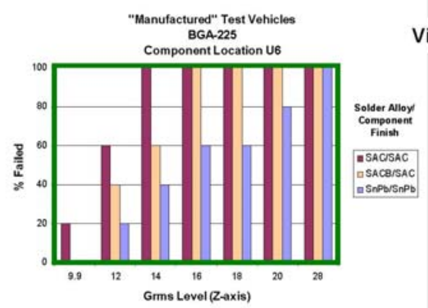
Thermal Cycling

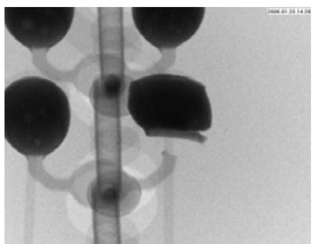
Combined Environments

Solder Performance -55 to 125°C Thermal Shock "Manufactured" Test Vehicles				
Component	Solder/Finish	1st Failure	N10	N63
CLCC-20	SnPb/SnPb	627	717	931
	SAC/SAC	79 (392)	477	681
	SACB/SACB	525	630	869
	SAC/SnPb	404	461	635
	SACB/SnPb	657	674	789
TSOP-50	SnPb/SnPb	961	NA	>1000
	SAC/SnCu	144, 278 (880)	NA	>1000
	SACB/SnCu	>1000	>1000	>1000
	SAC/SnPb	229, 250 (821)	NA	>1000
	SACB/SnPb	174	235	489
BGA-225	SnPb/SnPb	>1000	>1000	>1000
	SAC/SAC	>1000	>1000	>1000
	SACB/SAC	>1000	>1000	>1000
	SAC/SnPb	162	315	>1000
	SACB/SnPb	195	>1000	>1000

NA = Not enough failures to accurately determine

Vibration





BGA trace broken during vibration

PI: Jim Blanche, Allied Aerospace, Jim.F.Blanche@msfc.nasa.gov

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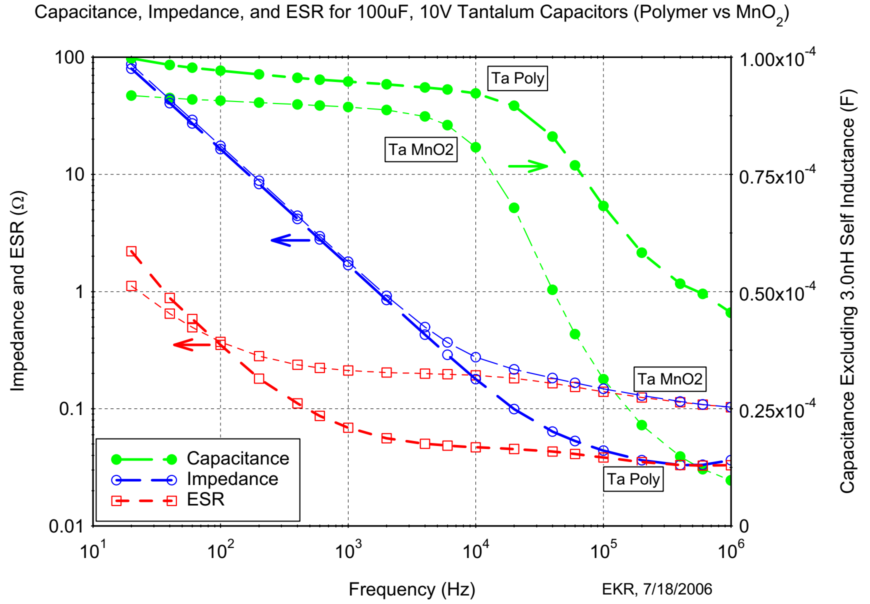
NASA EEE Parts & Packaging Program

Polymer Tantalum Capacitors

Better at High Frequency



MEWS 19

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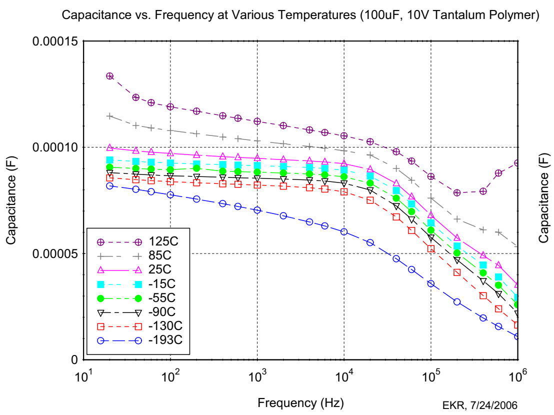
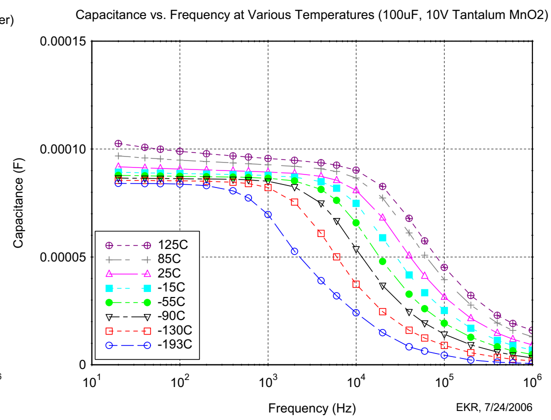
NASA EEE Parts & Packaging Program

Polymer Tantalum Capacitors

Better at High Frequency and Over Temperature Too!

Capacitance





PI: Erik Reed, JPL, Erik.K.Reed@jpl.nasa.gov

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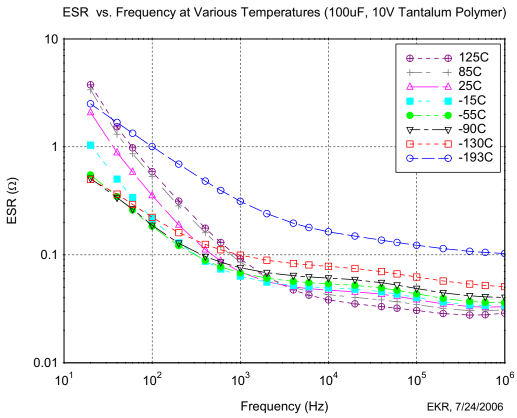
10/26/06 (24)

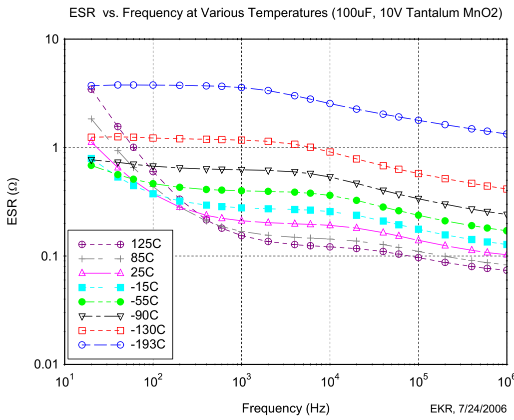
NASA EEE Parts & Packaging Program

Polymer Tantalum Capacitors

Better at High Frequency and Over Temperature Too!

Equivalent Series Resistance (ESR)





Life Testing is in Progress

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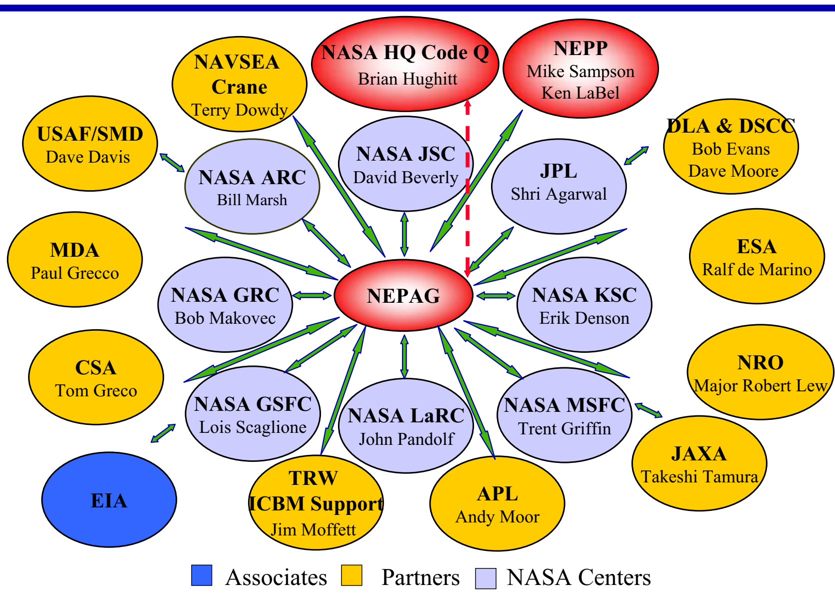
NASA EEE Parts & Packaging Program

NEPAG "Extended Family"



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NASA EEE Parts & Packaging Program

NEPAG Tasks and Activities

- Weekly US and Monthly international telecons
  - Typically 30+ participants
  - JAXA and ESA are on international calls
- Audits
  - Over 80 NEPAG supported US and international in FY06 Mostly space level, JANS, Class V and K
- Participation in MIL and non-government specification and standards activities:
  - EIA G11, G12, JEDEC, IPC
- Lead-free:
  - Executive Lead-Free (ELF) IPT, Lead-free Electronics in Aerospace Project (LEAP), JG-PP, CALCE (University of Maryland) etc.
  - Metal whisker website: http://nepp.nasa.gov/whisker
  - Continued whisker research

MEWS 19

10/26/06 (27)

NASA EEE Parts & Packaging Program

18-mm Long Tin Whisker!!!

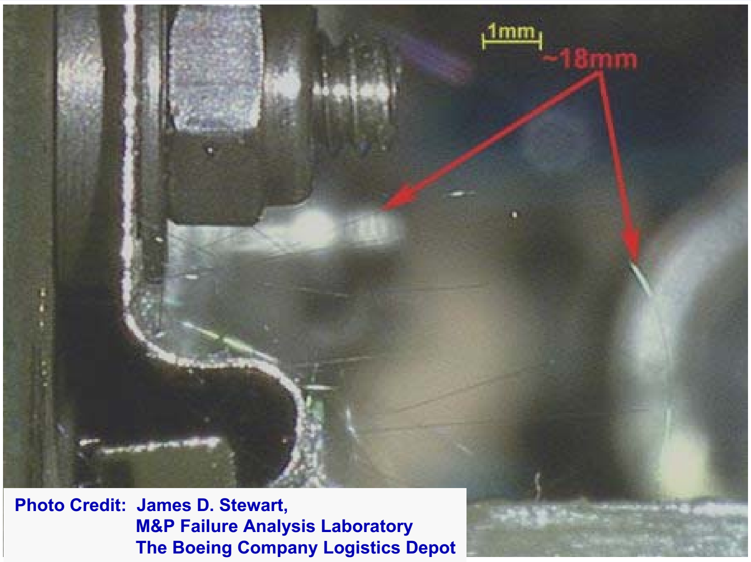

Photo Credit: James D. Stewart,
M&P Failure Analysis Laboratory
The Boeing Company Logistics Depot

PI: Jay A. Brusse, QSS, Jay.A.Brusse.1@gsfc.nasa.gov

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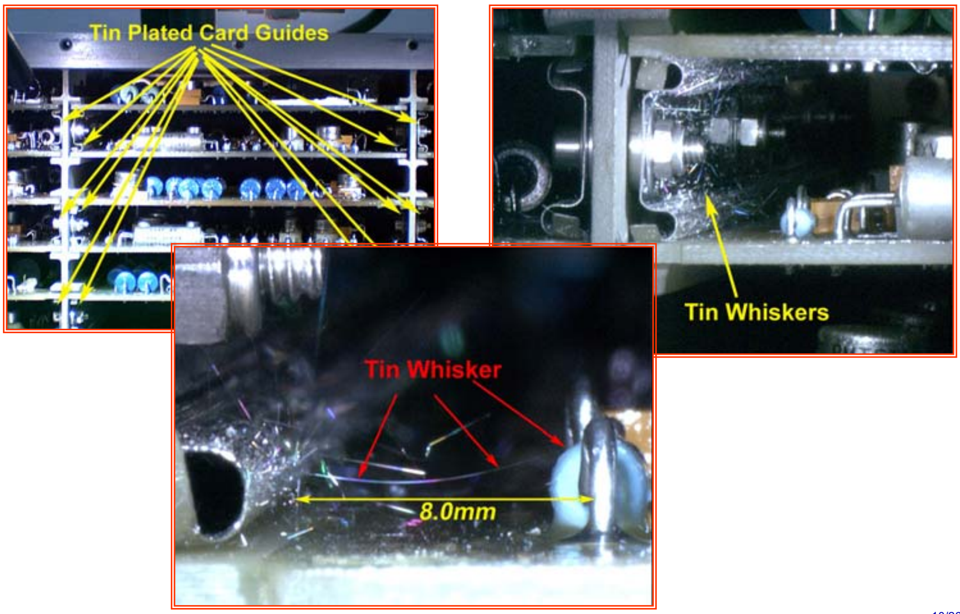
NASA EEE Parts & Packaging Program

Tin Whiskers on PCB Card Guides

Ref: "Tin Whiskers Found on ATVC S/N 0034", Don McCorvey, March 8, 2006



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NASA EEE Parts & Packaging Program

A Pb-Free Strategy for Space

- Require traditional tin-lead solders for all electronic assembly except when justified by technical need (such as a high melt point)
  - Approved GEIA-STD-0005-1 plan to define rules and controls
  - SAC and other "new" alloys will require special and exceptional rationale
- Require all tin-based platings and protective finishes to have a minimum of 3% Pb content unless:
  - A persuasive rationale is provided
  - Tin whisker mitigation strategy is supported by data and approved by NASA
  - GEIA-STD-0005-2, "Control Level 2C" because required by part number
  - Alternative, "wait-and-see" is *CHAOS*
- Perform checks for Pb content at incoming to prevent "escapes"
  - Use at least two analysis methods such as XRF for a quick look and SEM/EDAX for the final disposition
- Ensure suppliers have adequate materials checks and controls
- Continue to Study Whiskers Because Mistakes Will Be Made

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NASA EEE Parts & Packaging Program

MIL Specification Standardization

- **Memorandum of Understanding (MOU)**
  - Government HiRel/Space working on agreement with Defense Supply Center Columbus (DSCC)
  - Defines roles/responsibilities/expectations for participation in MIL auditing process
  - USAF, NRO, MDA, Navy, NASA
  - Working out authorization details
- **M38535 Engineering Practices (EP) Study**
  - August industry/government meeting was very productive
  - Revised draft almost be ready for official coordination
  - Most significant revision since “Acquisition Reform” in mid-1990’s
  - Addresses outsourcing control issues
  - New Technology Insertion approach still needs formulation

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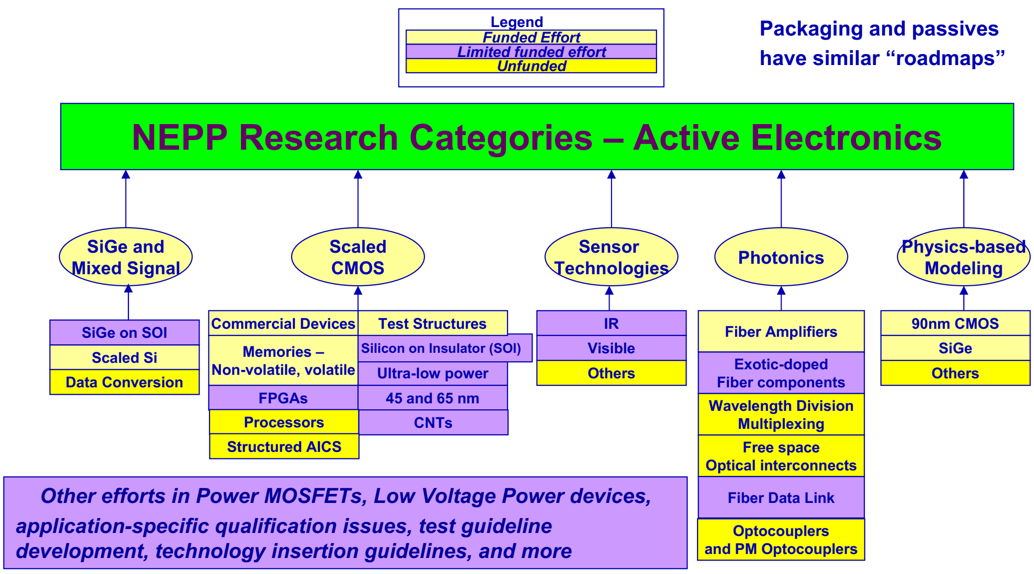
NASA EEE Parts & Packaging Program

FY07 Plans for NEPP Research:

Focus on “large value” results



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NASA EEE Parts & Packaging Program

IMD
Information Management & Dissemination

IMD on the Web:

- Provides information regarding EEE parts':
  - Reliability
  - Performance
  - Availability
  - Application
  - Radiation characteristics
  - Packaging
  - Cost
- Coordinates task reporting
- Methodically disseminates information generated by NEPP
- Maintains the website
- For its NASA customers:
  - Designers
  - Specialist researchers
  - Project engineers
  - Scientists
  - Program managers.

Manager: Dr. Lois Scaglione, GSFC, Lois.J.Scaglione@nasa.gov

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NASA EEE Parts & Packaging Program

Summary and Comments

- NEPP Provides Critical Guidance for Flight Projects
  - Challenge: Keeping ahead of the demand
- NEPP Partners Throughout the Aerospace Industry
  - NEPP/NEPAG leads in information exchange across the community
- NEPP Strives to Develop Cost-Effective Qualification Methods
  - Challenge: The ever-increasing cost of doing business
- NEPP is focusing on high-demand/high-return technologies with immediate value to flight projects
- New training modules are required for new technology insertion
  - NEPP has more than just parts, packaging, and radiation challenges
    - Currently collaborating with CNES, ESA and others on radiation training class (SERESSA)
  - NEPP is increasing its university presence
    - Shortfall of qualified parts, packaging, and radiation specialists
      - Example: Difficulty in finding US citizens for radiation positions
    - Scholarships, post-doc opportunities, etc are being considered

MEWS 19 10/26/06 (34)

GEIA G-12
Solid State Devices Committee Initiatives

Mark Porter - Chairman

19th Microelectronic Workshop
JAXA's Tsukuba Space Center, Ibaraki, Japan
October 25th through 27th, 2006

Summary Slide

- Committee Overview
- Collaborative Relationships
- Key Focus Areas & Initiatives

G12 Solid State Devices 2

Electronic Industries Alliance (EIA)

- The EIA is a national trade organization that includes the full spectrum of U.S. manufacturers, representing more than 80% of the $550 billion electronics industry.
- The Alliance is a partnership of electronic and high tech associations and companies whose mission is promoting the market development and competitiveness of the U.S. high tech industry through domestic and international policy efforts.
- EIA is comprised of more than 2,500 member companies whose products and services range from the smallest electronic components to the most complex systems used by defense, space and industry, including the full range of consumer electronic products.

Electronic Industries Alliance

- Government Electronics and Information Technology Association
- Consumer Electronics Association
- Electronic Components, Assemblies & Materials Assoc.
- JEDEC Solid State Products Technology Association
- National Science and Education Technology Partnership
- Telecommunications Industry Association

G12 Solid State Devices

3

Government Electronics and Information Technology Association (GEIA)

- GEIA represents the high-tech industry doing business with the government.
- Association members include companies involved in producing information technology (IT) solutions as well as advanced electronics products and services for defense and civil government markets.
- GEIA Members are systems integrators, suppliers, contractors, hardware manufacturers, and software providers in the IT, Defense and Communications Industries.
- GEIA connects industry to government through its renowned forecasting process.

Government Electronics and Information Technology Association

Systems, Standards and Technology Council (SSTC)

G Panels / Committees

G-11 Component Parts
G-12 Solid State Devices
G-33 Data and Configuration Management
G-34 Computer Resources
G-43 Quality
G-45 Human Factors
G-46 Electromagnetic Compatibility
G-47 Systems Engineering
G-48 Systems Safety
Avionics Process Management Committee
Compact Model Council
Input Output Buffer Information Spec.
Quality & Reliability Engineering

G12 Solid State Devices

4

G-12 Solid State Devices Committee

- The G-12 Committee develops solutions to technical problems in the application, standardization, and reliability of solid state devices.
- This is implemented by evaluation and preparation of recommendations for specifications, standards, and other documents, both government and industry, to assure that solid state devices are suitable for their intended purposes.
- Focus Areas ...
  - Standardization
  - Manufacturability
  - Specifications and Standards Impacting Solid State Devices
  - Quality and Reliability
  - System Performance (End Use)
  - Diminishing Manufacturing Sources
  - Market Consistency
  - Continued Improvement
  - Acquisition Reform
  - Best Commercial Practices
  - Commercial Part Insertion

G12 Solid State Devices

5

G-12 Active Member Companies

- BAE SYSTEMS
- Boeing Company
- Corfin Industries
- CSC ITS
- Defense Microelectronics Activity
- General Dynamics Corp
- Goodrich Fuel & Utility
- Honeywell
- L-3 Cincinnati Electronics
- L-3 Communication Systems*
- Lockheed Martin
- Northrop Grumman
- Raytheon
- Rockwell Collins
- Six Sigma*
- Tecnológica
- Textron
- United Space Alliance

As of September 24, 2006:
Voting Members (16)
Observing Member (2) *

G12 Solid State Devices

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Collaborative Relationships

Semiconductor Device Manufacturers

EIA Electronic Industries Alliance

Government Electronics Manufacturers

JEDEC — JEDEC Solid State Products Technology Association

GEIA — Government Electronics and Information Technology Association

JC Committees
- JC-10 Terms, Definitions & Symbols
- JC-11 Mechanical Standards
- **JC-13 Government Liaison**
- **JC-14 Quality & Reliability**
- JC-15 Electrical/Thermal Characteristics
- JC-16 Power Supply
- JC-22 Diodes & Thyristors
- JC-25 Transistors
- JC-40 Digital
- JC-42 Memory
- JC-50 Gallium Arsenide

G Panels / Committees
- G-11 Component Parts
- **G-12 Solid State Devices**
- G-33 Data and Configuration Management
- G-34 Computer Resources
- G-43 Quality
- G-45 Human Factors
- G-46 Electromagnetic Compatibility
- G-47 Systems Engineering
- G-48 Systems Safety
- Avionics Process Management Committee

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JEDEC JC-13

- The JC-13 Committee represents the manufacturing segment of the solid state device industry.
- The committee is responsible for standardizing quality and reliability methodologies for solid state products used in military, space, and environments requiring special use condition capabilities beyond those of standard commercial products.
  - Includes long-term reliability and/or special screening requirements

JEDEC — JEDEC Solid State Products Technology Association

JC-13 – Government Liaison
- JC-13.1 Discrete Devices
- JC-13.2 Microelectronic Devices
- JC-13.4 Radiation Hardness Assurance
- JC-13.5 Hybrids, RF/Microwave, MCM

Other JEDEC Committees
- JC-10 Terms and Definitions
- JC-11 Mechanical Standards
- JC-14 Quality and Reliability
- JC-15 Electrical and Thermal
- JC-16 Interface Technology
- JC-22 Diodes and Thyristors
- JC-25 Transistors
- JC-40 Digital Logic
- JC-42 Memory
- JC-61 Wireless Interface Networks

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Collaborative Relationships

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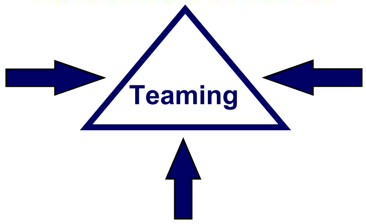
U.S. Government
- DSCC
- U.S. Army
- U.S. Navy
- U.S. Air Force
- NASA
- DMEA
- GIDEP
- DMPG



JEDEC

Europe & Asia
- Japan Aerospace Exploration Agency (JAXA)
- European Space Agency (ESA)
- British National Space Centre (BNSC)
- Deutsches Zentrum für Luft- und Raumfahrt e.V (DLR)

JC-13 Government Liaison
- JC-13.1 Discrete Devices
- JC-13.2 Microelectronic Devices
- JC-13.4 Radiation Hardness Assurance and Characterization
- JC-13.5 Hybrids, RF/Microwave, MCM

JC-14 Quality & Reliability

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Collaborative Relationships

- Information Sharing and Regular Communications with …
  - Automotive Electronics Council
  - Best Manufacturing Practices Center of Excellence
  - Center for Commercial Component Insertion (The C3I)
  - Centre National d'Etudes Spatiales (CNES)
  - Defense Semiconductor Association
  - The FIDES Group
  - International Electrotechnical Commission (IEC)
  - Institute for Printed Circuits
  - Italian Ministry of Defense
  - Semiconductor Assembly Council (SAC)
  - Society of Japanese Aerospace Companies

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Standards Purview

- EIA GEB1, DMSMS Management Practices
- EIA GEB2, Reducing the Risk of Tin Whisker-Induced Failures in Electronic Equipment
- EIA SSB-1, Guidelines for Using Plastic Encapsulated Microcircuits and Semiconductors in Military, Aerospace and Other Rugged Applications
- Design Guideline for Electrical & Electronic Parts Used in Satellite Applications
- MIL-PRF-38534, Hybrid Microcircuits, General Specification for
- MIL-PRF-38535, Integrated Circuits (Microcircuits) Manufacturing, General Specification for
- MIL-STD-883, Test Method Standard for Microcircuits
- MIL-HDBK-103, List of Standard Microcircuit Drawings
- MIL-STD-1835, Electronic Component Case Outlines
- MIL-PRF-19500, Semiconductor Devices, General Specification for
- MIL-STD-750, Test Method Standard for Semiconductor Devices
- MIL-HDBK-5961, List of Standard Semiconductor Devices
- MIL-HDBK-6100, List Of Case Outlines and Dimensions For Discrete Semiconductor Devices
- MIL-STD-1560, Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts
- Related Areas …
  - SD-18, Defense Standardization Program Guide for Part Requirement & Application
  - MIL-HDBK-454, General Guidelines for Electronic Equipment
  - MIL-STD-1686 & ANSI-ESD S20.20, ESD
  - Solderability Requirements & Lead-Free Issues

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Sub-Committees & Active Tasks

- **Space Parts Sub-Committee**
- **Plastic Encapsulated Microcircuit (PEM) Sub-Committee**
- **Lead-Free Sub-Committee**

STG95-04: RGA Issues (JC TG 97-02)
G00-10 Failure Rate Estimating Methods
G01-01 Scanning Acoustical Microscopy
G02-04 MIL-STD-1580 Rewrite & Coordination
G03-02 New Derating Standards
G03-09 Area Array Package Standardization
G05-01 PIND Testing
G05-02 Life Limiting Failure Modes
G05-03 Parts Management Reengineering
G05-04 Real-Time X-Ray
G05-05 Hot Solder Dip Standard
G05-06 Prohibited PM&P
G06-01 Counterfeit Part Risk Mitigation
G06-02 Leak Detection for UB Packages
G06-03 Schottky Boilerplate

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Key Focus Areas & Initiatives

- Lead-Free Issues
  - Lead-Free Issues Sub-Committee
  - GEIA-STD-0005-1 Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solders
  - GEIA-STD-0005-2 Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems
  - Developing Basis for Qualification of Lead-Free Solders in High Performance Applications
- Use of COTS Parts in Military and Aerospace Applications
  - Aerospace Qualified Electronic Component (AQEC)
- Counterfeit Parts in Military and Aerospace Applications (Task G06-01)
  - Teaming with SIA Counterfeit Parts Task Force
- Diminishing Manufacturing Sources and Material Shortages (DMSMS)
  - Diminishing Supplier Base for Space Qualified Parts
- Other Focus Areas
  - Failure Rate Estimating Methods (Task G00-10)
  - RGA Testing (Task G95-04)
  - Life Limiting Failure Modes (Task G05-02)

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Lead-Free Subcommittee

- DoD / Aerospace Industry Reliability Issues Associated With Lead-free Electronics
  - Pure-tin Plating And Finishes On Components
    - Possible Formation Of Tin Whiskers
  - Lead-free Solder In Boards And Circuits
    - Unknown Reliability
    - Will Require Changes In Production Practices
- Industry Standards And Guidelines Are Needed Which Enable Us To Continue To Produce Reliable, Supportable, Repairable, And Affordable DoD / Aerospace Electronic Systems
  - Joint Standards Being Developed By GEIA, AIA, and IEC

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Lead-Free Standards

- GEIA-STD-0005-1, Performance Standard for Aerospace and High Performance Electronic Systems Containing Lead-free Solder (Released June 2006)
  - **Used by "customers" to communicate requirements to aerospace / high performance electronic system "suppliers" Examples: Reliability, configuration control, repair, maintenance, and support**
- GEIA-STD-0005-2, Standard for Mitigating the Effects of Tin Whiskers in Aerospace and High Performance Electronic Systems (Released June 2006)
  - **Used by "customers" and "suppliers" to determine how much whisker mitigation is needed in a particular application. For each level of mitigation there are requirements regarding material monitoring, mitigating actions, and analyses.**
- GEIA-HB-0005-1, Program Manager's Handbook (Released June 2006)
  - **Used by program managers to address all issues related to lead-free electronics, e.g., logistics, warranty, design, production, contracts, procurement, etc.**
- GEIA-HB-0005-2, Technical Guidelines for Using Lead-free Solder in Aerospace Applications (Not Ready for Ballot)
  - **Used by "suppliers" to select and use lead-free solder alloys, other materials, and processes. It may include analytical methods, technical data, specific solutions, lessons learned, test results, etc.**
- GEIA-STD-0005-3, Test Protocol for Using Lead-free Solder (Mapping Out Document)
  - **Used by "suppliers" to qualify lead-free solder alloys, other materials, and processes.**

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Aerospace Qualified Electronic Component (AQEC)

- GEIA-STD-0002-1 Released September 2005
  - AQEC Requirements Standard
- Requires Defined Processes and Documentation
- Implementation is an Issue
- Working to Sign on Vendors

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Counterfeit Parts Task Group (G06-01)

- Teaming with SIA Counterfeit Parts Task Force
- Numerous Instances of Counterfeit Parts in Military and Aerospace Inventories
- "Counterfeiting" can refer to a variety of activities. It could be as simple as remarking scrapped or stolen and possibly nonworking parts—or as complex as illegally manufacturing complete parts from original molds or designs.
- A fake part may be relabeled to appear to come from a different manufacturer/broker or to appear to be a newer or even an older but more sought-after component than it actually is.
- Counterfeit parts are hard to spot and are all too often slipped into the supply chain by either unknowing or corrupt distributors. Among the most popular counterfeit products right now are cell phone batteries.
- Parts are not being found until they are in builds down stream which could end up to be very costly to replace or even more serious, there could be serious consequences like latent defect failures.

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Diminishing Supplier Base for Space Market Piece Parts

- Because Of The High Cost Of Access To Space, The Continued Availability Of Highly Reliable, Radiation Tolerant Piece Parts Is Essential To The Production Of Future Space Systems.
  - Increasingly, Space System Providers Are Being Forced To Rely On Fewer Qualified Piece Part Suppliers.
  - Consolidations That Have Occurred Over The Last 7-10 Years Have Resulted In Less Manufacturing Capacity And Less Supplier Choice.
  - This Is Resulting In Increased Cost, Increased Lead Times, And Increased Risk To Field Capable Space Systems On Schedule.
  - In Some Key Technology Areas There Is Only A Single Source Manufacturing Critical Piece Parts.
  - Disruptions Due To The Loss Of Experienced Personnel, Fire, Acts Of God, Or Terrorism Could Severely Cripple The Ability To Produce Needed Space Systems.
- With The Total Military Piece Part Market Share Already Below 0.5%, There Is Also Potential For Additional Manufacturers Exiting The Space Piece Part Business.
- G-12 Goal: Raise Awareness, Work to Improve Availability

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RGA Testing (Task G95-04)

- Residual Gas Analysis (RGA) Testing for water vapor content continues to be problematic…
  - High Moisture Content in cavity packages is a potential reliability risk.
  - Correlation/test lab repeatability problems extend from lab to lab and one piece of equipment to another.
  - Test is very sensitive and dependent upon many factors making it difficult to distinguish between an invalid test and a device failure.
  - Differences in procedures and calibration techniques among test labs demands a very high level of expertise to perform test, analyze results and determine reasons for non-correlation.
  - Concerns about testing very small packages and very large packages.

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RGA Testing (Task G95-04) - continued

- Longest Running Task Group In History
- New Focus on Equipment Calibration
- Benny Damron (NASA) and Mark Porter (General Dynamics) Visiting U.S. Laboratories
  - Understanding Process
  - Understanding Variables
  - Understanding Differences Between Laboratory Capabilities
- Additional Correlation Studies Planned
- 5000 ppm – Should This Be a Fixed Requirement?

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Conclusions

- GEIA G-12 Solid State Devices Committee activities
  - promote system reliability
  - minimize part obsolescence
  - enhance logistics readiness and interoperability
  - reduce cost of ownership to the government
- Our acquisition reform initiatives integrate commercial practices with military product requirements to ensure the semiconductor industry supports our needs for state-of-the art components without compromising equipment performance
- G-12 collaboration with …
  - Semiconductor Industry (JEDEC)
  - Government Agencies (DSCC, DoD Services, NASA, etc.)
  - Other industry and international participants (e.g. JAXA, ESA, etc.)

  … produces results toward resolving solutions to common problems

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G-12 Membership Information Cost

- Participating Committee Member (Voting)
  - One Committee $2000/year
  - Two Committees $3500/year
  - Three or More Committees $5000/year
- Observing Committee Member (Non-voting)
  - Participation in Any Committee $500/year

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G-12 Membership Information
Benefits of Membership

- Leverage business development, market planning and forecasting, and maintain a competitive edge
- Access major decision-makers across the federal government and networking with industry peers and competitors
- Participate in committees tailored to the interests of federal Contractors
- Extend your influence on future industry directions by developing industry standards for many management disciplines
  - Systems Engineering
  - Software Life Cycle Processes
  - Configuration Management

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Invitation to Attend

- Next Meeting
  - Date: January 8-11, 2007
  - Place: Savannah, GA
  - Hyatt Regency Savannah
- Following Meeting
  - Date: May 21-24, 2007
  - Place: Myrtle Beach, SC
  - Sheraton Myrtle Beach Convention Center
- See the G-12 web site at …

http://www.geia.org/

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For More Information

See the G-12 web site at …

http://www.geia.org/

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Micro & Nano Technologies at the European Space Agency

Laurent Marchand, ESA Components Division

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JAXA Micro-Electronics WorkShop, MEWS 19

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Overview

- MEMS Activities at ESA
  - RF MEMS
  - MOEMS
  - AOCS MEMS Sensors
  - Micro-Propulsion
- MEMS Based missions and technology demonstrators
- Nanotechnologies activities at ESA
- MNT Strategy and planning
  - CTB MNT Working Group
  - CTB MNT Dossier
- Conclusions

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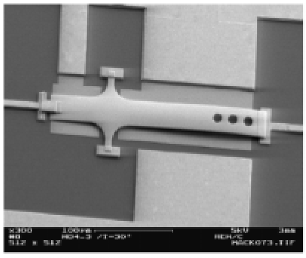
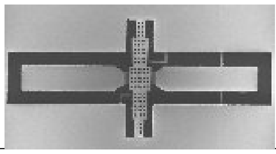
RF MEMS Activities 1/4



RF MEMS Switches completed activities:

- 3 activities to support RF MEMS switches for Telecom applications:
  - Daimler Crysler(Germany)
  - Alenia Alcatel Space (former Alenia, Italy)
  - IMEC (Belgium)

Parameter	Target figure	Alenia results
Frrequency band (GHz)	1-30	1-30
Max RF input power (W)	> 10	<3
Insertion loss (dB)	<0.4	< 0.3
Isolation (dB)	>50	>40
Return loss (dB)	>20	>20
Actuation voltage (V)	<50	<40
Switching time (s)	$< 15\ 10^{-6}$	$<15\ 10^{-6}$
Number of cycles	$> 10^{6}$	10^{6}
Operating temp. range (°C)	-25 to + 75	-25 to + 75



Overall results

- Best performances achieved with Alenia Alcatel Space Italy (see table) with series and shunt ohmic switches
- New Topologies (toggle switch) developed by Daimler Crysler (Germany)
- Important reliability issues experienced with capacitive switches like stiction, self actuation…
- 2 * 2 switching matrix prototyped
- Ohmic switches seems to be the most reliable technology today compared to capacitive switches

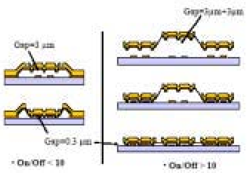
esa

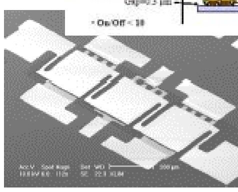
RF MEMS Activities 2/4

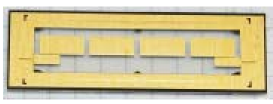
Non hermetic RF MEMS

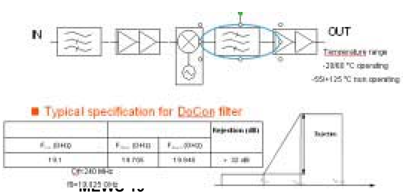
Innovative research programme with Alcatel Alenia Space Toulouse (France) and Limoges University (XLIM).

- New materials and design to avoid RF MEMS stiction (Diamond Like Carbon, Teflon, Al_2O_3(PLD and PECVD…) processing or RF behaviour issues.
- Design and manufacturing of dielectric-less RF switches. Selected by French MoD for follow on activity.







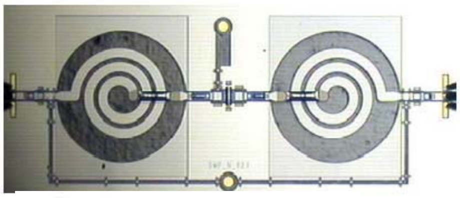


Industrialisation of MEMS membrane filters for space

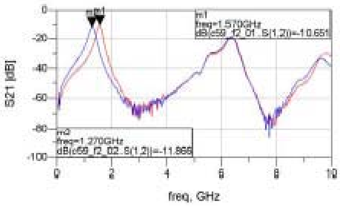
Alcatel Toulouse (France) and Limoges University (XLIM), Transfer from Limoges University to Industry (Reinhart Micro Technology, Switzerland, RMT) of Microwave filters for down-conversion (Do-Con filters) from Ka band receiver (30/20 GHz). Fabrication process transferred to industrial production (RMT). Status: 2 batches fabricated, 1st batch 50% yield with similar performances as lab samples. 2nd batch 90% yield. Industrial purchase already placed with RMT.

RF MEMS Activities 3/4

Tunable MEMS Filters



Earth Observation programme activity to investigate the suitability of RF MEMS technology for Tunable Filters covering Galileo (1.2 GHz) and GPS (1.57 Ghz) bands. Very narrow bandwidth (24 & 20.4 MHz)

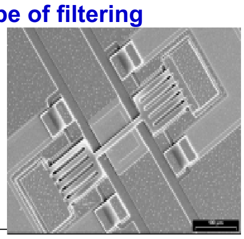


Results:

Narrow band difficult to achieve with MEMS technology, high insertion loss caused by passive devices. MEMS varactors: process not sufficiently controlled. FBAR seems a better technology for this type of filtering

ENDORFINS: ENABLING DEPLOYMENT OF RF-MEMS TECHNOLOGY IN SPACE TELECOMMUNICATION

Telecomn activity with IMEC (Belgium) to work on failure modes of RF MEMS, in view of their deployment in space and improve this reliability (for switches) through processing optimization. FMEA and 1st run completed, Completion summer 2007.



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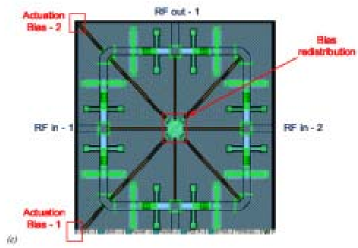
RF MEMS New Activities

Very Large Order Switch Matrices using MEMS Technology

"Redundancy Ring" 16 * 16 Switch Matrix	
Parameter	Specification
Frequency band	L, S, C, Ku or Ka-band
Bandwidth	Covering whole frequency band
Input match (50 Ohms)	-15 dB max
Output match (50 Ohms)	-15 dB max
Insertion losses	10 dB max
Gain variation	+/- 1dB
Isolation between channels	50 dB min
Maximum input power	0 dBm
Reconfiguration time	1 ms max

"IF connectivity" 16 * 16 Switch Matrix	
Parameter	Specification
Bandwidth	5.75 – 6.8 GHz min
Input match (50 Ohms)	-15 dB max
Output match (50 Ohms)	-15 dB max
Insertion losses	10 dB max
Isolation between channels	50 dB min
Maximum input power	0 dBm
Reconfiguration time	1 ms max



High reliability RF MEMS redundancy switch

Parameter	Specification
Frequency band	Ku-band
Bandwidth	Covering whole frequency band
Input match (50 Ohms)	-15 dB max
Output match (50 Ohms)	-15 dB max
Insertion losses	0.5 dB max (unpackaged)
Isolation between channels	50 dB min
Maximum input power	10 dBm
Reconfiguration time	1 s max
Operating temperature range	-20°C / +55°C
Storage temperature range	-50°C / +125°C
Lifetime (predicted)	15 years min (with 1000 actuation max)

Lifetime shall not be affected by "hot switching" which happens when the switching is done while the RF power is still applied (0 dBm max).

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MOEMS Activities 1/2

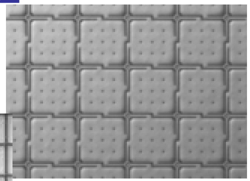
Adaptive Optic technology:

Overall objective: Increase aperture size of space telescopes; requires to correct aberrated wavefront from primary mirror Demonstration using:

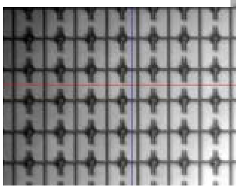
– Deformable Membrane Mirrors (DMMs); Micro Mirror Arrays (MMAs, 2 types: Phase shifting and Torsional (flip or tilt)

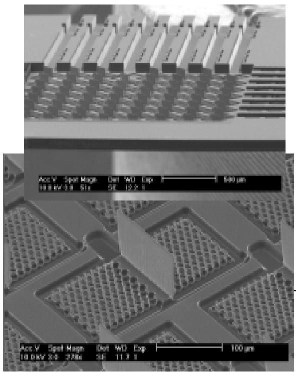
Partners: EADS Astrium Germany and Franhaufer Institute (Germany)

Piston mirrors



Torsional mirrors





Optical Handling of Microwave and Digital Signals*: S*AT 'N LIGHT.

Telecom activity in progress with Alcatel Toulouse (France) and Sercalo (Switzerland) to investigate MOEMS advantages for telecom payload with flexible beam-to-beam connectivity

- optical generation & distribution of high-frequency LO's (> 10 GHz)
- optical frequency mixing and down-conversion, e.g. from Ka (30GHz) to C (4GHz)
- optical cross-connection of μ-wave signals through MOEMS switches

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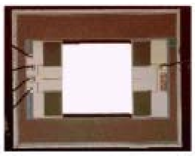
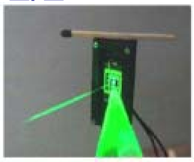
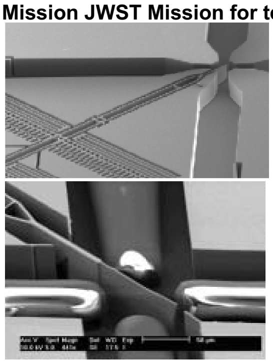
MOEMS Activities 2/2

MOEMS Test Effectiveness:

Activity to standardise efficient MOEMS acceptance test. Industrial partners IAF (Franhaufer) and EADS Astrium Munich (germany). Status: completed, Recommendations for MOEMS testing available. Preparation of James Webb Space Telescope Mission JWST Mission for testing the μ-shutters



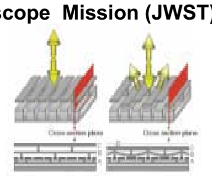




MOEMS Qualification Methodology

Activity to draft and validate by actual testing of commercial telecom MOEMS a specification and procedure for MOEMS Space Qualification. Industrial partners Alcatel Toulouse, IMEC (Belgium), MEMSCAP (France), SERCALO (Switzerland) & Laboratoire d'Astrophysique de Marseille (France). Basic qualification flow drafted, validation testing completed. Draft space qualification flow for MOEMS under preparation. Final presentation December 2006.

Preparation of James Webb Space Telescope Mission (JWST) for qualification of the micro-shutters



MOEMS Future activity:

Instrument concepts using dynamic diffraction gratings

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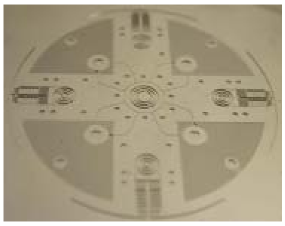
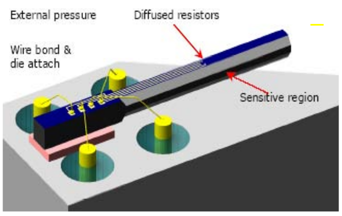
MEMS based Micro-Propulsion

Cold gas MEMS based micro-propulsion

Running research activities with Nanospace AB (Sweden). Development and on ground qualification of cold-gas micro-thruster capable of delivering continuous thrust levels between 0.1 to 10 mN, with a specific impulse of 45 s for nitrogen propellant.





Development and evaluation of MEMS pressure sensors

– Research activity in progress with PRESENS (Norway). Development and pre-qualification of high accuracy pressure sensor. Sensor technology is based on a patented silicon MEMS tubular structure with a piezo-resistive resistor bridge. The pressure sensors developed for satellite propulsion applications are calibrated for pressure ranges in between 3 and 10 bars.

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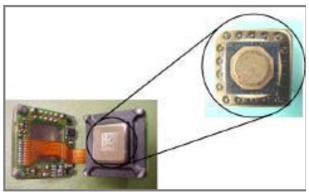
MEMS for AOCS 1/2

Industrialisation of Automotive BAe Systems UK angular rate sensor

Step 1: Procurement of MNT commercial devices, performance assessment and first Radiation testing: Reasonable performance but early drift due to the COTS discrete electronics during radiation

Step 2: Collaboration with EADS Astrium Toulouse (France), potential end – user and CNES, Physical evaluation (DPA), space compatibility (RGA, out/off gassing), Environmental testing (Temperature, humidity, shock & vibration tests), determination of lot dependence on performance, 1 failure during shock



Step 3: MEMS rate sensor development for space with Automotive Manufacturer: sensor improvement (resolution), electronic hardening, EQM,FM, integration on CRYOSAT 2: October 2007

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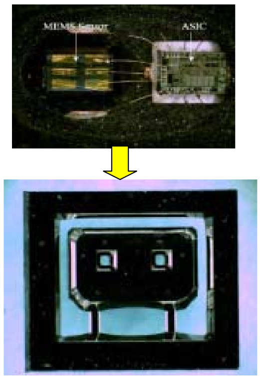
MEMS for AOCS 2/2

Evaluation of VTI (Finland) MEMS accelerometers



Activities:

- Performance assessment of non-space (automotive) commercial MEMS Accelerometers
- Physical evaluation, space compatibility
- Environmental testing (Shock, Vibration, Humidity…)
- Radiation testing

New Activities in AOCS:

A number of space applications, such launchers, transfer vehicles, re-entry vehicles, landers, rovers require an Inertial Measurement Unit (IMU), combining gyro and accelerometers measurements.

- ***Identification of accelerometer needs***
- ***Review of accelerometer market and trends***
- ***IMU performance study***
- ***Accelerometer preliminary specification, design and development plan***

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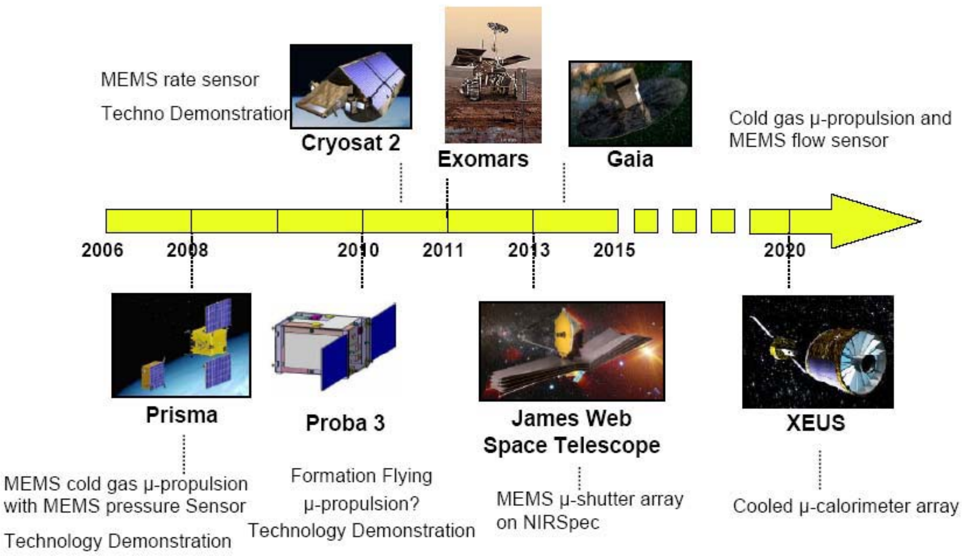
MNT Missions Timeline



MNT Demonstrators on CRYOSAT 2

MEMS rate sensor from BAe and SEA

Will fly as transparent (non flight critical) passenger for:

- **Attitude propagation, rate determination and failure detection**
- **Launch information: the micro-gyro will be switched on during launch**

Advantages of MEMS for inertial sensors

- **Low mass and small foot print**
- **No bearings, or moving items that wear out**
- **Low Power Consumption**
- **Solid state (more reliable that mechanical)**
- **Low Sensitivity to vibration & shock**
- **Low recurring costs**

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MNT Demonstrators on PRISMA

PRISMA: Technology Demonstration Satellite (F, S, D):

- **in-flight validation of sensor technologies and guidance/navigation strategies for spacecraft formation flying and rendezvous**
- **Launch end 2008**

2 MEMS based devices developed under ESA contracts will be on-board:

- **Digital pressure sensors from PRESENS (Norway)**
- **MEMS micropropulsion system from Nanospace AB (Sweden)**

Demonstration experiment:

- **MEMS will not be flight critical items**
- **Demonstration of TRL 7: Actual system completed and “flight qualified" through test and demonstration (ground or space).**

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MNT Demonstrators on PRISMA

Digital pressure sensors from PRESENS (Norway)

- **For the thrust feedback measurement**
- **Spinning-in from oil drilling industry**
- **Silicon MEMS tubular structure with a**
- **Piezo-resistive resistor bridge**
  - **High pressure sensing (3-10 bars)**
  - **Rugged against over-pressure**
  - **High accuracy**

ESA Support in the Technology Demonstration:

- **Development of Rad Hard ASIC**
- **Digitalisation of the command and control electronic**
- **Evaluation of the technology**
- **Reliability Testing**
- **On ground pre-qualification**

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MNT Demonstrators on PRISMA

MEMS μ-propulsion system from Nanospace AB (Sweden)

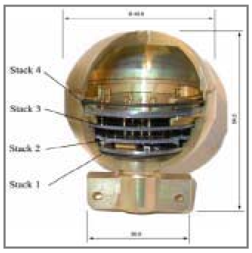
Micropropulsion is considered as enabler for Formation-flying space missions where very high precision is required.

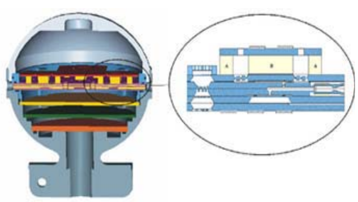
MEMS micro-valves & nozzles

Small size

Simplicity (reliability and low cost)

Low level, precise and low noise thrust





ESA support in the Technology Demonstration:

Development of various MEMS building blocks

Support to the fabrication process optimisation

PA/QA documentation

Evaluation of the technology

Reliability Testing

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MNT Space Projects: XEUS
(X-Ray Evolving Universe Spectrometer)

X-Ray spectrometry can be performed with a micro-calorimeter array, which senses the heat pulses generated by X-ray photons when they are absorbed.

Cooled μ-calorimeters for X-Ray detection:
MEMS enable small thermal capacitance, thermally isolated from substrate:

- Best energy resolution and X-ray absorption efficiency:
  - A good plasma analysis spectrometer requires 2 to 3 eV resolution
  - At 6 keV MEMS allow a resolution of 2.4 eV whereas for STJs (Superconducting Tunnel Junction) european competitors it is 16 eV!
- Multiplexing based on SQUID (Superconducting Quantum Interference Device):
  - Reduces the distance to the detector, the wiring and the heat of the body.
  - For STJs competitors, each sensor has traditional amplification, which requires tremendous wiring.

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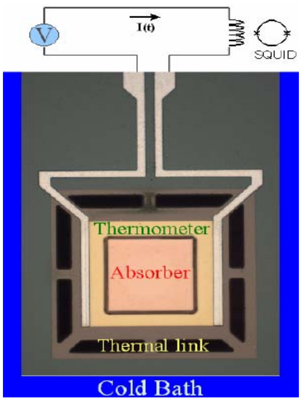
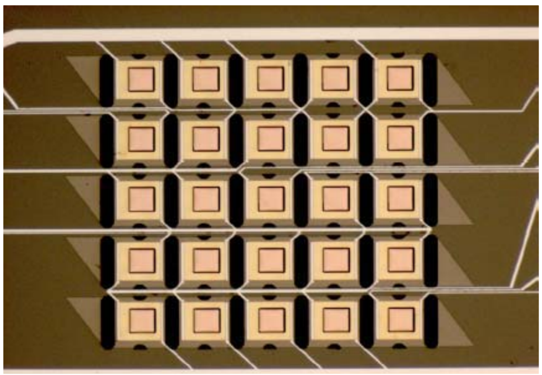
MNT Space Projects: XEUS
(X-Ray Evolving Universe Spectrometer)

Design and Fabrication: SRON and MESA+ The Netherlands





Flight horizon 2018-2022, currently TRL 4: Component and/or breadboard validation in relevant environment to be achieved by 2010

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MNT Space Projects: JWST
(James Webb Space Telescope)

NIR-Spec: Multi-image Near InfraRed Spectrometer

- **ESA/NASA Cooperation**
- **Will use MEMS micro-shutters**
- **Capable of 100 images observations at one time**
  - **Significant improvement on the current technology capability (only one object at a time)**
  - **Increased efficiencies of operation**
- **171 X 365 shutters arrays, 4 arrays, all individually addressable and programmable**
  - **Extremely flexible**
  - **Tiny shutters that can be opened in the pattern of objects hence targeting objects of interest.**

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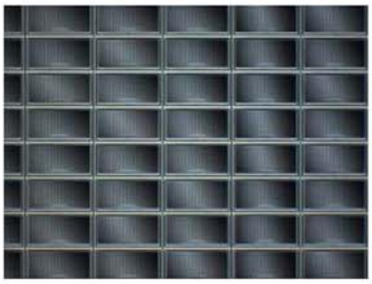
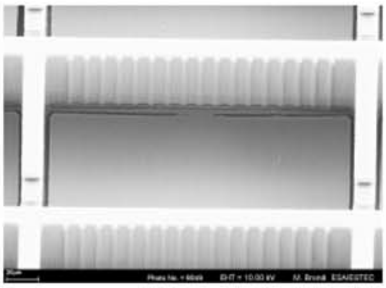
MNT Space Projects: JWST
(James Webb Space Telescope)

Micro-shutters manufactured by NASA/GSFC:





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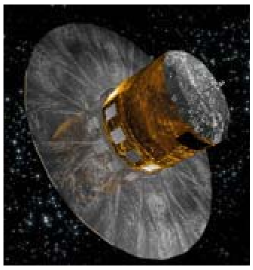
MNT Space Projects: GAIA



GAIA:

- Replacement for HIPARCOS spacecraft
  - In 1993: HIPARCOS Astrometric Accuracy: 1-10 milliarcs
  - GAAI in 2011 : 20 µarcs
- Will use MEMS flow sensor
- Very accurate pointing required => order of µN thrust is mandatory
- µN thrust only available with cold gas micro propulsion
  - Need for very accurate (1 µN) and fast time response (10 Hz) flow sensor
- MEMS is the only solution available today

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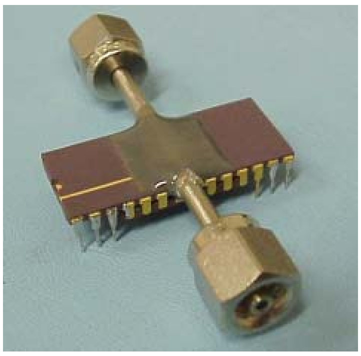
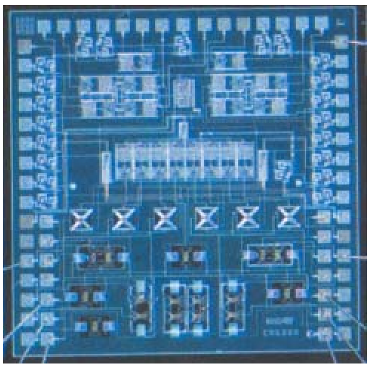
MNT Space Projects: GAIA

MEMS Flow Sensor, AAS Florencia, Italy





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Nanotechnology: Activities completed 1/2

Nematic elastomer composites'

Demonstration of feasibility and use of a novel electromechanically actuated membranes. Carbon nanotubes were immersed in a silicone matrix and pre-aligned. In an electric field the fibers are exerting a momentum and cause mechanical contraction (expansion) of the silicone matrix. The mechanical response is fast and reversible. A bending movement with a membrane on sample level has been demonstrated. TRL 2

Assessment of mechanical improvement of aluminium alloy using nano-particles

The study was addressing the possibility to disperse nanoparticles in Al 6061 as strengthening agent (to act the same way as nano-precipitates produced during heat-treatment of the strongest aluminium alloys). The aim was to increase alloy mechanical strength while keeping the good corrosion behaviour and the low density. Two routes have been followed (liquid and powder metallurgy). The outcome is that liquid route is not feasible, solid route could eventually lead to improved properties but still requires development efforts. TRL 1-2

Assessment of failure tolerance by incorporation of hollow fibres

Assessment of failure tolerance by incorporation of hollow fibres in composite materials with special resin/catalyst system. Results were encouraging, study requires follow-on activity. TRL 1

Nanotechnology: Activities completed 2/2

Self Healing Materials – a first step to bio-mimetic materials

One of the constraints of spacecraft (structures) is their inability to self repair damages that may happen in orbit. Damages could be caused internally (thermal cycling, debonding, fatigue etc.) or externally by e.g. impacts. In the field of nano-engineering materials there are several concepts evolving by which materials could become more damage tolerant. So far two competitive precursor studies where carried out. TRL 1

Assessment of failure tolerance by incorporation of capsules in a polymer.

Results were not encouraging and further improvements of incorporation etc. required. Challenges encountered are the typical problems of distribution/agglomeration/interfacial engineering ... of nano-particles. TRL 0

Investigations on hybrid polymers for Space Applications

The purpose of the study was to evaluate novel applications of hybrid polymers (inorganic/organic nano-composites) for space applications. Possible applications are improvement of UV resistance of polymers, ATOX resistance and passivation of polymer films and/or composites. Spin-In of other nano-engineered materials development used. TRL 1-2

Nanotechnology : Activities in Progress 1/2

Radiation Stable Optical Adhesives

Development of radiation stable optical adhesives for space applications with focus on (V)UV and thermal stability for applications with high radiation fluxes, e.g. solar cells, laser optics. The strategy can cover the application of SiOx nano-clusters and particles, the small size needed for optical performance. The end-product should be readily for qualification and competitive to other commercial systems. TRL 2 -> 3

Nanotube composite materials

Objective: Reinforcement by nanotubes. The aims are to disperse small volume fraction of CNT in a ceramic matrix and to align high volume fraction of CNT in metal matrix. Materials are characterised with respect to application field identified. TRL: 1-> 1/2

Flexible carbon nanofibre foam (carbon nanofibre networks)

- Development of materials made of CNT/CNF network and assess their potential damping vibration and heat dissipation capacity. Potential application fields are also surveyed. TRL: 1-> 1/2

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Nanotechnology: Activities in Progress 2/2

Proof of concept for Self sealing materials for space

Assessment of self sealing materials for autonomous crack closure. Evaluation of novel concepts of how self sealing of materials structures can be achieved. The restoration of structural integrity after damage (impact etc.) is a materials engineering challenge. Possibly nano-engineered materials (reagents, catalysts etc.) could be enabling. TRL: 1 ->1/2

Proof of concept for Aerogel applications

Aerogels contain nanopores of air that are only a few hundred times larger than atoms. Aerogels are the lightest known solids available with reported density down to three times that of air. Therefore Aerogels have very interesting weight specific properties. The purpose of the study is to assess some fundamental properties of aerogels (thermal conductance, acoustic/thermal insulation) and evaluate possible future space applications. TRL: 1 → 1/2

Non conventional matrix / carbon reinforced composites for applications in space

The aim of the study are to establish a route to build a 3D CNT network, achieving high loadings – to adapt the interface toward matrices and to infiltrate the network by those matrices– The material relevant properties are measured. TRL: 1/2-> 2

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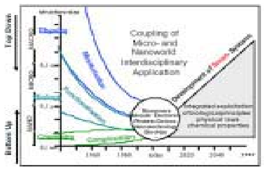
Nanotechnology



Future Activities:

✓ **Nanotechnologies for space: roadmaps and applications:**

Objectives:

Address state of the art outside and inside the space sector. Define potential contribution of nanotechnologies: technological information allowing potential use of nanotechnologies. Establish axes of collaboration to favor development of nanotechnologies: technological key issues and competence centers well positioned in the field of interest.

Recommendations with the elaboration of a "Nanotechnology Roadmap"

✓ **Nanomaterials for improved thermal conductivity**

Nanotechnology and in particular nano-fibres or nano-powder or carbon nanotubes could be used in composite materials to modify the physical properties, such as the strength, the thermal conductivity and the CTE. Objective: identifying possible nano-materials which could significantly improve the thermal dissipative properties of standard space qualified epoxy. Prototyping and validation via a demonstrator

✓ **Nanotechnology for Space Solar Cells**

Nanotechnology could permit a new degree of freedom for solar cell design due to the possibility to engineer quantum opto-electronic properties that are otherwise fixed for a given material. Feasibility of at least one design for incorporation of nanotechnology in solar cells for space applications. Manufacturing and testing of demonstration devices to evaluate potential for space.

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The MNT Component Technology Board (CTB)

MNT CTB Membership

- **Members:**
  French Space Agency (CNES), EADS Astrium Germany, Alenia Acatel Space Italy, Alenia Acatel Space, Toulouse (France), EADS Space Transportation (France), 3D + (France), EADS Astrium UK, EADS Corporate Research Centre (Germany), ESA.
- **Observers:**
  Italian Space agency (ASI), British National space centre (BNSC), German Space Agency (DLR), Finish Technology Centre (TEKES), Swedish National Space Board (SNSB)

MNT CTB Scope:

- **Identify MNT components considered to be of strategic importance for future space applications based on existing or anticipated user requirements**
- **Establish a consolidated multi-year strategic plan for space MNT devices with technology roadmaps**
- **In coordination with MNT users define / propose the relevant study, development, evaluation, and research activities**
- **Assess technologies / components, manufacturer capabilities, technology trends**
- **Estimate the necessary resources, funding, time scales and define priorities for the various activities**
- **Determine the necessary prerequisites and conditions to make these MST technologies/components available in line with project schedules**

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CTB MNT Dossier

- All inputs gathered from CTB members
- Drafts roadmaps available for RF MEMS, MOEMS, μ-propulsion, other sensors (AOCS, pressure), thermal management
- Line items: defined
- Actions items: to be improved
- Distribution for review (ESA and industry): December 2006
- GADs (General Activity Description) and detailed activity proposals: Q1 2007

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CTB MNT Roadmaps

RF MEMS

Action Line	Technology	Actual TRL	2007	2008	2009	2010	2011	2012
RF1	RF MEMS switch for reconfigurable microwave appication	TRL4	TRL5		TRL6		TRL7	
RF2	RF MEMS switch for antenna application	TRL3		TRL4			TRL5	
RF3	Micromachined filters switch for on-board microwave application	TRL5		TRL 6			TRL7	
RF4	RF MEMS switches with power handling capability	TRL2	TRL 3		TRL4		TRL5	
RF5	RF MEMS switches with dynamic performance compatible with T/R switches	TRL1		TRL2		TRL3		TRL4
RF6	Bulk accoustic device for high Q and high frequency filtering	TRL5	TRL 5		TRL6		TRL7	
RF7	RF MEMS varactor for high Q high tunability VCO and phase shifters	TRL3	TRL4			TRL5		

MOEMS

Action Line	Technology	Actual TRL	2007	2008	2009	2010	2011	2012
MO1	Piston Micro-Mirror-Arrays, large size, large stroke, high density, for adaptive optics	TRL3	TRL3	TRL4	TRL5	TRL5	TRL6	TRL7
MO2	Micro-Shutter-Arrays for spectroscopy and switching	TRL3	TRL3	TRL4		TRL5		TRL6
MO3	Tilt Micro-Mirror-Arrays, large size, high density, for spectoscopy and switching	TRL3	TRL3	TRL4	TRL5	TRL5	TRL6	TRL7
MO4	Dynamic and programmable diffraction gratings (DPDG) for spectroscopy	TRL1	TRL2	TRL3	TRL4	TRL5		TRL6

ESA TRL reference
Level 1: Technology concept and/or application formulated.
Level 2: Analytical & experimental critical function and/or characteristic proofof-concept.
Level 3: Component and/or breadboard validation in laboratory environment.
Level 4: Component and/or breadboard validation in relevant environment.
Level 5: System/subsystem model or prototype demonstration in a relevant environment (ground or space).
Level 6: System prototype demonstration in a space environment.
Level 7: Actual system completed and "Flight qualified" through test and demonstration (ground or space).
Level 8: Actual system "Flight proven" through successful mission operations.

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Conclusions 1/2

- MEMS technology is now sufficiently mature for use as mission critical components for scientific missions, additional efforts on reliability and qualification are still required for EO and Telecom Applications.
- Additional collaboration and exchange with JAXA on MEMS could be envisaged for reliability testing and space qualification methodology
- Nanotechnology for European Space Applications are still low TRL (TRL 0 -1) but proof of concept activities are under initiation

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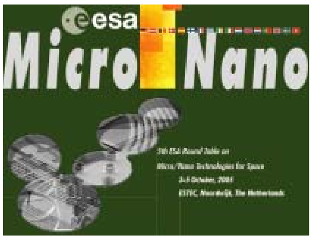
Conclusions 2/2

- Invitation: 6th ESA MNT Round Table
  - **ESA/ESTEC The Netherlands**
  - **8 -12 October 2007**
  - **3 days workshops**
  - **2 days Courses on Nanotechnology**



MNT Contacts at ESA:

- **AOCS:** Stephane.Dussy@esa.int
- **Micro-propulsion:** Martin.Lang@esa.int
- **RF MEMS:** Francois.Deborgies@esa.int
- **MOEMS:** Josep.Maria.Perdigues.Armengol@esa.int & Kotska.Wallace@esa.int
- **MEMS Packaging, Reliability and Qualification:** Laurent.Marchand@esa.int
- **Nanomaterials:** Laurent.Pambaguian@esa.int
- **Nanotechnology:** Laurent.Marchand@esa.int & Laurent.Pambaguian@esa.int
- **MNT Coordination:** Laurent.Marchand@esa.int

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CENTRE NATIONAL D'ÉTUDES SPATIALES

Status of main CNES activities with regard to strategic technologies and components in the domain of silicon ICs

Jean-Louis VENTURIN
With the participation of
Marielle BELASIC
Jean BERTRAND
CNES Toulouse - France

19th Microelectronics Workshop

JAXA Tsukuba Space Center

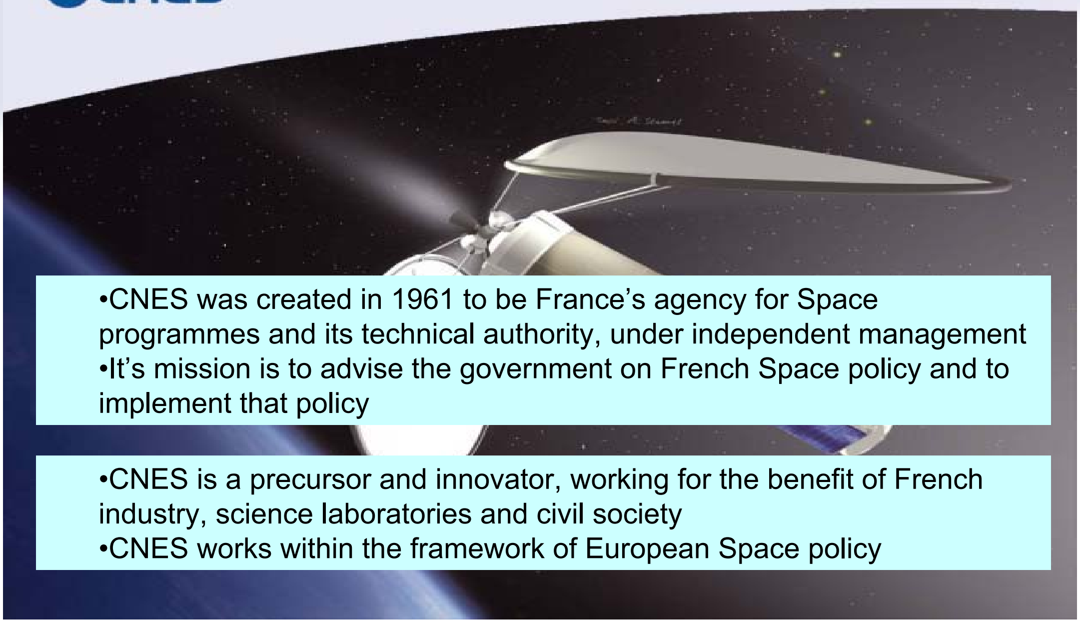
26th October 2006 **19th Microelectronics Workshop** 1

OUTLINE

- **Presentation of the CNES**
- **Introduction to strategic technologies and components**
- **Objectives**
- **Process for selecting the actions**
- **ST MICROELECTRONICS – Radiation Hardened Power MOSFET**
- **ATMEL 0.18 µm CMOS Technology**
  - ✓ **Technology characterization and hardening**
  - ✓ **Products development**
- **High speed A/D converter evaluation**
- **Conclusions**

26th October 2006 **19th Microelectronics Workshop** 2

Presentation of the CNES



- CNES was created in 1961 to be France's agency for Space programmes and its technical authority, under independent management
- It's mission is to advise the government on French Space policy and to implement that policy

- CNES is a precursor and innovator, working for the benefit of French industry, science laboratories and civil society
- CNES works within the framework of European Space policy

CNES and its European partners

- CNES represents France within the European Space Agency (ESA)
- It leads a multinational programme that is consistent with European programmes
- CNES implements the strategy decided upon by the French government for participation in the European Space programme
- CNES and its European partners work closely together as part of an assistance network for first level customers

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CNES fosters bilateral and multilateral cooperative ventures:

- with other European countries, either directly or jointly (through direct bilateral cooperation or cooperation via ESA)

- with other major Space nations: United States, Russia, Japan, India, China, etc.

- via specific projects with several partners: Latin America, Israel, Thailand, Algeria, Canada, etc.

26th October 2006 **19th Microelectronics Workshop** 6

International cooperation

➢**JAXA-CNES collaboration on space parts: an example**

- **Initiated in 2003 by our Presidents**
- **Report during yearly Symposium**
- **4 themes of collaboration :**
  - ✓Common Commercial components policy,
  - ✓Radiations Environment (environment models, in flight experiments),
  - ✓Joint Components Evaluation Techniques
  - ✓Strategic components (submicron technologies, microprocessor, FPGA, memories, A/D and D/A converters, Power MOSFET, DC/DC converters, … => Japanese SOI FPGA involving ATMEL and OKI decided in this framework.

CNES has four centres pursuing complementary missions, for preparing the future and carrying out projects

It has a staff of over 2,400 including almost 1,800 engineers and managers (35% of whom are women)

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An ambitious Space policy for France

Serving the general interest in the following fields:

- **access to Space**
- **sustainable development**
- **applications for the general public**
- **Space science and preparing the future**
- **security and defence**

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CNES budgets (multilateral share in millions of current euros)

- multilateral share of subsidies

	2005	2006	2007
National programme	**681.5**	**691.6**	**702.0**
Access to Space: Launchers and CSG	**118.8**	**110.3**	**116.4**
Space applications	**450.9**	**473.9**	**476.6**
• General public	32.0	25.7	26.0
• Sustainable Development	82.5	89.3	87.5
• Space sciences and preparing the future	101.8	102.1	104.6
• Security and Defence	85.3	106.6	120.6
• Shared resources	149.4	150.2	137.9
Central Directorates (inclusive of VAT)	**111.8**	**107.4**	**109.0**

• **Commercial businesses** (Satellite positioning, Station keeping operations) **~300M€**

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France's contribution to ESA (in millions of current euros)

	2005	2006	2007
French contribution	**685.00**	**685.0**	**685.0**
Access to Space: launchers	**44.35%**	**40.31%**	**42.89%**
Space applications	**46.96%**	**51.08%**	**55.70%**
• General public	8.03%	15.42%	16.86%
• Sustainable development	9.03%	13.37%	16.29%
• Space sciences and preparing the future	29.90%	22.29%	22.55%
• Security and defence	0.00	0.00	0.00
ESA administration and debt management	**8.69%**	**8.61%**	**1.41%**

Introduction to strategic technologies and components

➢**CNES and ESA coordinated initiatives followed by the European Components Initiative phase 1 have led, among many others to the implementation of :**

- **Strategic developments to ST Microelectronics :**
  - ✓Radiation Hardened Power MOSFETs
- **And ATMEL :**
  - ✓0.18 µm technology hardening (both ESA and CNES contracts)
  - ✓Products development based on 0.18 µm CMOS hardened technology
    - o LEON 2 FM : 32 bit - 100 MIPS SPARC processor (ESA)
    - o 280 K gates SRAM based FPGA (CNES)
    - o Evaluation of high speed A/D converter

➢**A status of the activities in which CNES is involved is given**

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Objectives of Strategic technologies and components (1/2)

➢To contribute to the European non dependence

- Avoid possible embargo (ITAR restriction, …),
- Increase the share of European components in our projects
- Reduce the procurement schedules and prices
- Improve the quality assurance by the use of the ESCC standard
- Contribute to the exploitation of the European capabilities in terms of space components
- Propose, in time, state of the art technologies and components with a good readiness level and at a reasonable cost.

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Objectives of Strategic technologies and components (2/2)

➢To contribute to the space industry competitiveness

- **Equipment manufacturers**
  - ✓Allow the space industry to have access to state of the arts components
  - ✓Increase systems and equipment performances
  - ✓Be able to propose new applications (New Generation telecom payloads requiring high computation capacity, …)
- **Component manufacturers**
  - ✓Develop a production capacity of HiRel radiation hardened components to a reduced number of component manufacturers
  - ✓Develop as much as possible their products portfolio in order for them to be attractive and get back a significant revenue => Assurance of their commitment to the space business.

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (1/7)

➢**The contract**

Remarks : Apart the European non dependence, monopolistic position of IR

- **Amount : ~ 4 MEuro (4.8 M$)**
  - ✓Shared between ESA and CNES
  - ✓Development, ESCC evaluation and qualification of 14 state of the art types of Rad Hard Power MOSFET for immediate use
    - Total dose resistance : min 100 KRad
    - No SEB and SEGR for LET min of 37 MeV/(mg/cm2)
  - ✓N and P types
  - ✓Rated Voltage from 60 V to 250 V
  - ✓3 different packages : TO 254A, SMD 0.5 and TO 39.

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (2/7)

- **Types description**

Device #	ST Line	Polarity	Package	Main performances Rated Volt / Ron / Qgate	ST Rad Hard designation	IR Rad Hard Reference	Main performances Rated Volt / Ron / Qgate
1	HG6F	N	SMD0.5	60V / 30mOhm / 50nC	STRH40N6SY3	IRHNJ57034	60V / 30mOhm / 45nC
2	HG6K	N	TO254AA	60V / 12mOhm / 155nC	STRH100N6FSY3	IRHM57064	60V / 12mOhm / 160nC
3	HG0C	N	TO39	100V / 160mOhm / 25nC	STRH8N10STF3	IRHF7130	100V / 180mOhm / 50nC
		N	TO39			IRHF57130	100V / 80mOhm / 50nC
		N	SMD0.5			IRHNJ67130	100V / 42mOhm / 35nC
4	HG0K	N	TO254AA	100V / 24mOhm / 160nC	STRH100N10FSY3	IRHMS67160	100V / 11 mOhm / 165nC
5	HN25	N	SMD0.5	200V / 200mOhm / 50	STRH13N20FSY3	IRHNJ57230	200V / 200mOhm / 50nC
6	HN2S	N	TO254AA	200V / 44mOhm / 180nC	STRH60N20FSY3	IRHMS67260	200V / 29mOhm / 240nC
7	HNB2	N	TO257AA	250V / 550mOhm / 30nC	STRH10N25ESY3	IRHY57234CMSE	250V / 410mOhm / 28nC
8	HNB8	N	TO254AA	250V / 70mOhm / 220nC	STRH40N25FSY3	IRHM57264SE	250V / 66mOhm / 165nC
9	HP6H	P	TO254AA	60V / 50mOhm / 150nC	STRH50P6FSY3	IRHM9064	60V / 50mOhm / 300nC
10	HP6M	P	TO254AA	60V / 18mOhm / 320nC	STRH80P6FSY3	IRHMS597064	60V / 16mOhm / 160nC
11	HP0D	P	TO257AA	100V / 300mOhm / 40nC	STRH12P10ESY3	IRHY9130CM	100V / 300mOhm / 45nC
12	HP0J	P	TO254AA	100V / 60mOhm / 192nC	STRH40P10FSY3	IRHM9160	100V / 73mOhm / 290nC
		P	TO254AA			IRHMS597160	100V / 50mOhm / 170nC
13	HP23	P	SMD0.5	200V / 500mOhm / 70nC	STRH8P20SY3	IRHNJ597230	200V / 505mOhm / 40nC
14	HP2M	P	TO254AA	200V / 100mOhm / 260nC	STRH30P20FSY3	IRHMS597260	200V / 103mOhm / 175nC

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Hardened Power MOSFET

➢**JAXA developments**

9 N channels types developed:

> TO 254 100V
- **2SK4048, 18 mOhms, 42 A,**
- **2SK4049, 33 mOhms, 42 A,**
- **2SK4050, 69 mOhms, 15 A,**

> TO 254 200V
- **2SK4051, 33 mOhms, 42 A,**
- **2SK4052, 69 mOhms, 33 A,**
- **2SK4053, 155 mOhms, 14 A,**

> TO 254 250V
- **2SK4054, 45 mOhms, 42 A,**
- **2SK4055, 98 mOhms, 27 A,**
- **2SK4056, 230 mOhms, 12 A,**

Short term availability : 3 different sources of Power MOSFET worldwide => Competition is open and space industry is interested.

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (3/7)

➢**Work Packages (1/5)**

- **WP1 Assessment of ST Microelectronics Power MOSFET technologies and component part types**
  ✓Characterization of ST commercial technologies completed => Not completely compatible with space applications especially for N channel transistors
  ✓Simulation of radiation effects completed => adaptation of 3 commercial processes :
  o STRIPFET for low voltage (20 V to 100 V) N and P channel,
  o MESH OVERLAY for medium voltage (100 V to 250 V) N channel and P channel,
  o PWER MESH for high voltage N channel (200 V to 600 V) N channel.
- **WP2 N and P channel Power MOSFET Radiation Hardening development program**
  ✓Definition of target devices data sheets => completed
  ✓Radiation hardening plan (Process changes, simulation of radiation effects, layout rules, …) completed => Definition of :
  o Best process and design changes to improve the radiation hardening
  o Electrical performances and reliability impacts

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (4/7)

➢Work Packages (2/5)

- **WP3 Design, manufacturing and characterization of a set of N and P channel Power MOSFET Prototypes**
  - ✓Design, manufacturing and characterization of N and P channel prototypes completed => 4 types produced :
    - o N channel 100 V (STRH100V10FSY3) and 200 V (STRH60N20FSY3)
    - o P channel 100 V (STRH40P10FSY3) and 200 V (STRH30P20FSY3).
  - ✓ Radiation testing of N and P channel Power MOSFET Prototypes
    - o Total ionizing dose completed => preliminary results OK to 100 KRad
    - o SEB completed => No Burn out at 37 MeV/(mg/cm2)
    - o SEGR completed => results interpretation in progress.
- **WP4 Production and evaluation of first Rad Hard devices**
  - ✓Manufacturing and final electrical testing completed => products subjected to ST internal qualification and ESCC evaluation
  - ✓ST internal qualification and ESCC Evaluation done simultaneously

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (5/7)

➢Work Packages (3/5)

- **WP4 Production and evaluation of first Rad Hard devices (continuation)**
  - ✓PID (Product Identification Document)
  - ✓Evaluation in conformance with ESCC 2265000 standard
    - o Group 1 : Control group completed
    - o Group 2 : Destructive test : Step stress completed => failures mode and mechanism under investigation, Radiation test, Construction analysis, package test and electrical test to be launched now
    - o Group 3 : Endurance test : to be launched

Details of the evaluation test plan given next slide

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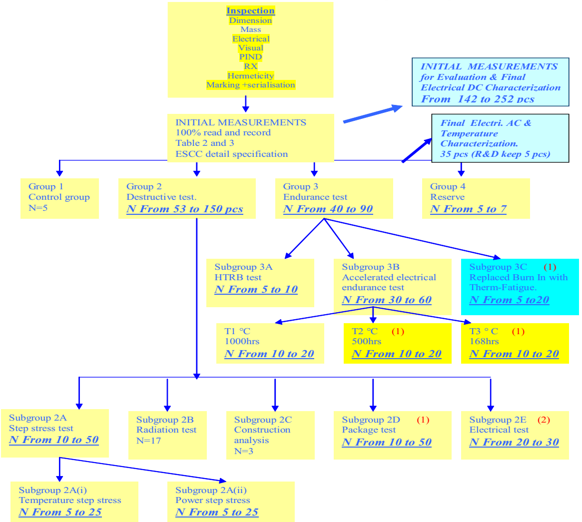
ST MICROELECTRONICS – Radiation Hardened Power MOSFET (6/7)

➢**Work Packages (4/5)**

ESCC test plan



Note: (1) For HN2S & HP2M silicon lines
(2) Parts coming from AC/Temp. Final Electr. Characterization

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ST MICROELECTRONICS – Radiation Hardened Power MOSFET (7/7)

➢**Work Packages (5/5)**

- **WP5 Design and manufacturing of the remaining family types**
  - ✓Target data sheets completed
  - ✓Prototypes manufacturing completed
  - ✓Electrical characterization completed => Compliant the preliminary data sheets
  - ✓Radiation testing to be done
  - ✓Delta evaluation to be defined if necessary

- **Complementary activities**
  - ✓Strong involvement of CNES and ESA in the radiation characterization of the prototypes (in progress)
  - ✓Industry provided with samples for benchmarking (in progress)

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ATMEL 0.18 µm CMOS Technology (1/11)

➢**Several contracts placed by CNES and ESA to develop this offering**

- **Amount 6 M Euro (~7 M$) including 50% ATMEL participation**

✓0.18 µm commercial CMOS technology characterization and hardening
- Radiation evaluation of the 0.18 µm technology
- Characterization and capability assessment of the 0.18 µm technology
- ESCC evaluation
- Single event transient sensitivity assessment and circumvention techniques evaluation

✓Product development
- ASIC offering
- SRAM based 280 Kgates FPGA

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ATMEL 0.18 µm CMOS Technology (2/11)

➢**0.18 µm commercial CMOS technology characterization and hardening (1/3)**

- **Radiation evaluation of the 0.18 µm commercial technology**

✓TID assessment
- Around 400 KRad
- Limitation for 1.8 V transistors with W/L < 0.2 which have been excluded
- Limitation for 3.3 V transistors => redesign

✓Heavy ions assessment
- No latch up up to 70 MeV/(mg/cm2)

Activity completed

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ATMEL 0.18 µm CMOS Technology (3/11)

➢0.18 µm commercial CMOS technology characterization and hardening (2/3)

- **Radiation capability and process variation tolerance (TID and SEL) assessment of the 0.18 µm CMOS Technology**
  - ✓3 different lots tested
  - ✓Several lots including process modifications within tolerances have been tested
    - ⇒ Results :
      - -Good capability of the process with respect to the specifications and the design rules
      - -No impact of the process variations (plasma back-end, Shallow Trench isolation, anneal after poly gate)
    - Activity completed

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ATMEL 0.18 µm CMOS Technology (4/11)

➢0.18 µm commercial CMOS technology characterization and hardening (3/3)

- **ESCC evaluation of the 0.18 µm technology using the ATC18RHA library**
  - ✓Construction analysis, electrical tests, thermal tests, mechanical tests, endurance tests
  - ⇒Results :
  - No defect except limitations of 1.8 V I/O to EDC testing
  - These functions have been withdrawn from the ASIC ATC18RHA library.
  - Redesign of these functions now completed.

  Activity completed

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ATMEL 0.18 µm CMOS Technology (5/11)

➢0.18 µm commercial CMOS technology characterization and hardening (4/4)

- **Single event transient sensitivity assessment and circumvention (1/2)**
  - ✓Scope and Objectives : to get an accurate characterization of the Single Event Transients phenomenon for the CMOS .18µm (AT58KRHA) technology
    - - Device simulation using 3D tools, in order to get the characteristics of the current pulse generated in the silicon for the targeted technology.
    - – Design and manufacturing of a test vehicle dedicated to SET assessment. This T.V. will be tested under heavy ions and protons in order to correlate with simulation.
    - – The T.V. also include some patented design techniques (dual stream redundancy) in order to prevent SET propagation.
  - ✓Contract : 5 WPs
  - - feasibility study and work plan
  - - 3D simulation of SET
  - - Design, manufacturing and characterization of the SET test vehicle
  - - Heavy ion and proton testing
  - - Correlation between simulation and experimental results
  - - Proposal for a "SET hardening" option for ATC18RHA ASIC library.

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ATMEL 0.18 µm CMOS Technology (6/11)

➢0.18 µm commercial CMOS technology characterization and hardening (5/5)

- **Single event transient sensitivity assessment and circumvention (2/2)**
  - ✓Status
    - - 3D simulation give very interesting results. Influence of several parameters have been evaluated (T° , process, supply voltage…). Simulation are consistent with available experimental results.
    - - Test Vehicle design achieved during summer 2006. Several variation of the "dual stream redundancy" will be evaluated. Each of these variation provide different compromise in term of velocity, fan out, power and silicon consumption. SET sensitivity of each type of logic gate will also be measured.
    - - Test Vehicle availability expected end of November, first heavy ion test planned in January 2007.
    - - Final report is planned for 2Q2007.

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ATMEL 0.18 µm CMOS Technology (7/11)

➢Product development (1/2)

- **CMOS 0,18µm ASIC for Space (1/2)**

✓Contract

The ATC18RHA Hardened ASIC family development have been funded by ESA and CNES. ESA contract covers standard cell library hardening, CNES contract concerns embedded memory synthesizer and compiler.

- 5 WPs
  - Specification and development plan.
  - Memory Library development.
  - Design, manufacturing and electrical characterization of a test vehicle.
  - Correlation with simulation.
  - Radiation characterization.

✓Status

- ESA and CNES contracts started in January 2003, end in December 2004.
- 2 test vehicles have been manufactured and tested. One dedicated to radiation test of Standard Cell and Memory library, the other dedicated to electrical characterization of I/O buffers, PLL, LVDS and Standard Cell elements.

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ATMEL 0.18 µm CMOS Technology (8/11)

➢Product development (2/2)

- **CMOS 0,18µm ASIC for Space (2/2)**

✓ATC18RHA features

- Up to 5.5Million gates ; 1.8V Core
- Up to 593 I/O, 3.3V I/O (PCI compatible) ; cold sparing capability.
- 655Mbps LVDS buffer.
- Package MQFP256 / 352 ; MCGA472 / 625.
- SEL immune > 70MeV/mg/cm² ; TID > 100kRad parametric (tested no drift at 300krad)

✓SEU performances achieved

Orbit	Compiled SRAM	Compiled SRAM + EDAC	Not hardened Synthesized SRAM	Hardened Synthsized SRAM	Not hardened Flip-flop	Hardened Flip-flop
GEO	$1{,}3.10^{-6}$	5.10^{-10}	4.10^{-7}	$1{,}7.10^{-11}$	7.10^{-7}	9.10^{-10}
LEO 53° - 1000km - Spot	1.10^{-6}	$1{,}2.10^{-8}$	6.10^{-7}	1.10^{-12}	1.10^{-6}	5.10^{-11}
LEO 98° - 852km	7.10^{-7}	4.10^{-9}	3.10^{-7}	4.10^{-12}	5.10^{-7}	2.10^{-10}
LEO 98° - 600km	3.10^{-7}	$1{,}5.10^{-9}$	$1{,}2.10^{-7}$	$2{,}5.10^{-12}$	$2{,}4.10^{-7}$	$1{,}3.10^{-10}$
LEO 51° - 450km - ISS	2.10^{-7}	3.10^{-10}	5.10^{-8}	8.10^{-13}	1.10^{-7}	4.10^{-11}

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ATMEL 0.18 µm CMOS Technology (9/11)

➢Product development (3/5)

- **SRAM Based 280kgates FPGA : ATF280E (1/2)**

✓Features of the new Hardened SRAM based FPGA:

- 0,18µm CMOS 6LM ; 120x120 CoreCell = 280 000 equiv. ASIC Gates.
- 115kbit FreeRAM (32x4 blocs) ; single/dual port ; Sync/Async 10ns SRAM.
- Max 320 I/O (3.3V) ; Core 1.8V ; 8 LVDS Transceiver ; 8 Global clock.
- 100MHz internal speed ; 66MHz I/O (PCI compatible) ; 200MHz LVDS buffers.
- JTAG capability ; real time transparent self-test of configuration integrity.
- Available in MQFP256 and MCGA472 Package.
- Power consumption 1µW/MHz/CoreCell (target)
- SEL immune > 70MeV/mg/cm² ; TID > 100kRad parametric.
- All memory point are hardened (Flip-Flop, config, FreeRam, latch). SEU immunity is expected as high as 80MeV/(mg/cm²) for all memory points, except FF around 40MeV/(mg/cm²).

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ATMEL 0.18 µm CMOS Technology (10/11)

➢Product development (4/5)

- **SRAM Based 280kgates FPGA : ATF280E (2/2)**

✓Contract

– 6 Work packages :

Specification and development plan
Chip design (using AT58KRHA hardened technology)
Design kit development (hardware / software)
Manufacturing, characterization, correlation and validation
EDAC IP development and validation
Pre-industrialization (writing SMD and ESCC detailed spec, manufacturing 1 lot to mil grade with R&R)

✓Status :

Chip design completed, Tape out W41, first silicon mid-December.
Design kit manufacturing coming soon, availability expected in January 2007.
Radiation testing planned Q1/2007
Prototype availability expected in June 2007

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ATMEL 0.18 µm CMOS Technology (11/11)

➢Product development (5/5)

- **New development : SRAM based FPGA on SOI technology (JAXA development)**
  - ✓Feasibility phase in progress thanks to JAXA/CNES cooperation,
  - ✓JAXA, OKI, ATMEL, HIREC and CNES involved,
  - ✓OKI 0.15 µm SOI technology
  - ✓Results of CNES study related to SRAM Based 280kgates FPGA (ATF280E) (architecture, design methodology, tools, …) directly injected in this activity in order to optimize the efforts,
  - ✓Expected 750 Kgates thanks to the technology scaling factor (0.15 µm vs 0.18 µm), and the efficient hardening techniques allowed by the SOI technology,
  - ✓Activity in progress. Completion before the end of this year.

  Next slide presented by JAXA to the last teleconference between JAXA – ESA – DLR – CNES to illustrate this activity

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5.FPGA Feasibility Study between Japan and France

Target Specification

Wafer Process	LET_{th}	Number of Gates	Programming
SOI/0.15um (FDSOI)	64 [MeV/(mg/cm^2)]	700k	SRAM

Schedule(tentative)

Feasibility Study (2006) → Available to Users (2009)

	2006(CY)	2007	2008	2009
JAXA	• Design Rule • Database • Rad-Hard Design	• Demonstration Sample	• Qualification Sample Manufactur • QT	• JAXA QPL/QML
Atmel	• Cell Design • Layout Design • Performance Estimation	• Demonstration Sample	• Development of Software Tools	

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High speed A/D converter evaluation

➢**AT 84AS008 A/D converter**

- **Manufacturer : E2V Grenoble (former ATMEL)**
- **Features of the product :**
  ✓10 bit, 2.2 Gbps
  ✓Power consumption : 4 W
  ✓Differential non linearity : 0.8 LSB
  ✓Signal-to-noise and distortion ratio : 45 DB
- **Contract : 300 K€ (360 K$)**
  ESCC evaluation based on ESCC 2269000 (ETP)
  ✓Electrical characterization
  ✓Construction analysis
  ✓Life test
  ✓Thermal and mechanical tests
  ✓Radiation tests
- **Status**
  The activity is completed. This product is compatible with space applications.

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Conclusions (1/2)

- **The European non dependence in strategic technologies and components is essential for the competitiveness of our space industry,**
  - Equipment manufacturers,
  - Components manufacturers.
- **Examples of CNES activities within the European initiative have been reported**
- **The lessons learned to lead to a success can be listed :**
  - It is necessary for space agencies to commit a continuous financial effort :
    ➢To support the components manufacturers and increase their products portfolio,
    ➢To develop, evaluate the up to date technologies and products,
    ➢To allow these components manufacturers to propose to the space industry performing products at attractive prices.
  - It is also mandatory to get at the earliest the commitment of the users by
    ➢Involving them in the selection at the beginning
    ➢Involving them all along the activity for getting their feedback on the performances vs their needs
  - And be able to readapt the objectives if necessary.

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Conclusions (2/2)

- **And for the future the way forward is a new challenge :**
  - How to gather more financial resources to tackle the very expensive technologies needed ?
  - How to select the strategic products and which is the drivers in terms of projects ?
- **The answer for Europe is the new European Components Initiative (Phase 2) with the following goals :**
  - The extension of the number of space agencies participating to the financial efforts,
  - The better integration of the industry needs,
  - The commitment of the components manufacturers on the decided objectives and actions.
- **The answer outside Europe is strong collaborations with other agencies in order to harmonize the developments and increase the market size :**
  ✓JAXA-CNES on going collaboration is a good example (eg : OKI ATMEL JAXA CNES collaboration for the next FPGA)
- **The targeted technologies/components in the domain of silicon ICs are :**
  - Deep submicron CMOS technologies,
  - High speed serial links (~10 Mbps)
  - High speed low consumption A/D and D/A converters,
  - FPGAs
  - …

  => **For New Generation Telecom payload as projects drivers.**

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Activity Report of Space Electronic Components Subcommittee

October 26, 2006

Kazunori Ohnishi
College of Science & Technology
Nihon University

1. Background of Establishing Space Electronic Components Subcommittee

Reported by NASDA task team on 2002

- Increase in cancellation of certification
- Specificity of space parts compared to general industrial parts:
  - High reliability (radiation, vacuum, and microgravity environments)
  - High-mix low volume production (high price, high risk, maintenance of manufacturing lines)
  - Decrease in professional engineers (technicalconsistency)
  - Overseas product issues (delivery period, EL etc.)
  - Others

Table 1-1. Shipping Status of NASDA Certified Parts (Active)

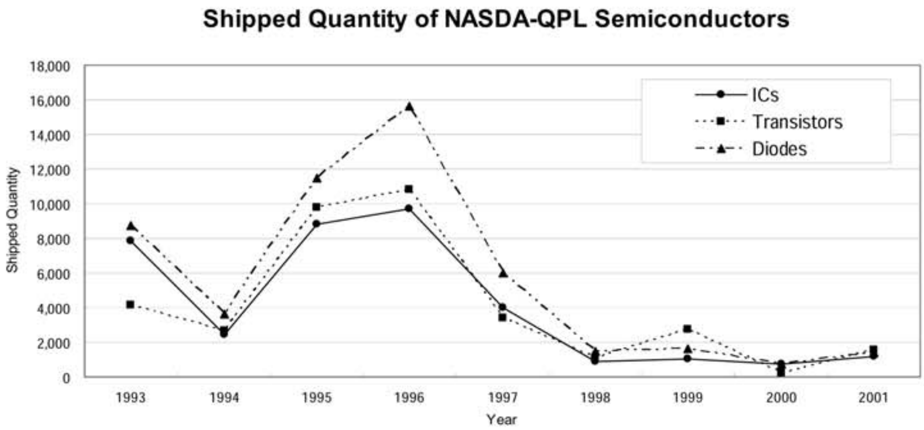
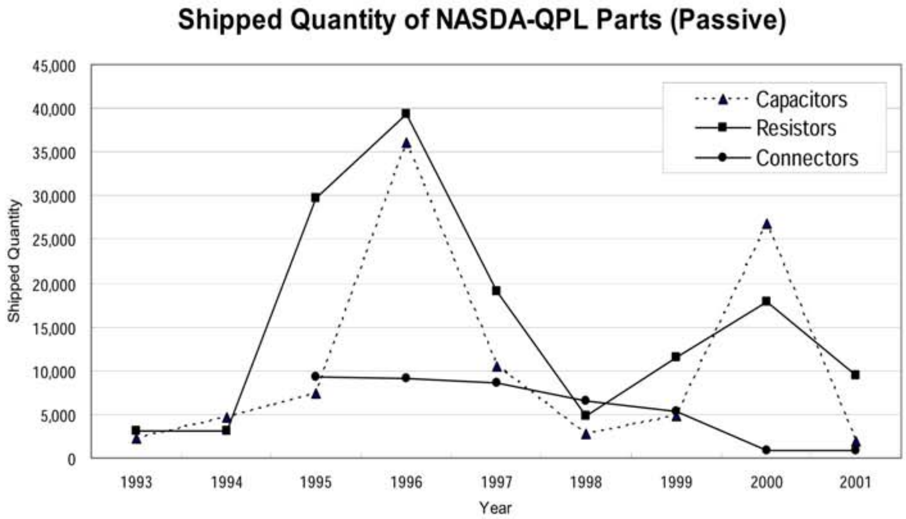
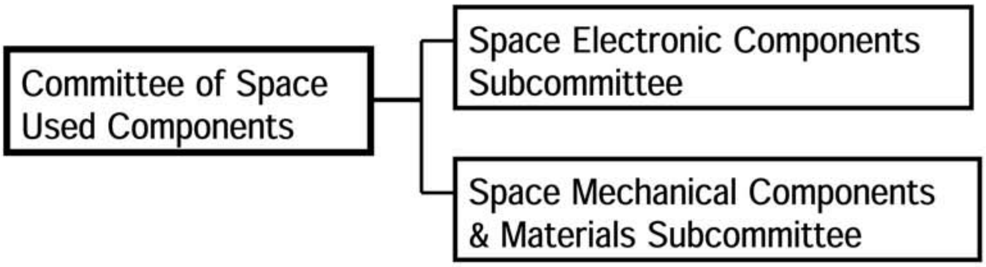


Table 1-2. Shipping Status of NASDA Certified Parts (Passive)



2. System of Space Used Components Committee



3. 10 Recommendations to President of JAXA

1. The importance of components in space technology
2. To keep stable procurement of space used components and progress the component technology
3. Enrich the basic technology and estimation technology of components and data base system
4. Development of Essential Parts

10 Recommendations to President of JAXA (Continue)

5. Supplication and application of developed parts
6. Study of high reliability (radiation effects and application of commercial parts to space use)
7. Estimation process of imported parts
8. Development of frontier parts and progress of the space use parts
9. Verification in space
10. Promoting the registration system of space electronic parts

4. Major Targets

1. Making sure of Reliability
2. Development of essential parts
3. Application of commercial parts to space use

5. Development of Essential Parts

1. Inspection of importance and needs
   (questionnaire survey to manufacturers and users)
2. Making the order of priority
3. Decided at the committee
4. Submit a report to the president of JAXA

6. Critical EEE Parts for Space

In 2003, critical EEE parts for space were selected at the Space Electronic Components Subcommittee.

Items that QT is completed

- High performance 64bit MPU (320MIPS)
- Power MOSFETs (Rad-hard, 100/200/250V)
- DC/DC converters (40W, +/-15V dual output)

Items in design and evaluation phase

- Synchronous Static RAM (36Mbit, 100MHz)
- Programmable device
- Opt-couplers

Candidates for Second Phase

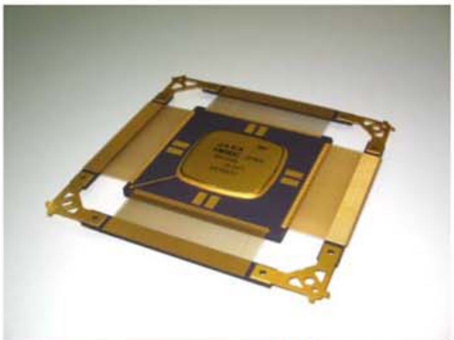
- Mixed Signal LSIs, Power fuses, Crystal Oscillators

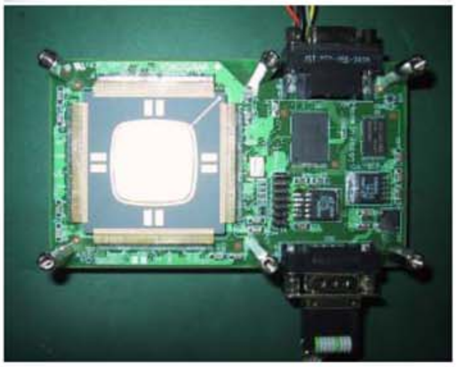
6-1 New 64bit MPU for space

- MIPS64 5kf architecture
- 200MHz (320MIPS)
- On-chip peripherals

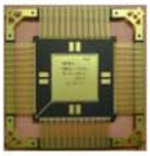
In some missions / components, the evaluation for installing this MPU is advanced.

- SOHLA-1 satellite
- PLANET-C
  (Venus exploration mission, launch schedule : 2008 or later)
- Bepi Colombo
  (Mercury exploration mission , launch schedule : 2009 or later)
- SpaceCube II

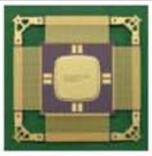




6-2 Performance comparisons of old and new MPU



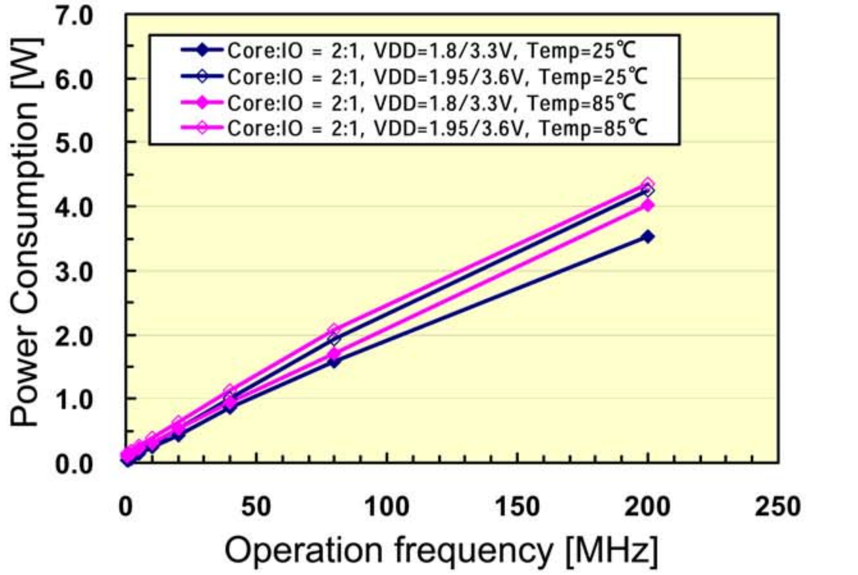
Previous type



New MPU

Items	NASDA R4901-IDFPR	HR5000
Architecture	64bit,RISC,FPU	64bit,RISC,FPU
Performance	40MIPS	320MIPS
Max.Operation frequency	25MHz	200MHz
Process technology	0.35μm	0.18μm
Supply voltage	3.3V	1.8V(core) 3.3V(I/O)
I/O voltage	3.3V/5.0V	3.3V
Power consumption	1.1W(typ.)	2.8W(150MHz 1.8V 85℃) 5.0W(200MHz 1.8V 85℃)
TID	>1kGy(Si)	>1kGy(Si)
SEU	6.5E-4 error/dev/day	1.89E-6 error/dev/day
SEL	>LET 39	> LET 64

6-3 Power consumption of MPU

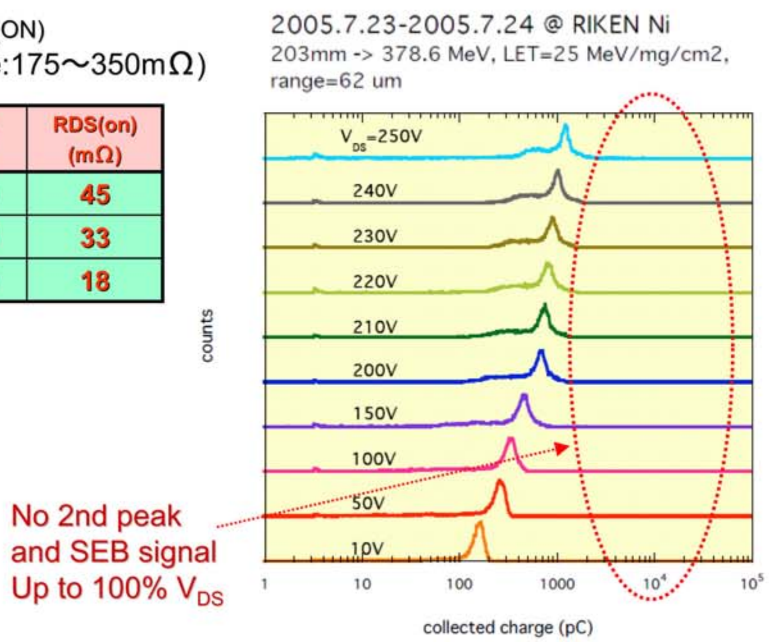


Measurement result of the power consumption when the cache access is continuously repeated.

6-4 New Power MOSFET for Space

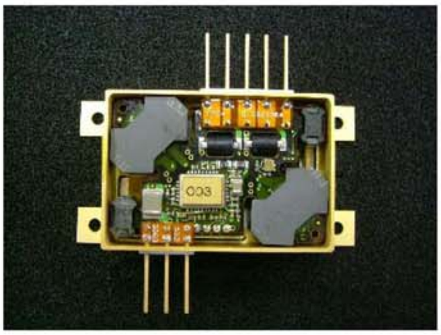
- SEB/SEGR Hardened with patent structure
- Lowest $R_{DS(ON)}$
  (Previous type:175～350mΩ)

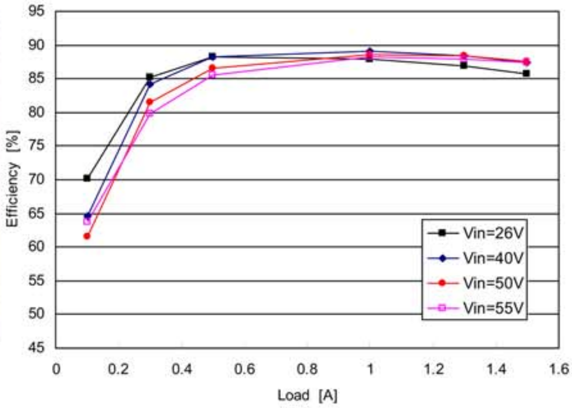
Part Number	VDS (V)	RDS(on) (mΩ)
2SK4054	250	**45**
2SK4051	200	**33**
2SK4048	100	**18**



6-5 New DC/DC converter for space

- Unique structure with no magnet wires for chokes/transformers
- Direct connection to 50V unregulated bus.
- High efficiency (85～90%)





7. Future Activities and Expectation to JAXA

- International Cooperation
- Construction of Space Use Parts Data Base
- The Problem of Lead-Free Solder
- Application of Commercial Parts to Space
- Education

END

Activity Report of Space Mechanical Components & Materials Subcommittee

Toshio HONDA
Tokyo Electronic Systems Corporation
Chairman, Space Mechanical Components & Materials Subcommittee

19th Microelectronics Workshop

October 26, 2006 Tsukuba, Ibaraki, JAPAN

The subcommittee member

Chairman: Toshio HONDA, TokyoElectronic Systems Corporation
Acting chairman: Mineo SUZUKI, JAXA

External member

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Toshio OGATA., National Institute for Materials Science
Katsuhiko AKIYAMA, Mitsubishi Heavy Industries, Ltd.
Hideo OGUCHI, Ishikawajima-hHarima Heavy Industries Co., Ltd.
Masao AKIYAMA, IHI Aerospace Co., Ltd.
Jun NAKAGAWA, Mitsubishi Electric Corporation
Akira SASAKI, NEC TOSHIBA Space Systems, Ltd.
Kazuo NATORI, Mitsubishi Precision Co., Ltd.
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Yoshihide KIYOSAWA, Harmonic Drive Systems Inc.
Tomio NAKATA, Tamagawa Seiki Co., Ltd.
Shohachiro YAMAGUCHI, Nippon Paint Co. Ltd.

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1. Committee on Space Component Technology – History-

(a) Establishment of the Committee

- In response to serious space component problems, such as decline in domestic production, withdrawal of some components from QPL, NASDA Committee on Space Component Technology was established to seek the solution.
- Under the Committee, Space Mechanical Components & Materials Subcommittee was set up (September 2002).
- Secretariat was Office of Research & Development
- The committee issued a report based on discussion in two sub-committees. In the report 10 item recommendations were issued (June 2003).

(b) Establishment of JAXA

- Upon the merge of ISAS, NAL & NASDA into JAXA, JAXA Committee on Space Component Technology was established (October 2003)
- Secretariat was Space Component Engineering Center
- The subjects of the Committee extended, including ISAS & NAL activeties.

(c) JAXA Vision

- JAXA Vision was released (March 2005).

(d) Re-organization of Institute of Aerospace Technology

- R&D groups were re-organized into discipline engineering groups (October 2005)
- Secretariat changed to Electronic, Mechanical Components and Materials Engineering Group.

2. Mechanical components to be developed by JAXA

(1) Frontier components

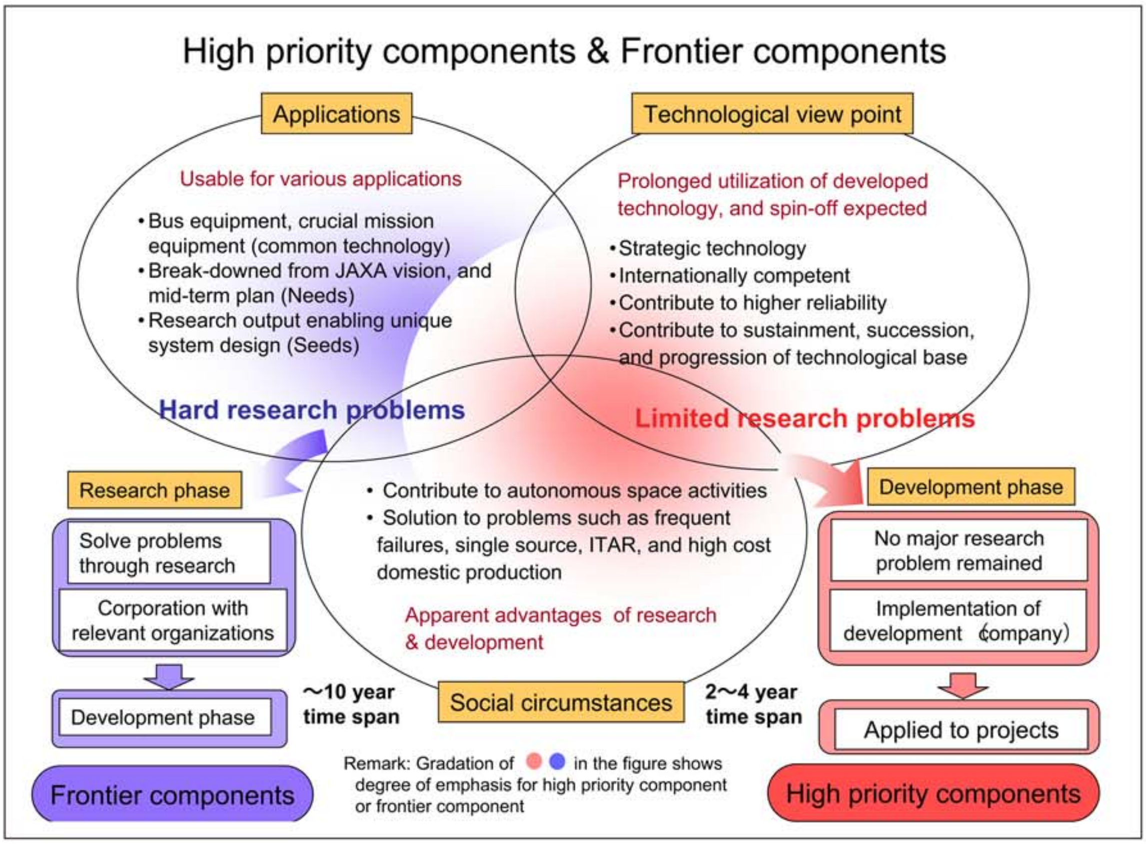
Components which need innovative research to solve technological problems, and to meet future space requirements.

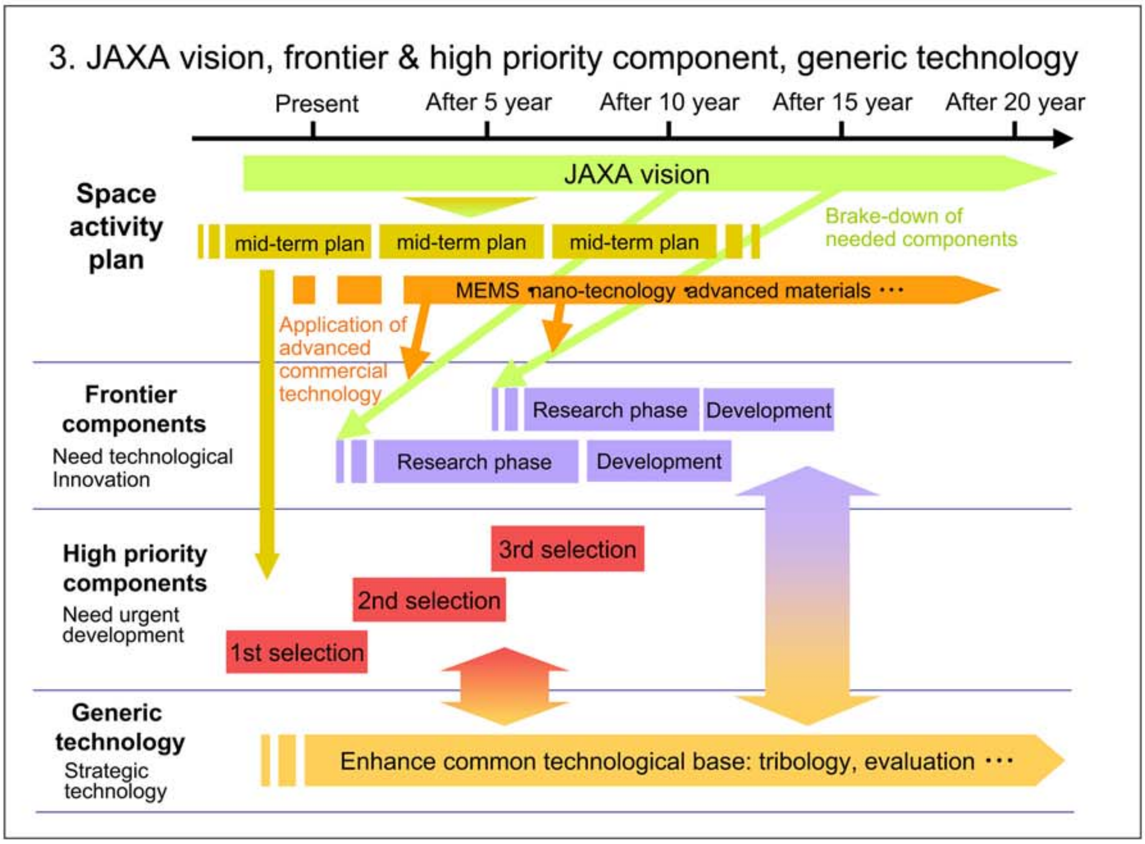
(2) High priority components

Components which
- have problems such as frequent failures, withdrawal from QPL, single source, ITAR, etc., and
- are required urgent development, and
- are expect to be used in various applications for prolong period.

(3) Generic technology

Strategic technology which Japan should keep for steady and advanced space development. Through R&D activities, technology level will be kept, handed to next generations, and improved.


High priority components & Frontier components
Applications
Technological view point
Usable for various applications
•Bus equipment, crucial mission equipment (common technology)
•Break-downed from JAXA vision, and mid-term plan (Needs)
•Research output enabling unique system design (Seeds)
Prolonged utilization of developed technology, and spin-off expected
•Strategic technology
•Internationally competent
•Contribute to higher reliability
•Contribute to sustainment, succession, and progression of technological base
Hard research problems
Limited research problems
Research phase
Solve problems through research
Corporation with relevant organizations
Development phase
• Contribute to autonomous space activities
• Solution to problems such as frequent failures, single source, ITAR, and high cost domestic production
Apparent advantages of research & development
Development phase
No major research problem remained
Implementation of development (company)
Applied to projects
~10 year time span
Social circumstances
2~4 year time span
Remark: Gradation of in the figure shows degree of emphasis for high priority component or frontier component
Frontier components
High priority components


3. JAXA vision, frontier & high priority component, generic technology
Present
After 5 year
After 10 year
After 15 year
After 20 year
Space activity plan
JAXA vision
mid-term plan
mid-term plan
mid-term plan
Brake-down of needed components
MEMS nano-tecnology advanced materials ···
Application of advanced commercial technology
Frontier components
Need technological Innovation
Research phase
Development
Research phase
Development
High priority components
Need urgent development
3rd selection
2nd selection
1st selection
Generic technology
Strategic technology
Enhance common technological base: tribology, evaluation ···

Function enhancement of Latching Valve

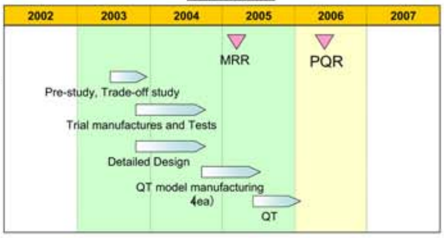
High-priority components
1st selection

- Post Qualification test Review was done successfully. (August.11.2006)
- Function enhancement was accomplished in accordance with design strategy that is to take over the Pedigree design, drawings, production and inspection process.
- JAXA will carry out further evaluation tests in order to accumulate technical data.
- Now on sale!

Difference between Current valve and Enhanced valve

Item	Current LV	**Enhanced LV**
Reverse Cracking Pressure *(ID of Outer nozzle)*	*Unregulated* *2.238mm² (φ4.90mm)*	*1.38MPa(nominal)* *3.490mm² φ5.06mm)*
Test fluid of Internal leakage	*GN_2*	*GHe*
Development Framework	*JAXA／IHI／Moog Japan*	*JAXA／Moog Japan* *※Development efficiency improvement*
Special affairs	*・Inheritance of Pedigree design, drawings, production and inspection process* *・Valve capability confirmation test (Mechanical environment, e,g, Shock, Random vibration)* *・Valve cost 15%OFF because of Development framework optimization*	

Schedule



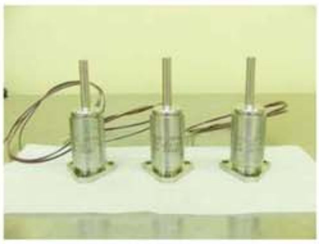
20N-class Thruster valve

High-priority components
1st selection

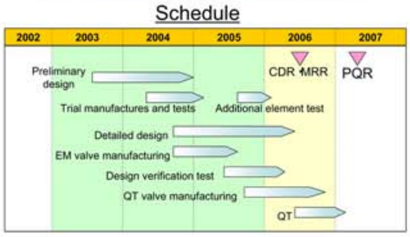
- Critical Design Review is scheduled to be held in this October. The manufacturing documents are prepared.
- In order to create a "ROBUST" valve, the Japanese methodology of quality and reliability control engineering was applied from the beginning stage of development. (TOYOTA's design method / TAGUCHI Method with CAE)

Typical performance specification

Item	Development specification	Remarks
Compatible fluid	*N_2H_4,MMH,GHe,GN_2,H_2O,IPA*	
MEOP	*2.80MPa*	
Proof／Burst Pressure	*7MPa / 10MPa*	*Test of surge pressure*
Pressure drop	*≦0.172MPa @12.7g/sec H_2O*	
Internal leakage	*≦1×10^{-5}scc/min @MEOP,GHe*	
Operating Voltage	*23.5 ～32 Vdc*	
Coil resistance	*65 ohm ±10% @20degC*	
Response (Opening)	*≦15msec @28Vdc,MEOP,20degC*	
Cycle life	*≧1,000,000 cycle @Wet&Dry*	*Confirmation of capability*
Temperature range	*4 ～149degC @Operating*	*Confirmation of High tmp capability*
Weight	*≦0.30kg*	



Schedule



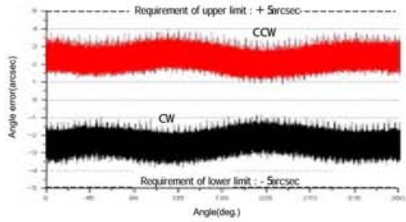
Resolver

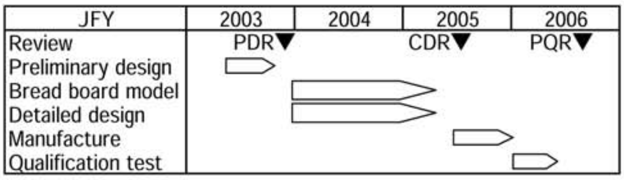
High-priority components
1st selection

•Post-Qualification Review & Final Revew was done successfully.
(July.24.2006)

Qualification test model

Description	Resolver	Optical encoder
Outer shape Diameter	125 mm	137 mm
Width	67 mm	79 mm
Bore Diameter	18 mm φ	—
Sensing method	Electromagnetic induction	Optical
Angular accuracy	<±0.0015°(±5arcsec)	<±0.0015°(±5arcsec)
Resolution	21 bit	18 bit
Mass	<2.0kg (.82kg)	<2.2kg
Power	<2.6W (2W)	<5W
Input/Output	Differential type (EIA RS422)	Differential type (EIA RS422)





•Results of Accuracy qualification test
•Worst case is Low temp.condition (-30deg)
•All data are within an accuracy requirement (±5arcsec)
•Now on sale!

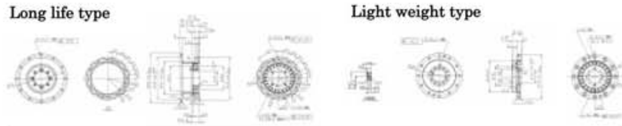
CW : Clock-wise
CCW : Counter clock-wise

Harmonic Drive Gear

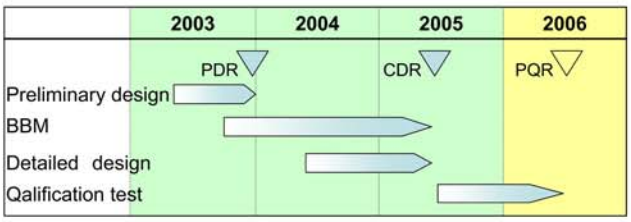
High-priority components
1st selection

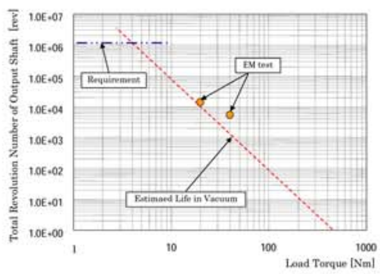
•Under life testing (Long life type)

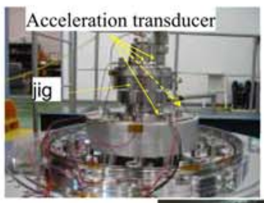
Long life type　　Light weight type



Item	Long life type	Light weight type	Existing product
Dimension	82φ×30.4L	70φ×14.0L	70φ×35.0L
Mass	221g	103g	370〜300g
Lifetime	10^6 rev.	100 rev.	app.10^5 rev.
Lubricant	Synthetic Hydro-Carbon oil, grease		Solid lubricant
Angle transfer rate	< 30arc-sec	< 60arc-sec	< 30arc-sec
Operating temperature	−10〜+80℃	−30〜+80℃	−10〜+80℃

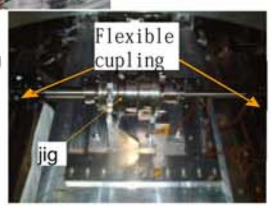






Vibration test

Thermal vacuum test

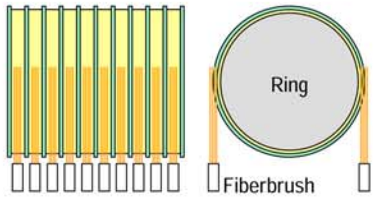


Components to be developed

High-priority components
2nd selection

Two items were selected as having high priority to be developed. Now, cooperative research is under way.

(1) Slipring
- Research status: Evaluation is under way to select appropriate brush, ring & plating materials
- Application: Solar array drive mechanism (SADM)
- Purpose: Small, light-weight SADM
- Point of development: High reliability & low cost



Fiberbrush type slipring

(2) Low shock hold-down & release mechanism
- Research status: Preliminary operation tests were perfomed. International cost competition is a problem. Target cost is in consideration.
- Application: Hold-down & release mechanism for Solar array paddle (SAP)
- Purpose: Reduction of release shock for SAP
- Point of development: Unique mechanism & high reliability


A model for preliminary laboratory test

4. JAXA's activities on space materials

A variety of materials have been used for space applications to meet the requirements of projects. New materials are sometimes adopted. Establishment of evaluation technology about space environment for many types of space materials is important.

(1) Present major activities
- Evaluation of compatibility of materials to space environment
  * Modified thermal control films for superior durability & higher performance
  * Imported electric wire sheath materials (polymers)
  * Commercially available high performance paints, adhesives, etc.
- Materials Database System
  Obtained data are registered in a database (http://matdb.jaxa.jp), and open to public.

(2) Planned activities
- Continue evaluation of space compatibility for imported materials
- R&D for advanced new materials, such as electrically conductive thermal control polymer films, superior durability & higher performance materials.
- Improve evaluation technique, compile characteristics of materials

5. Problems related to Space Mech. Comp. & Materials Subcommittee

(1) Definition of Mechanical Components

The word “mechanical component” is interpreted in several ways: (a)mechanical parts such as springs, (b)mechanical element such as ball bearings, (c)mechanisms such as flywheels. The sub-committee covers all of (a)-(c) & related basic technology such as tribology, without clarifing the definition of “component”.

(2) Subjects of the sub-committee expanded

Due to the merge of ISAS, NAL, NASDA into JAXA, components for ISAS’s scientific satellite, and basic research at NAL became the subjects discussed in the sub-committee.

(3) Requirements for mechanical components

Needed future mecahnical components should be extracted from JAXA Vision. To set the requirements for the components, system design is mandatory. This task is insufficient.

(4) Enhanced secretariat

From October 2005, a discipline engineering groups (Electronic, Mechanical Components and Materials Engineering Group) became secretariat. The subjects of the sub-committee is far beyond the group’s activities. Participation of related groups in the sub-committee is needed.

発表資料

ワークショップ 2日目

平成18年10月27日（金）

Development Status for JAXA Critical Parts, 2006

October 27, 2006

Electronic, Mechanical Components and Materials Engineering Group, JAXA

Satoshi Kuboyama

Background

- Increased demands for high performance space systems
- Increased cost for LSI fab.
- Decreased availability of cutting edge devices for space applications

Mismatch of demand and supply

Critical parts for space systems were selected to develop advanced space systems by Space Parts Engineering Committee

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Critical Parts (First Phase Items)

	FY2003	FY2004	FY2005	FY2006	Remarks
64bit MPU	Evaluation ▲ES	▲QT sample	QT	Completed	Commercial Foundry
DC/DC Converter	Production for QT		QT	28V input	In-process Element Screening
POL, DC/DC Converter				Feasibility Study	Low voltage distributed power system
Power MOSFET	Evaluation ▲Shipped for DC/DC	Production for QT	QT	500V New Package	Mixed Device Production
32M bit Burst SRAM	Feasibility Study	Design	Evaluation	3D Packaging	Commercial Foundry
SOI ASIC		Basic Evaluation	Feasibility Study	Cell Library	Commercial SOI Foundry
SOI FPGA				Feasibility Study	With ATMEL (France)

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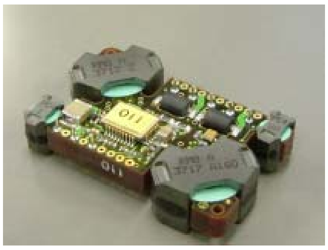
DC/DC converter

- Unique structure with no magnet wires for chokes/transformers
- Direct connection to 28V/50V unregulated bus
- Synchronous rectification for high efficiency



☑ QT was successfully completed except RGA. RGA failure was resulted by incorrect test method. RGA will be completed by the end of FY2006.

☑ The variant for 28V input will be additionally qualified by the end of FY2006

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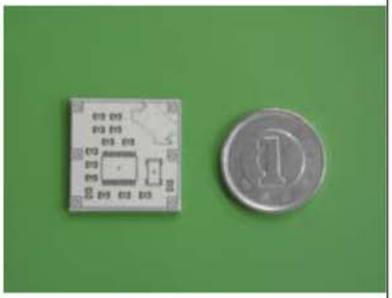
POL type DC/DC converter

- Unique structure with no magnet wires for chokes, extremely small outline for distributed power system
- Direct connection to +15V output of DC/DC converter to produce 1.5V, 1.8V……..
- Synchronous rectification for high efficiency, 95%



☑ Feasibility study is started to establish the target specification and development schedule

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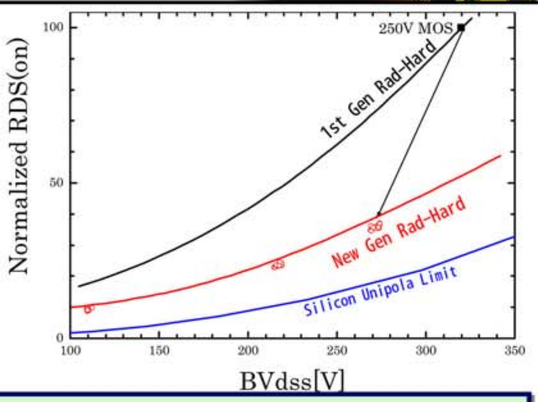
Power MOSFETs

- SEB/SEGR Hardened up to 100% $V_{(BR)DSS}$
- Lowest $R_{DS(ON)}$
- Patented structure



☑ QT for 100/200/250V devices was successfully completed by the end of FY2005 with TO-254 package.

☑ Radiation hardness was successfully demonstrated for 500V prototype devices

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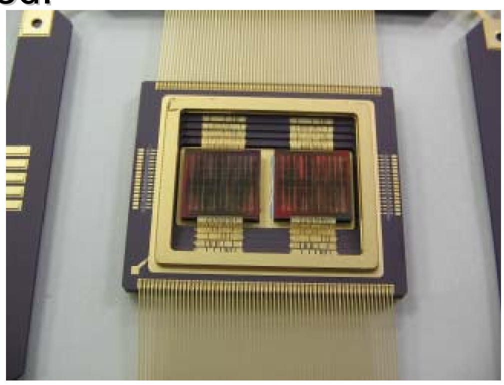
Burst SRAM

- 100MHz synchronous operation for high performance 64bit microprocessor.
- Separated address decoders and cell blocks to prevent multi-bit SEUs in a word. It ensures that all errors are correctable by the EDAC on the MPU.
- High density
  - 36Mb, 72(64 data and 8 ECC)-bit x 512k-word
  - 20Mb, 40(32 data and 8 ECC)-bit x 512k-word

Burst SRAM (Cont.)

- 0.18μm commercial process with patented HBD (hardness-by-design) technology for control logic.
- Mixed production with high performance 64bit MPU
- Design was finalized for QT and the 3D packaging structure was demonstrated.
- 3D packaging process will be established by the end of FY2006.
- QT completion is targeted early FY2007.



SOI ASIC

- 0.15μm commercial FDSOI foundry with patented SET/SET free primitive circuits
- 1.5V for core and 3.3V for I/Os.
- SEU/SET hardened cell library will be available by the end of FY2006.

- SEU/SET : SEU/SET free up to LET of 64MeV/(mg/cm^2).
- TID : 30krad(Si). Package with radiation shielding is available for higher TID requirements.

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SOI FPGA

- 0.15μm commercial FDSOI foundry with patented SEU/SET free primitive circuits.
- 1.5V for core and 3.3V for I/Os.
- 700k ASIC gates.
- Rad-hard RAM based reconfigurable FPGA.
  - No need of periodic scrubbing

- SEU/SET : SEU/SET free up to LET of 64MeV/(mg/cm^2).
- TID : 30krad(Si). Package with radiation shielding is available for higher TID requirements.

Electronic, Mechanical Components and Materials Engineering Group

Candidates for Second Phase

Critical parts to be developed in second phase were discussed at the Space Parts Engineering Committee. Discussion has been started with ESA and CNES for possible collaborations for these devices.

Candidates are:

- Mixed Signal LSIs
- Power fuses
- Crystal Oscillators

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Conclusions

- For MPU, power MOSFET and DC/DC converter, QTs were completed by the end of FY2005.
- Developments for POL type DC/DC converter and FPGA were started as feasibility studies.
- Candidates for the second phase were discussed at Space Parts Engineering Committee. Discussion has been started with ESA and CNES for possible collaborations for these devices.

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Establishment of LSI Production System Adopting COT for Space Application

Oct. 27th, 2006

Mikihiko URANO
High-Reliability Engineering & Components Corporation

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1.Background (cont.)

- Customers can produce LSI speedy, simply, inexpensively.
  - Customers can produce LSI using commercial foundries, and do not need to have their own production lines of LSI.
  - Customers can design the mask layout to fabricate LSI wafers by themselves.
    - Design rules of the mask layout can be provided by foundries.
    - CAD (computer-aided design) tools can be utilized to generate the mask layout.
  - Customers can realize the complex system by using IP (Intellectual Property) on a chip.

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2.Feature

- LSI production system adopting COT (Customer Owned Tooling) for space application are :
  - Cell layouts (F/F, Latch, etc.) in the mask are introduced by HBD (Hardness-by-Design) method against for SEU/SET.
  - Two or more LSIs can be placed on the same mask and fabricated on the wafer (Multi-project-run method).
  - Specialized companies (Foundry, Assembly House and Test Laboratory) handle each step of LSI production process.
  - The quality assurance company integrates specialized companies and assures the quality and the reliability of LSI for space application.

- The wafer banking can supply LSI stably for the long term to customers.

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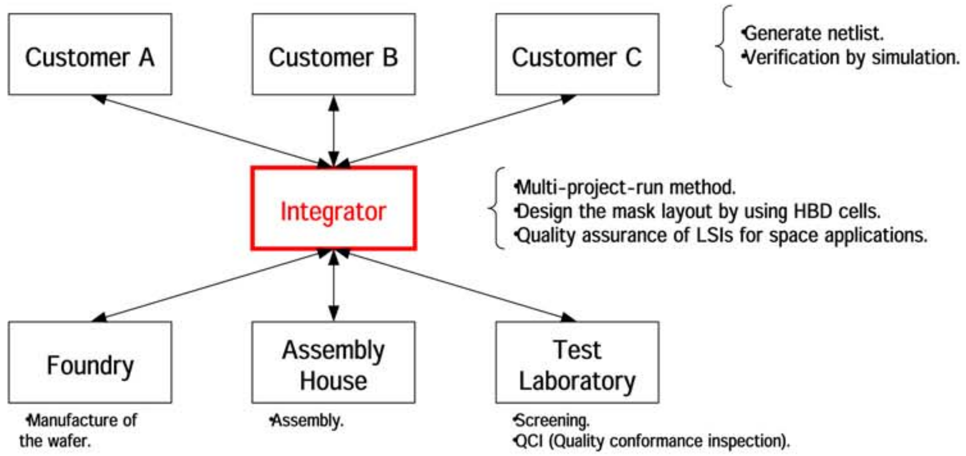
3. Establishment

3.1 LSI production system adopting COT



Relationship among Customers, Integrator, Foundry, Assembly House and Test Laboratory of LSI production system adopting COT

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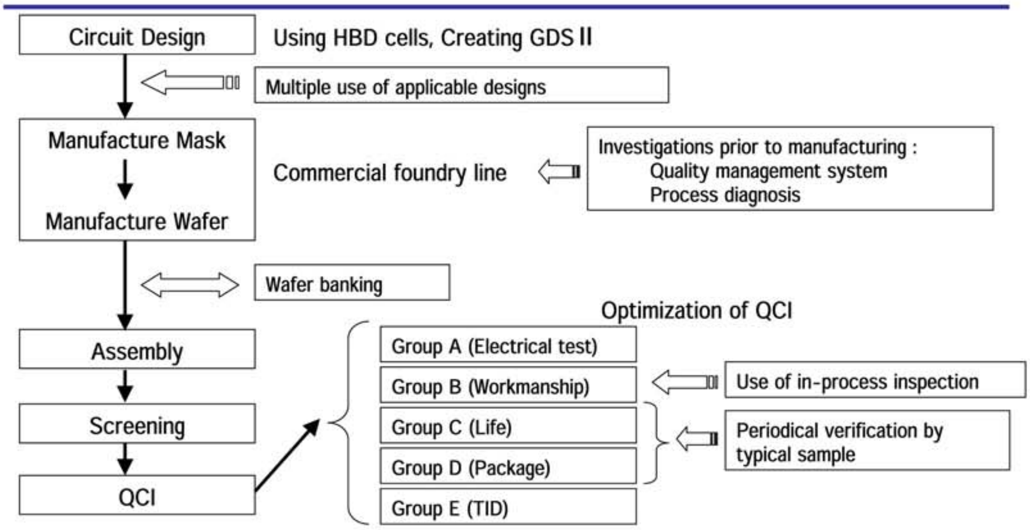
3. Establishment

3.1 LSI production system adopting COT (cont.)



Flow of LSI production system adopting COT

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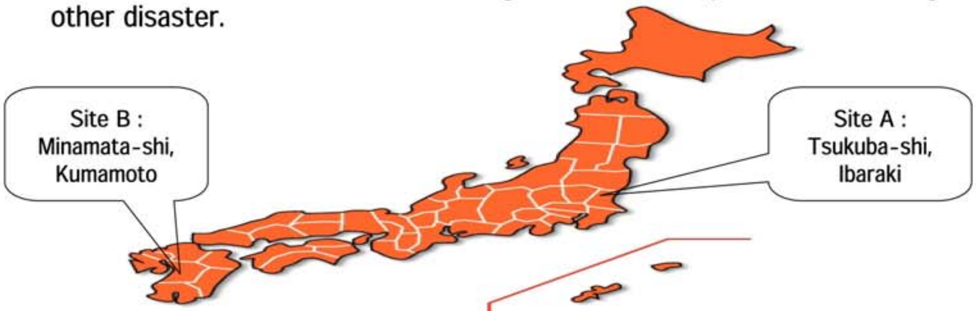
3. Establishment

3.2 Wafer banking

- There are two sites of wafer storage facilities in JAPAN.
  - Two sites reduce risks of wafer damage such as earthquakes, fires, or any other disaster.



	Temperature	Related humidity	Atmosphere
Site A	15℃ to 35 ℃	30% or less	N_2 gas
Site B			Dry air

Sites and conditions for storage of the wafers

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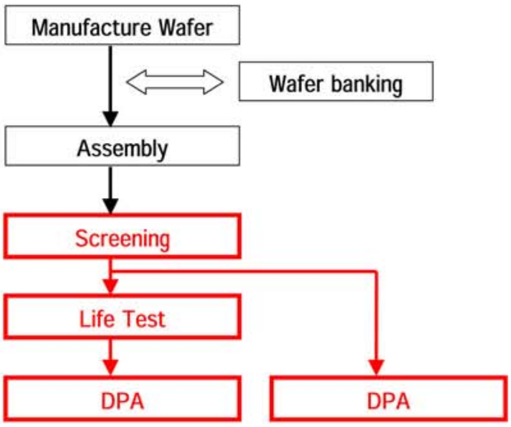
3. Establishment

3.2 Wafer banking (cont.)

Evaluation flow :Screening, Life Test and DPA



Screening

	Item	Conditions
1	Temperature cycling	-65℃ to +150℃, 10 cycle
2	Interim (pre burn-in) electrical parameters	Room temperature
3	Burn-in test	125℃, 240 hours
4	Interim (post burn-in) electrical parameters	Room temperature
5	Final electrical parameters	Low and High temperature
6	External visual	

Life Test

	Item	Quantity	Conditions
1	Steady state life	22	125℃, 1000 hours
2	End-point electrical parameters	22	

DPA

	Item	Quantity	Conditions
1	Internal visual and mechanical	3	
2	Bond strength test	3	
3	Die shear test	3	

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4. Results

4.1 LSI production system adopting COT

- 320MIPS 64bit MPU was developed with LSI production system adopting COT for space application, and was fully successed in the development test (equivalent to QT) in accordance with JAXA-QTS-2010.
- 320MIPS 64bit MPU is going to be qualified to JAXA QML products in accordance with JAXA-QTS-2010 by the end of Nov. 2006.
  - JAXA 2010/10101XZR for Low-power consumption type.
  - JAXA 2010/10102XZR for High-speed type.

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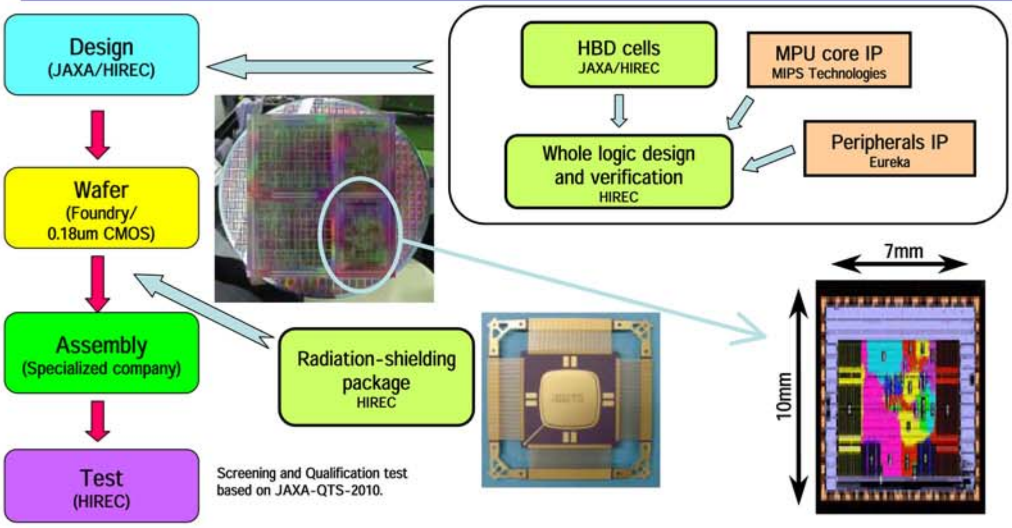
4. Results (cont.)

4.1 LSI production system adopting COT



LSI production system adopting COT for 320MIPS 64bitMPU

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4. Results (cont.)

4.2 Wafer banking

- The long term storage of the wafers started in Feb. 2004.
- 1st evaluation tests of the wafers prior to the storage were performed on:
  - Wafer A (0.8um, Bulk, CMOS)
  - Wafer B (0.18um, Epi, CMOS)

Storage and 1st Evaluation Test on Wafers

Wafer	Storage		1st Evaluation Test	
	Started in	Quantity	Complete	Quantity
Wafer A	Feb. 2004	20 wafers	Mar. 2005	1 wafer
Wafer B	Jan. 2005	12 wafers	Feb. 2006	1 wafer

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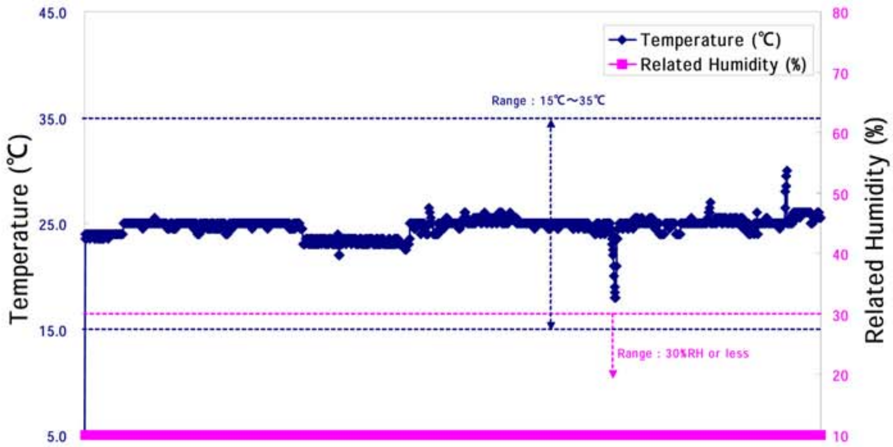
4. Results (cont.)

4.2 Wafer banking (cont.)



Temperature and Related Humidity data of Site B

HIREC-TD-E06041

4. Results (cont.)

4.2 Wafer banking (cont.)

Summary of 1st Evaluation test on Wafer B

Result of Screening

	Screening item	Results: Accept	Results: Reject
1	Temperature cycling	100	0
2	Interim (pre burn-in) electrical parameters	100	0
3	Burn-in test	100	0
4	Interim (post burn-in) electrical parameters	100	0
5	Final electrical parameters	100	0
6	External visual	99	1 (1)

Note (1) Lead with depression.

Result of Life test

	Life test item	Results: Accept	Results: Reject
1	Life test	25	0
2	End-point electrical parameters	25	0

Result of DPA for the samples after completion of screening

	DPA item	Results: Accept	Results: Reject
1	Internal visual and mechanical	3	0
2	Bond strength test	3	0
3	Die shear test	3	0

Result of DPA for the samples after completion of Life test

	DPA item	Results: Accept	Results: Reject
1	Internal visual and mechanical	3	0
2	Bond strength test	3	0
3	Die shear test	3	0

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5. Maintenance

5.1 LSI production system adopting COT

- Established LSI production system adopting COT for space application will be maintained.
  - The typical samples will be manufactured and evaluated for the periodical QCI (Group C and D).
- More LSIs will be produced in the system:
  - Burst SRAM (same design rule as 320MIPS 64bit MPU)
  - SOI ASIC

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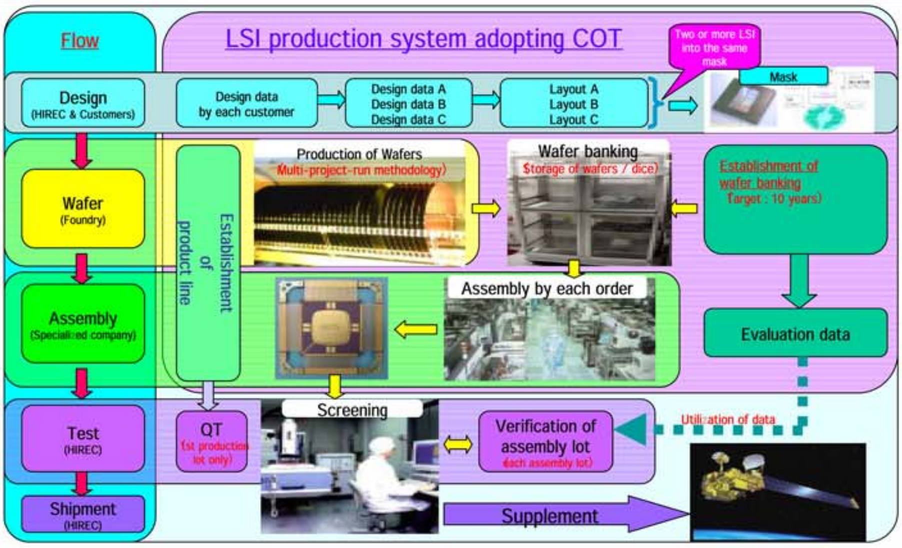
5. Maintenance (cont.)

5.1 LSI production system adopting COT (cont.)



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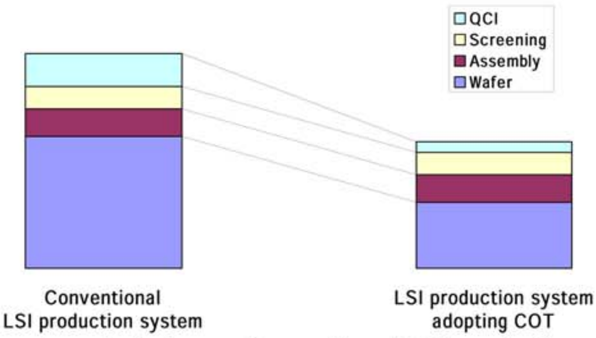
5. Maintenance (cont.)

5.1 LSI production system adopting COT (cont.)

- Cost can be reduced by applying LSI production system adopting COT.



Comparison of costs between Conventional LSI production system and LSI production system adopting COT

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5. Maintenance (cont.)

5.2 Wafer banking

- Wafers will be evaluated periodically.
  - At the beginning of storage.
  - 2, 4, 7 and 10 years after storage.
- Other wafers (different design rule, substrate, etc.) will be evaluated for the evaluation for long term storage.

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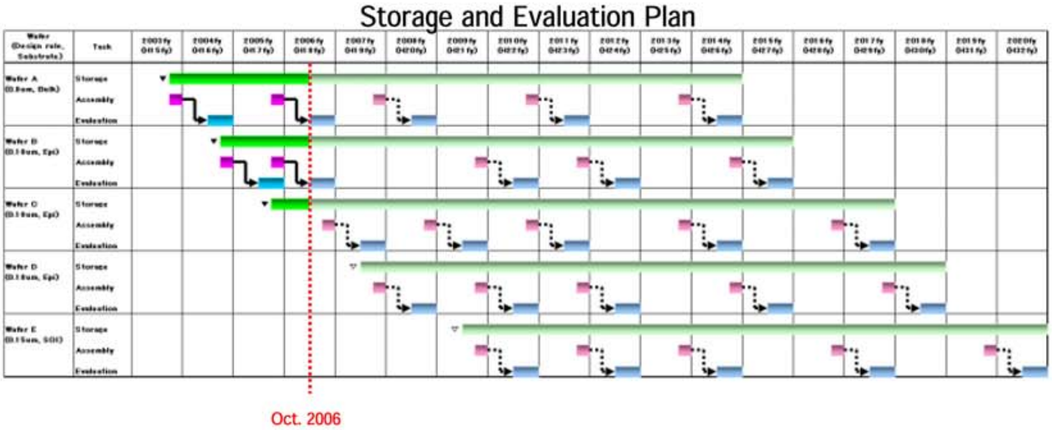
5. Maintenance (cont.)

5.2 Wafer banking (cont.)

Storage and Evaluation Plan



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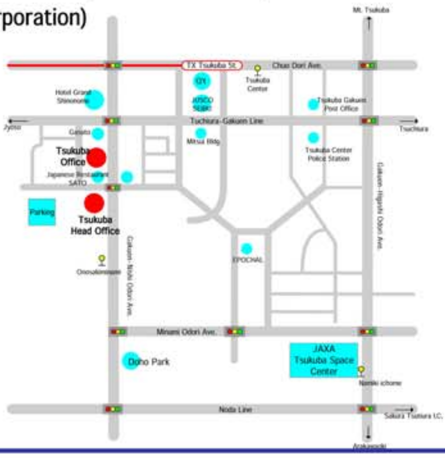
6. Information

- HIREC changed the company name on Oct. 25th, 2006.
  - High-Reliability Engineering & Components Corporation

  (Formerly: High-Reliability Components Corporation)
- HIREC homepage :
  - http://www.hirec.co.jp



19th MICROELECTRONICS WORKSHOP

Page 20

OKI

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OKI FD-SOI TECHNOLOGY

- Fully Depleted SOI for Ultra Low Power and Radiation Hardness-

October, 27th, 2006

Semiconductor R&D Division

Semiconductor Business Group

Oki Electric Industry Co., Ltd.

1

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Contents

 2

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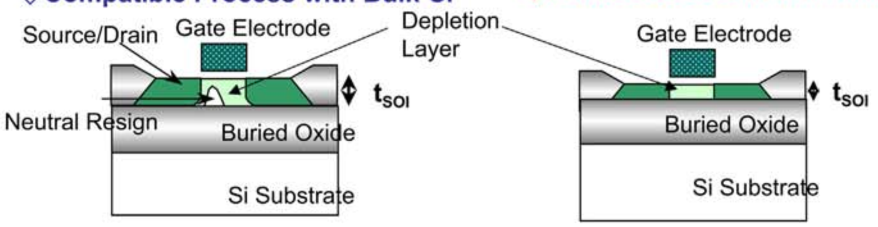
PD-SOI vs FD-SOI

PD-SOI (Partially Depleted)

◆Thick SOI Thickness t_{SOI})
～0.1- 0.2um
◆Depletion Layer < T_{SOI}
↓
◇Large Floating body effect
◇High Drive Current by Kink effect
→ High speed application
◇Compatible Process with Bulk-Si

FD-SOI (Fully Depleted)

◆Thin SOI Thickness t_{SOI})
< 0.05um
◆ Depletion Layer > T_{SOI}
↓
◇Less Floating body effect
◇Better Subthreshold Slopes
→ Low-V_{th} is available
◇Process Issues in thin-film SOI



Oki chooses FD SOI with the advantage of low voltage operation

 OKI CONFIDENTIAL 3

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Why OKI selected FD-SOI?

Features of FD-SOI

✓Low Parasitic Source/Drain cap.
✓Near-ideal Subthreshold Slope
✓Small Substrate Bias Effects
✓Small Floating Body Effect
✓Low temp. Coefficient
✓Simple & Complete Isolation
High-Q, High Fmax on High-R Sub.
✓Low NF

⇩

Suitable Area of FD-SOI

✓Low voltage (Low operating Power)
$P = f \cdot C_L \cdot V_{dd}^2$
with ultra low stand-by power
✓RF & Analog Integration
✓High Temperature & Rad Hardness

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Current Status of PD-SOI and FD-SOI

◆ PD-SOI (Partially Depleted)

High-speed microprocessors

- IBM: PowerPC and mainframe CPU's
- Free scale: PowerPC
- AMD: Athlon processors
- Sony (with IBM and Toshiba) : Cell, PS3

◆FD-SOI (Fully Depleted)

Low-power application

- Oki: solar cell watch, long-wave RF decoder

Technology Node option beyond 32nm (R&D)

- Intel, many major companies

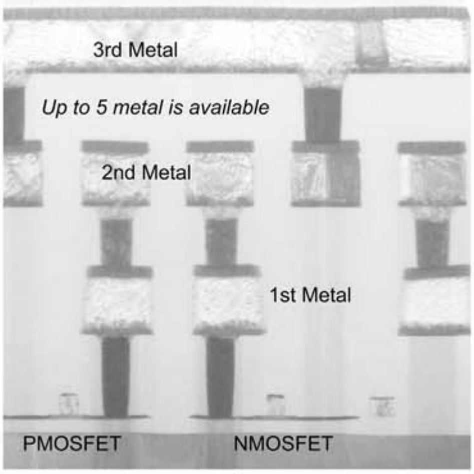
At present, only Oki has an experience of mass production of FD-SOI

 5

OKI

Oki FD-SOI Device Structure & Process

Cross-section TEM of 0.2um SOI



○Lpoly = 0.2 mm ○SOI Thickness under Gate = 50nm

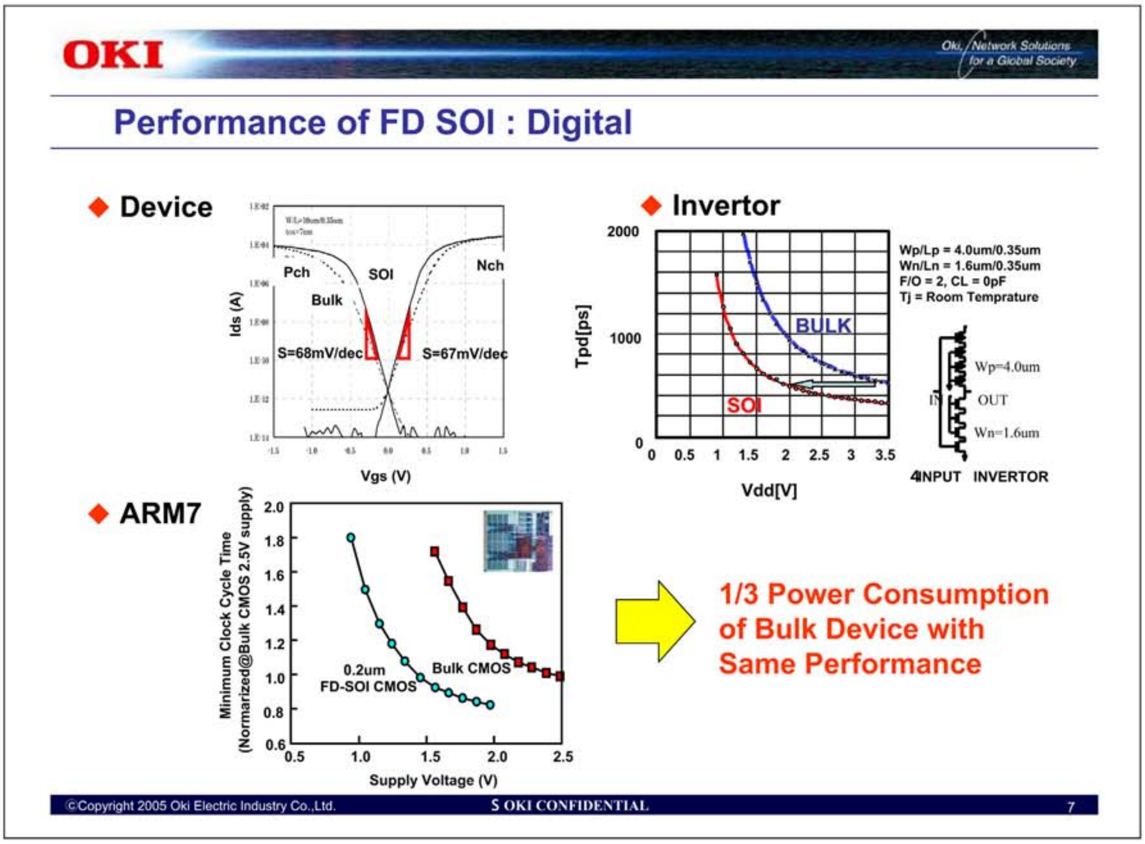
Substrate : BONDED WAFER

◆0.35um SOI Process
- Gate length : 0.35um
- Gate Oxide thickness : 7nm
- Wiring Pitch : 1.4um

◆0.2um SOI Process
- Gate length : 0.2um
- Gate Oxide Thickness : 4.5nm
  4.5nm/7nm for 3.3V
- Wiring Pitch : 1.0um
- MIM, Inductor

◆0.15um SOI Process (shuttle)
- Gate length : 0.14um
- Gate Oxide Thickness : 2.5nm
- Wiring Pitch : 0.52um
- MIM, Inductor

 6


OKI
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Performance of FD SOI : Digital
Device
Pch
SOI
Nch
Bulk
Ids (A)
S=68mV/dec
S=67mV/dec
Vgs (V)
Invertor
Tpd[ps]
2000
1000
0
BULK
SOI
0 0.5 1 1.5 2 2.5 3 3.5
Vdd[V]
Wp/Lp = 4.0um/0.35um
Wn/Ln = 1.6um/0.35um
F/O = 2, CL = 0pF
Tj = Room Temprature
Wp=4.0um
IN
OUT
Wn=1.6um
4INPUT INVERTOR
ARM7
Minimum Clock Cycle Time (Normarized@Bulk CMOS 2.5V supply)
2.0 1.8 1.6 1.4 1.2 1.0 0.8 0.6
0.2um FD-SOI CMOS
Bulk CMOS
0.5 1.0 1.5 2.0 2.5
Supply Voltage (V)
1/3 Power Consumption of Bulk Device with Same Performance
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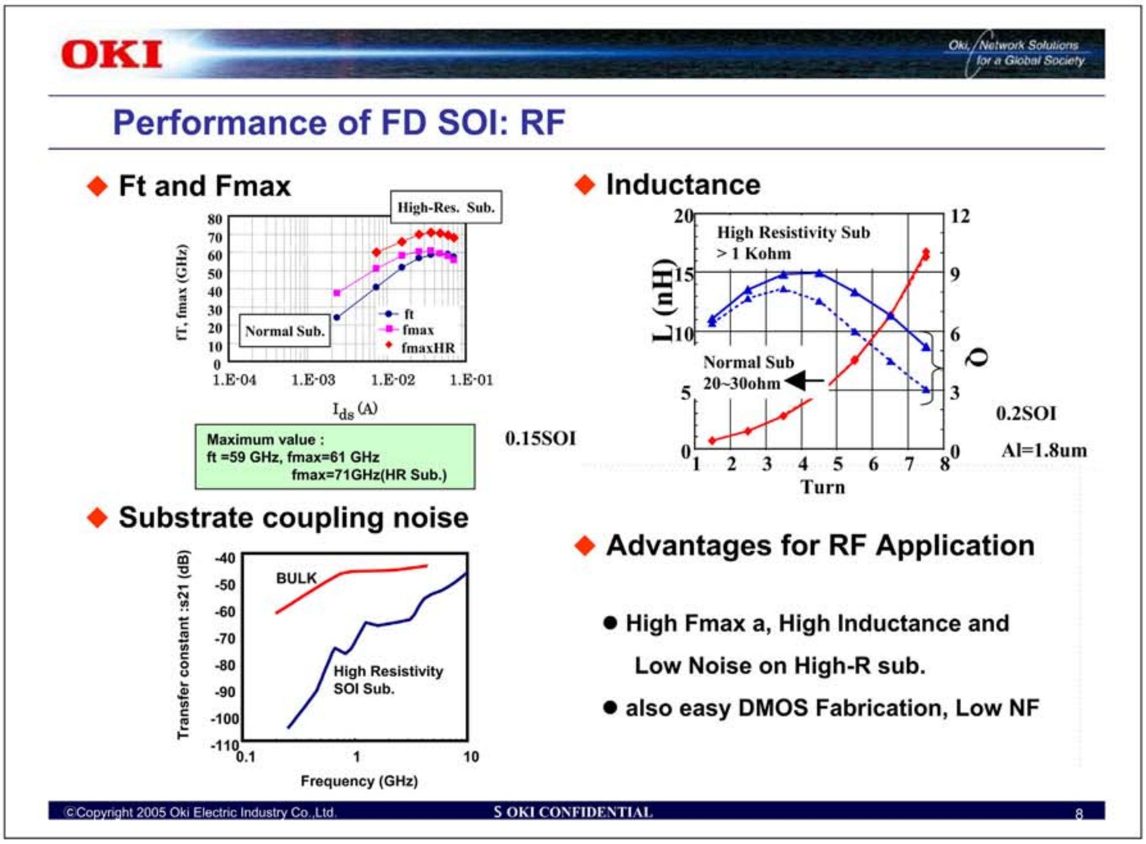
OKI
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Performance of FD SOI: RF
Ft and Fmax
High-Res. Sub.
fT, fmax (GHz)
80 70 60 50 40 30 20 10 0
Normal Sub.
ft
fmax
fmaxHR
1.E-04 1.E-03 1.E-02 1.E-01
Ids (A)
Maximum value :
ft =59 GHz, fmax=61 GHz
fmax=71GHz(HR Sub.)
0.15SOI
Inductance
High Resistivity Sub
> 1 Kohm
L (nH)
Q
Normal Sub
20~30ohm
20 15 10 5 0
12 9 6 3 0
1 2 3 4 5 6 7 8
Turn
0.2SOI
Al=1.8um
Substrate coupling noise
Transfer constant :s21 (dB)
-40 -50 -60 -70 -80 -90 -100 -110
BULK
High Resistivity SOI Sub.
0.1 1 10
Frequency (GHz)
Advantages for RF Application
● High Fmax a, High Inductance and Low Noise on High-R sub.
● also easy DMOS Fabrication, Low NF
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Oki is the first and only one mass production supplier of FD-SOI.

Mass production LSI's

- **Casio custom watch LSI**
- **Radio Controlled Receiver LSI**
- **Radio Controlled Signal Processor LSI**

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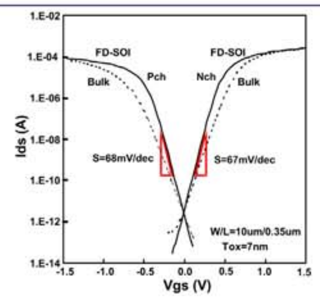
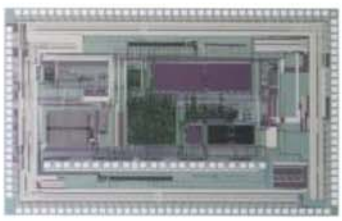
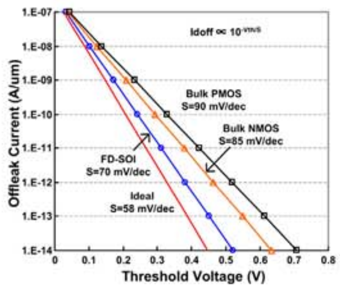
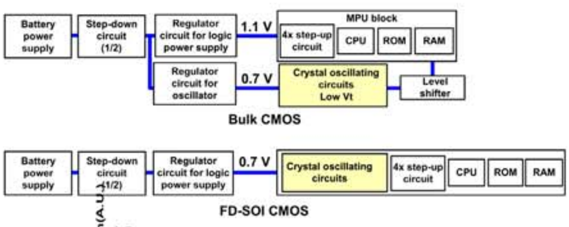
Ultra Low Power Watch LSI

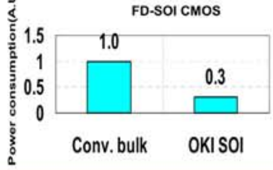




http://www.casio.co.jp







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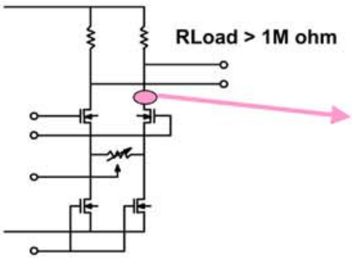
Radio Controlled Clock LSI

Time CODE Receiver LSI

	OKI	Vender A	Vender B
Device type	SOI	Bipolar	Bipolar
Supply Voltage	1.1～3.6V	1.8～3.6V	1.2～3.6V
Sensitivity	0.7μVrms	1μVrms	1μVrms
Active current consumption	17μA	55μA	200μA

ML6190A



Small Junction capacitance realized high sensitivity at low supply current.

One Stage of AGC Amplifier

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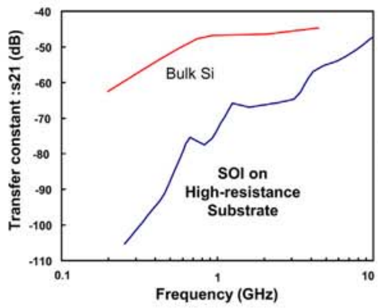
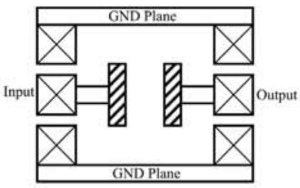
Radio Controlled Signal Processor LSI

Time CODE Processor LSI

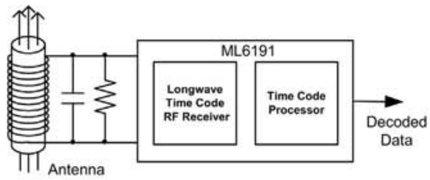


Isolation by SOI Substrate



TEG Structure

ML6191



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Status of 0.15SOI

- Change from 0.15 SOI (6” of R&D) to 0.15SOI LL (8” of production line)
  - Foundry Compatible 0.15 Design Rule & Cover Bulk Tr Specs.
    - \- Process Technology
      - STI (for SOI), Liner SiN (for SOI)
      - Metal 0.52 ⇒ 0.39(1M) /0.48 (<2M)
    - \- Transistor :
      - Vdd=1.5V, IO=3.3V
      - Ion/Ioff
        - Low Leakage (LL) Ioff<2E-12A/um
- Status:
  - 1st SPICE, Process Flow completed @ 6”
  - Transfer from 6” to 8” started

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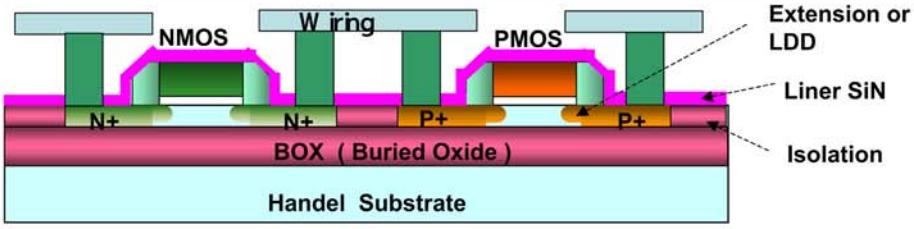
Key Process of 0.15SOI LL @ 8”



Process	0.15 @ 6”	0.15 SOI LL @ 8”	Status
BOX	200nm	145nm	
Isolations	M-LOCOS	STI	FS @ 6” Complete Trasfer to 8” started
Transistor		Optimize extension & LDD	
Liner SiN	No	Yes	
Wiring	0.52 um	0.39/0.48 um	Integration stady @ 8” Started
SRAM 6Tr	3.88 um2	2.96 – 3.1 um2	
12Tr	9.7 um2	(4.5 um2)	

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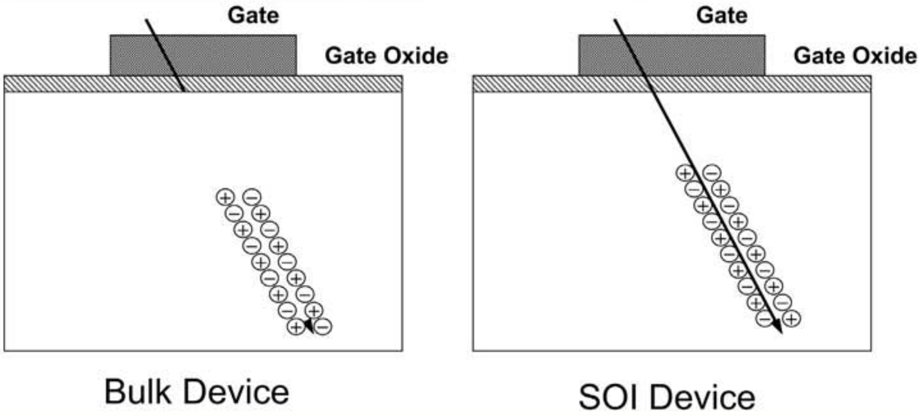
Terrestrial Cosmic Ray-Induced Soft Errors

Sun tries to cope with server flaw

For the past year, Sun Microsystems Inc. has struggled to solve a mysterious fault that can cause its high-end servers to crash unexpectedly, an embarrassing problem for a computer maker that routinely refers to its servers as "rock solid" reliable.

By David Hamilton
The Wall Street Journal Online
November 7, 2000, 4:00 PM PT

(http://zdnet.com.com/2100-11-525403.html?legacy=zdnn)



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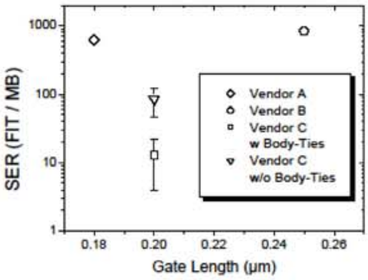
SER comparison between Bulk and SOI

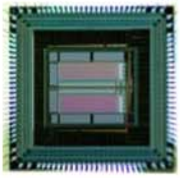
SER between Bulk and SOI

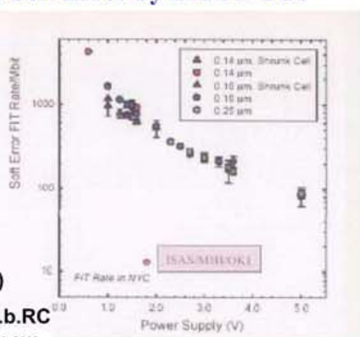
	Vendor A	Vendor B	Vendor C	Vendor C
V_{DD}	2.5 V	5 V	1.8 V	1.8 V
Device Size	4 Mo	1 Mo	256 ko	256 ko
Techno-logy	0.18μm bulk	0.25μm bulk	0.2μm SOI FD w Body-Ties	0.2μm SOI FD w/o Body -Ties
LET_{TH} (fC/μm)	7	14	80	36
Sensitive surface S_D or S_G (μm²)	0.06	0.35	0.24	0.24



J.Baggio et al., IRPS, 2004

JAXA & Mitsubishi Heavy Industry & Oki Press Release(April 20 2004)
-1/100 Soft Error by Oki FD-SOI -





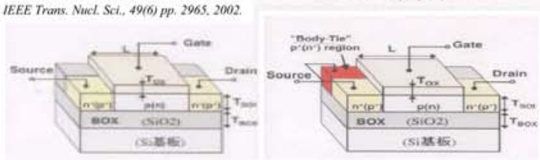
LET: 9 MeV/(mg/cm2)

by Body Contact

LET: 45 MeV/(mg/cm2)

By Body Contact + f.b.RC

IEEE Trans. Nucl. Sci., 49(6) pp. 2965, 2002.



IEEE NSREC Data Workshop Rec., pp. 48, 2001.
IRPS 2004, pp.677.
IEEE Trans. Nucl. Sci., 51(6) pp. 3349, 2004.

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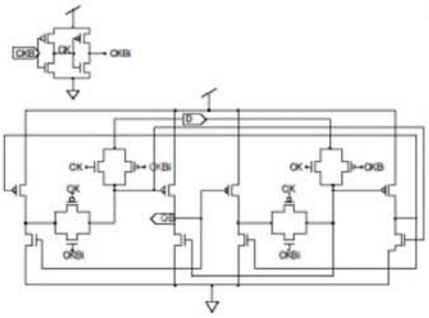
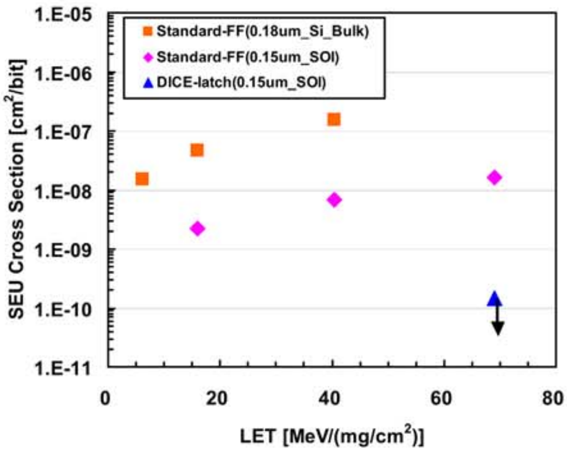
Single-Event Upset testing result

(Evaluation data are offered from JAXA)

Test device fabricated bv OKI 0.15um FD-SOI

DICE circuit
(Dual Interlocked Storage Cell)





SEU cross-section
(Standard vs HBD latch cell)

HBD: Hardness By Design

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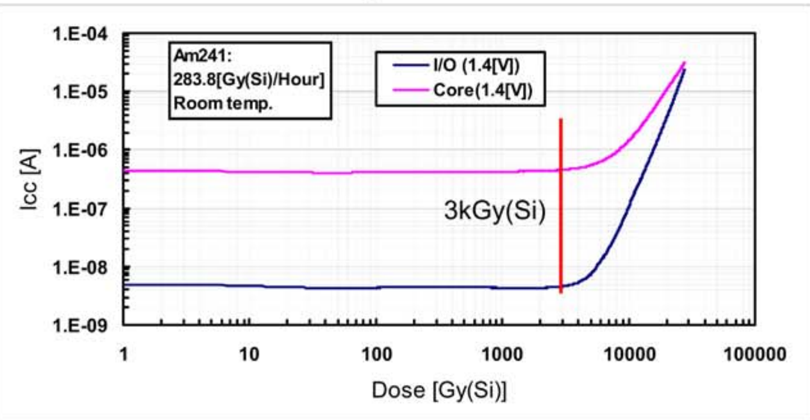
Total Ionizing Dose testing result

(Evaluation data are offered from JAXA)

Test device fabricated by OKI 0.15um FD-SOI



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PD-SOI vs FD-SOI

HIREC/JAXA Simulation results

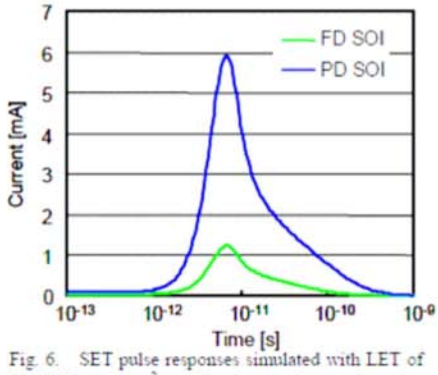

Fig. 6. SET pulse responses simulated with LET of 17 MeV/(mg/cm²). (The ion track was Gaussian with a characteristic radius of 70 nm. The timing of charge generation was also Gaussian centered at 5 ps with a characteristic width of 0.5 ps.)

Optimization for SEU/SET Immunity on 0.15 μm Fully Depleted CMOS/SOI Digital Logic Devices

A. Makihara,[1] H. Shindou,[2] M. Midorikawa,[2] S. Onoda,[3] T. Hirao[3], T. Ohki,[4] Y. Takahashi,[4] and S. Kuboyama[2]

[1] High-Reliability Components Corporation, [2] Japan Aerospace Exploration Agency, [3] Japan Atomic Energy Agency, [4] Nihon University

Thin Si layer

And

Less Bipolar action

 20

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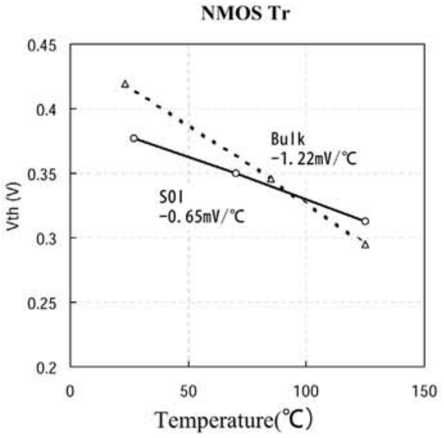
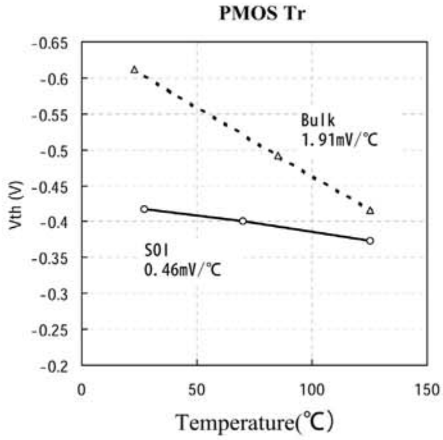
Small Temperature Dependence of FD-SOI

FD-SOI is also suitable for High Temperature Application

- **small temperature coefficient**
- **no junction area (only gate peripheral)**





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Summary

Oki has been focusing on FD-SOI technology.

1) FD-SOI is suitable for Low Power & Low Standby and also Analog/RF embedded applications.

2) Mass production with FD-SOI has already started.
- **Custom Watch LSI**
- **Radio Controlled Clock LSI**
- **Ultra low power RTC**

3) FD-SOI is also suitable for Space and harsh environment by Rad-hard, high temp. characteristics and Latch Up Free.

We continue to explore Ultra Low Power applications with FD-SOI.
And also, focusing on Rad-hard & High Temp. fields

OKI

The LSI Process Diagnosis technology

Oki Engineering Co., Ltd.

Daiki Tanaka, Kazuhiro Yabe, Hidehisa Kubota

Japan Aerospace Exploration Agency (JAXA)

Katsufumi Noda, Satoshi Kuboyama, Hiroyuki Shindou

27th of October 2006

THE 19th MICROELECTRONICS WORKSHOP

 OKI Engineering Corp. 2006.10.27

OKI

Overview

The background about the research

LSI process diagnosis technology, developed with JAXA, as a technology for evaluating the diversion of COTS semiconductor components, for use in space equipment where high-reliability is required.

The mutual verification of LSI process diagnosis and reliability test

Mutual verification in combination with reliability testing. These experiments were conducted to study the suitability of LSI process diagnosis technology.

The application

The example to have applied to the part for the automobile industry.

The plan in the future

The building of compatible and a data base to the 0.09 um process.

 OKI Engineering Corp. 2006.10.27

OKI

Background of the development of LSI process diagnosis technology

- **In recent years, it has become difficult to procure devices (with guaranteed high-reliability) for space projects due to cost and other issues. Technology for selecting commercial components, or diverting such components, has become a critical issue.**
- **In selecting/diverting commercial components by evaluating reliability for space use, device selection by reliability testing has become more difficult for today's devices with improved reliability.**

Requires

Development of an effective device selection method

3

 OKI Engineering Corp. 2006.10.27

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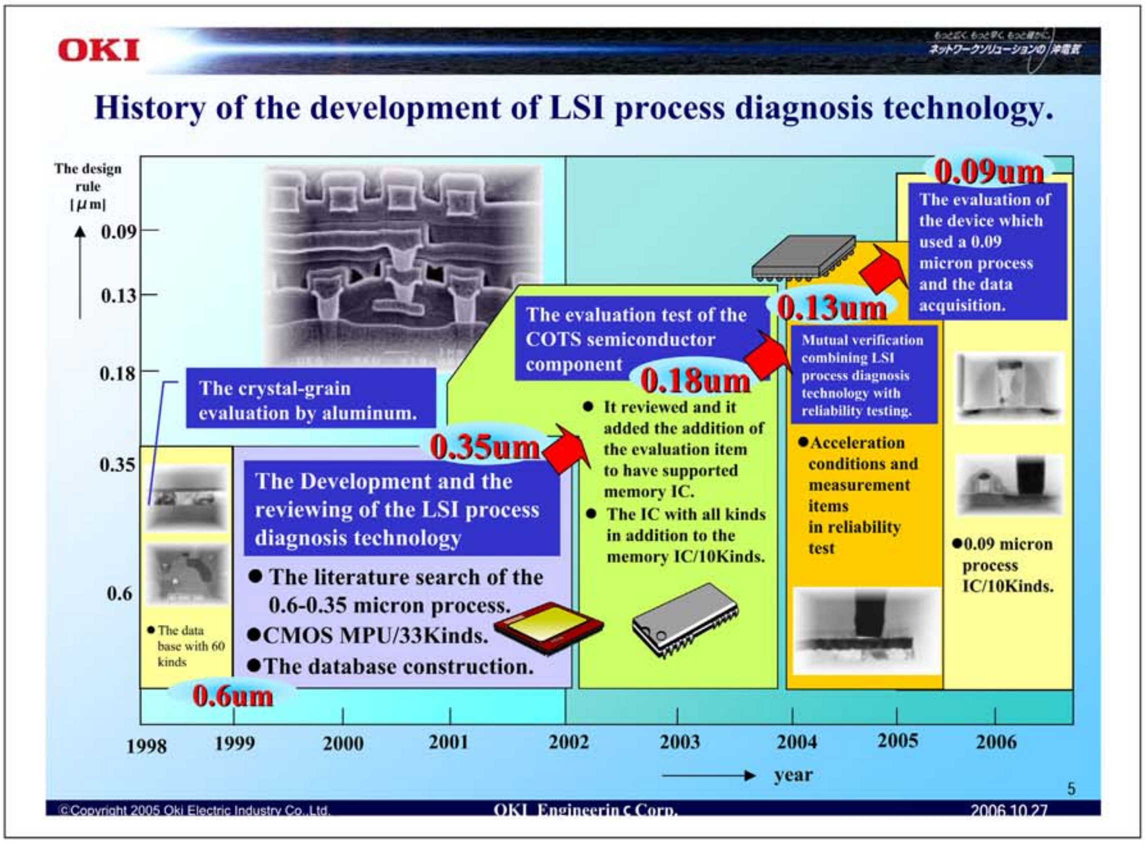
Concept

- The diversion technology of the COTS semiconductor component to use for the space equipment that a hi-reliability is needed.
- It evaluates a wafer process efficiently.
- Low cost.
- The speed. (It evaluates in short time.)
- The prompt.
- The extensibility.
- The research of the Reliability test and the way of making up DPA effectively.

 OKI Engineering Corp. 2006.10.27


OKI
History of the development of LSI process diagnosis technology.
The design rule [μm]
0.09
0.13
0.18
0.35
0.6
The crystal-grain evaluation by aluminum.
The Development and the reviewing of the LSI process diagnosis technology
● The literature search of the 0.6-0.35 micron process.
●CMOS MPU/33Kinds.
●The database construction.
● The data base with 60 kinds
0.6um
0.35um
The evaluation test of the COTS semiconductor component
0.18um
● It reviewed and it added the addition of the evaluation item to have supported memory IC.
● The IC with all kinds in addition to the memory IC/10Kinds.
0.13um
Mutual verification combining LSI process diagnosis technology with reliability testing.
●Acceleration conditions and measurement items in reliability test
0.09um
The evaluation of the device which used a 0.09 micron process and the data acquisition.
●0.09 micron process IC/10Kinds.
1998 1999 2000 2001 2002 2003 2004 2005 2006
year
5
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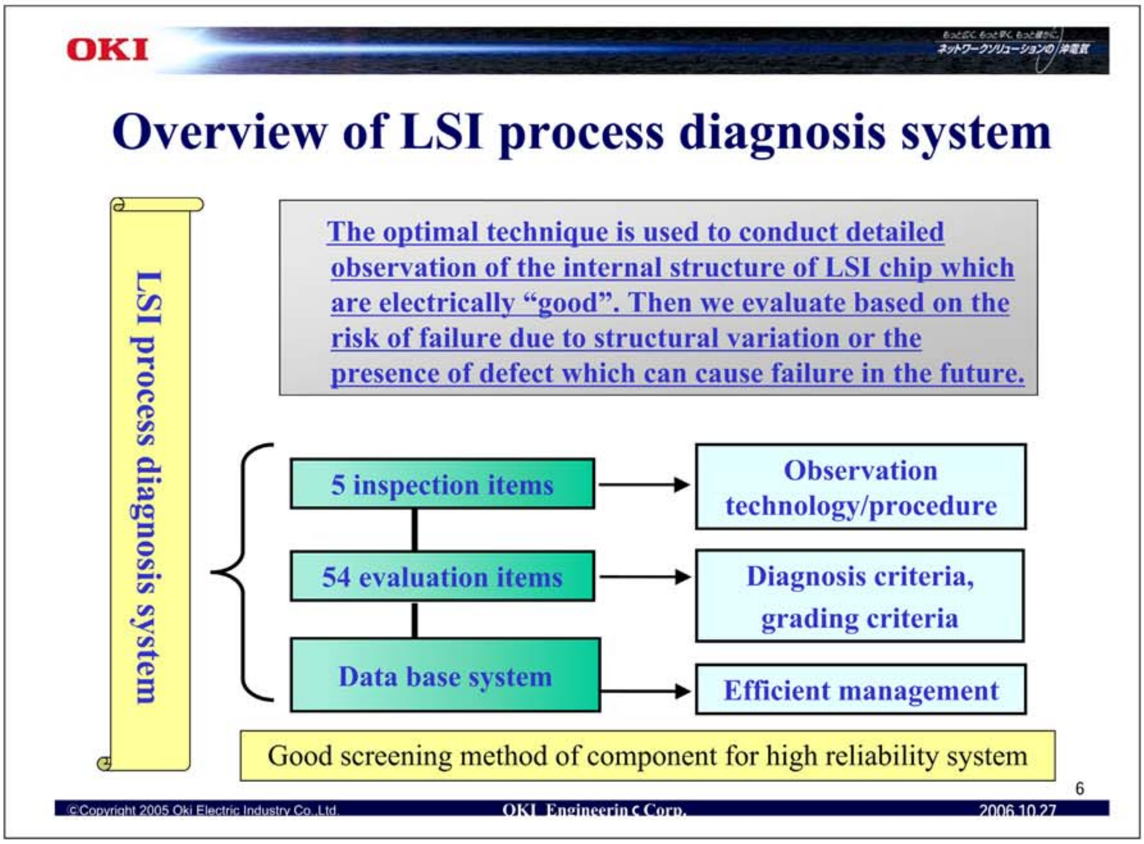
2006.10.27


OKI
Overview of LSI process diagnosis system
LSI process diagnosis system
The optimal technique is used to conduct detailed observation of the internal structure of LSI chip which are electrically "good". Then we evaluate based on the risk of failure due to structural variation or the presence of defect which can cause failure in the future.
5 inspection items
54 evaluation items
Data base system
Observation technology/procedure
Diagnosis criteria, grading criteria
Efficient management
Good screening method of component for high reliability system
6
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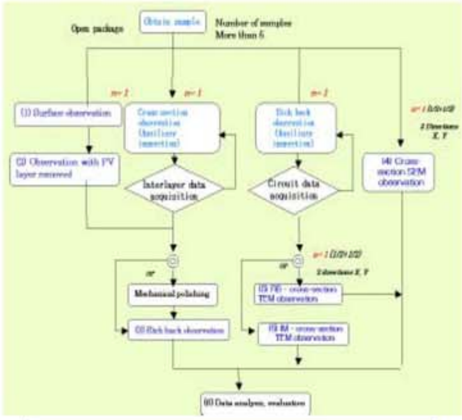
OKI

Inspection items for process diagnosis, and detected defects

No.	Inspection item	Equipment	Object of inspection
1	Surface observation	OM	Passivation Metallization
2	Observation with PV layer removed	SEM	Metallization (Top)
3	Etch back observation	OM/SEM	Interlayer insulating layer Metallization, substrate
4	Cross-section SEM observation	SEM	Layered structure Interconnection, gate electrodes, contacts etc.
5	Cross-section TEM observation	TEM	Layered structure, Composition Gate oxide, contacts etc.



At least 5 samples for inspection
Destructive inspection
Large volume inspection is impossible
Small quantity sampling inspection method (MIL883)

7

OKI

Evaluation criteria for LSI process diagnosis

Classification and point reduction categories for detected defects

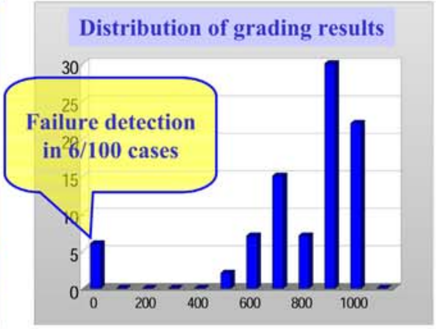
Classification	Seriousness of defect	Status	Score				Remarks
			A	B	C	D	
I	Major defect	Fatal	-1000	—	—	0	High probability of causing malfunction
II	Intermediate defect	Marginal	-300	-200	-100	0	Medium probability of causing malfunction
III	Minor defect	Hold	-30	-20	-10	0	Small probability of causing malfunction
IV	No classification	—	—	—	—	0	—

*Evaluation items are classified into a total of 54 items. (Create analysis sheet)
*Ease of defect occurrence, ease of malfunction occurrence (Criteria guidelines)
-Frequency of problem detection in past analysis of non-defective components.
-Frequency of malfunction occurrence in malfunction analysis.
*This part is constantly being adjusted due to changes caused by modification of the process.

OKI ネットワークソリューションの沖電気

Classification of diagnosis results

Grading category	Grading rank	Judgment
Excellent	1000	Pass
Very good	751～999	
Good	501～750	
Passing	251～500	
Below averaging	1～250	Hold
Failure	0	Fail

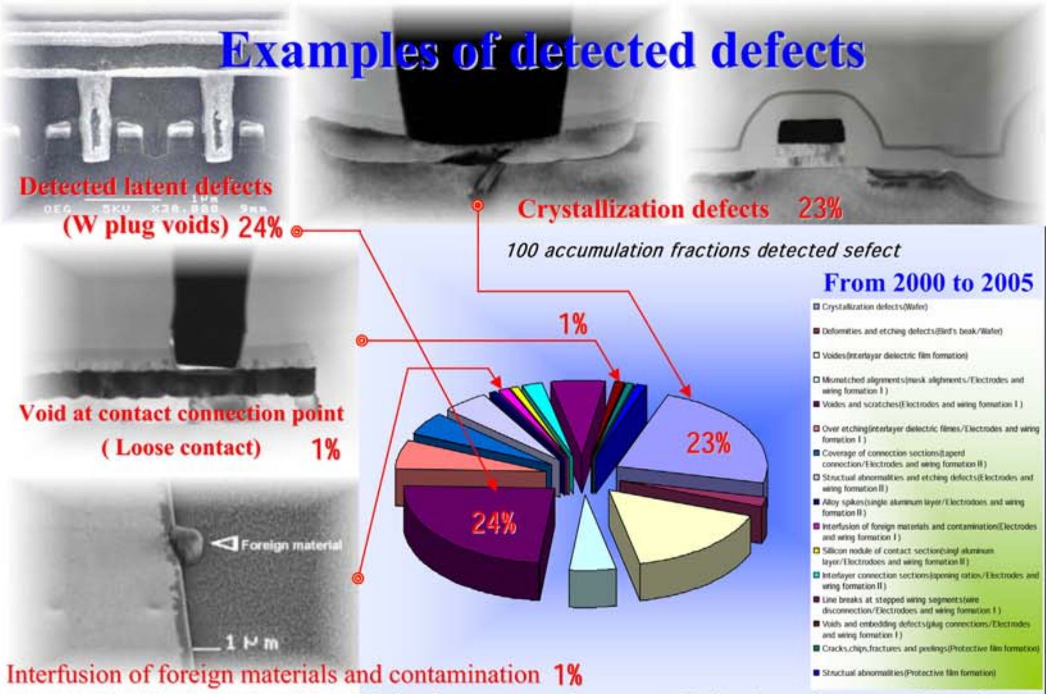


A point reduction system is used, where points are subtracted from the original 1000 points, according to the position, type and size of each detected defect.

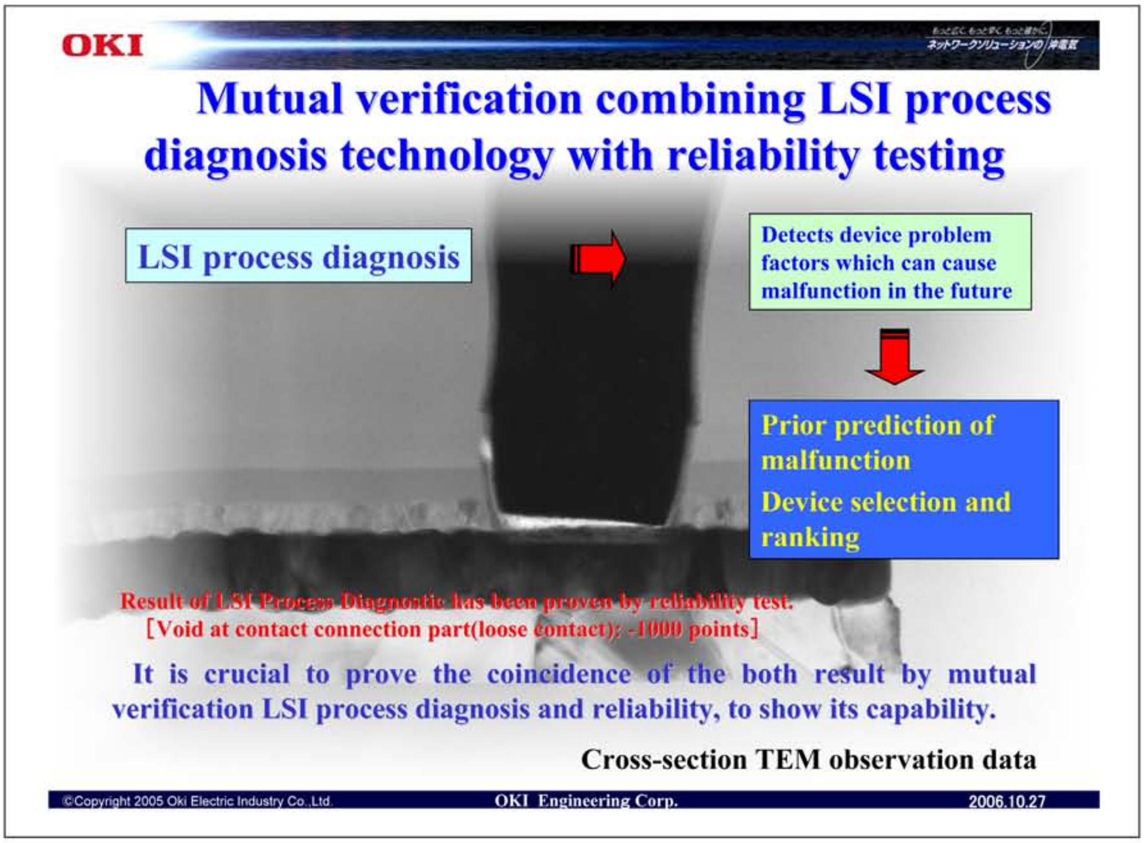
9

OKI ネットワークソリューションの沖電気

Examples of detected defects



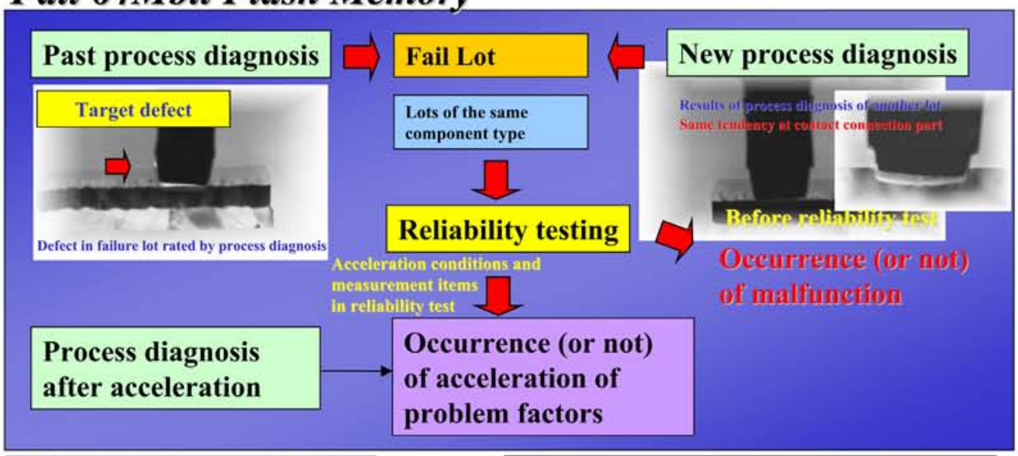
The risk of using these kind of devices in a system can be prevented by implementing process diagnosis



OKI

Mutual verification experiments

Fail 64Mbit Flash Memory



Applicable component type	Classifi-cation	Quantity [Pcs.]
Flash-Memory)	Existing(B)	15
	New(3)	20
	New(4)	20

Test Condition	DC,Function,AC,Margin
Acceleration Test	High temperature operation test/ Thermal shock test

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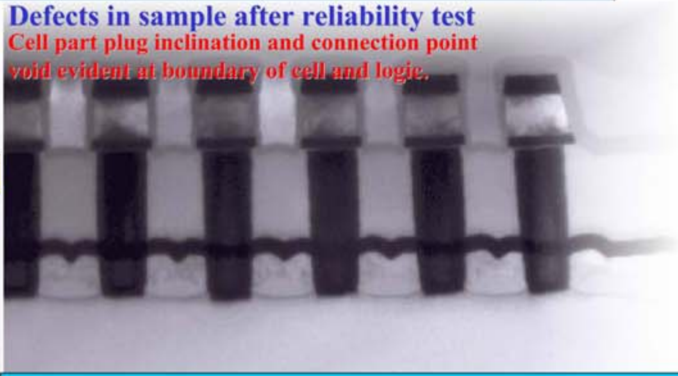
Reliability Test Result

Applicable component type	Classifi-cation	Quantity [Pcs.]	High-temperature energized test time [Hr] /Failure Count [Pcs.]						Total number of failure parts	Failure mode
			Initial	168	300	500	1000	2000		
Flash-Memory	LOT 1	15	0	0	0	0	0	2	2	FCT
	LOT 2	20	0	0	0	0	0	0	0	−−−
	LOT 3	20	0	0	0	0	0	0	0	−−−

Detection of target defect

Defects in sample after reliability test

Cell part plug inclination and connection point void evident at boundary of cell and logic.



Functional defects occur at 2000 hours in high-temperature testing

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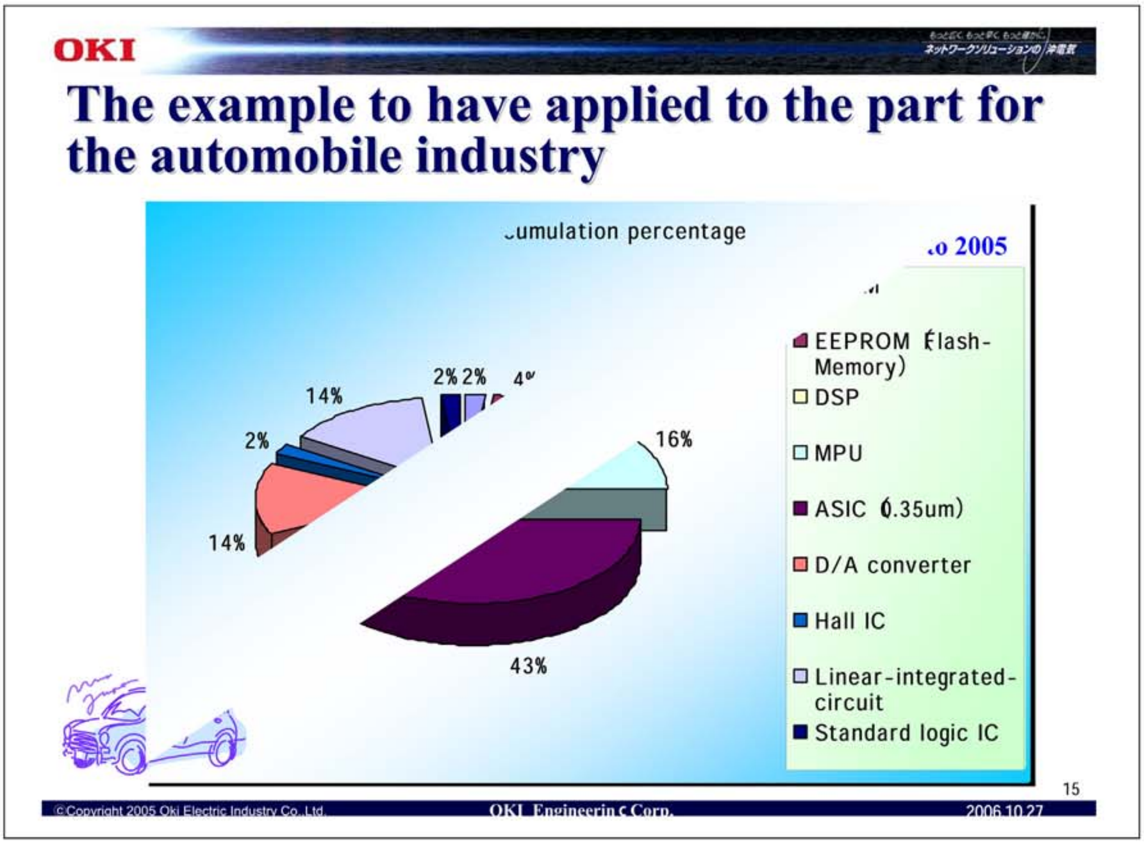
Summary of mutual verification

As a result of mutual verification via reliability testing for 3 lots each of 2 component types, it was confirmed that function fail occur in 2 pcs/15 pcs for the product (same lot with failure in structural analysis) after 2000 hours of high-temperature stress testing.

Process diagnosis was conducted on the devices where electrical defects occurred, and, as a result, a major defect was detected at the targeted contact part.

In short-term reliability testing and electrical characteristic testing, undetectable latent defects which can result in malfunction could be detected and selected by the process diagnosis method, and thus the effectiveness of the process diagnosis method was confirmed.

14


OKI
The example to have applied to the part for the automobile industry
umulation percentage
o 2005
14%
2%
14%
2% 2%
16%
43%
EEPROM (Flash-Memory)
DSP
MPU
ASIC (0.35um)
D/A converter
Hall IC
Linear-integrated-circuit
Standard logic IC
15
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OKI
Schedule
subject
The system to have supported a super minute-ization device.
It is compatible to the device of the three dimensional structure.
It makes the evaluation to have supported an assembly process flaw fuse.
It complements to the data base.
The dater gathering of the 0.09 micron process.
The first stage floor
The evaluation item and the acceptance standard creating which was optimized to the 0.09 micron process.
It reflects in the data base.
The second-stage
The dater gathering of the minute process of super.
The phase 3
2006
2007
2008
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2006.10.27

Research on Mechanical Moving Components for Space Use

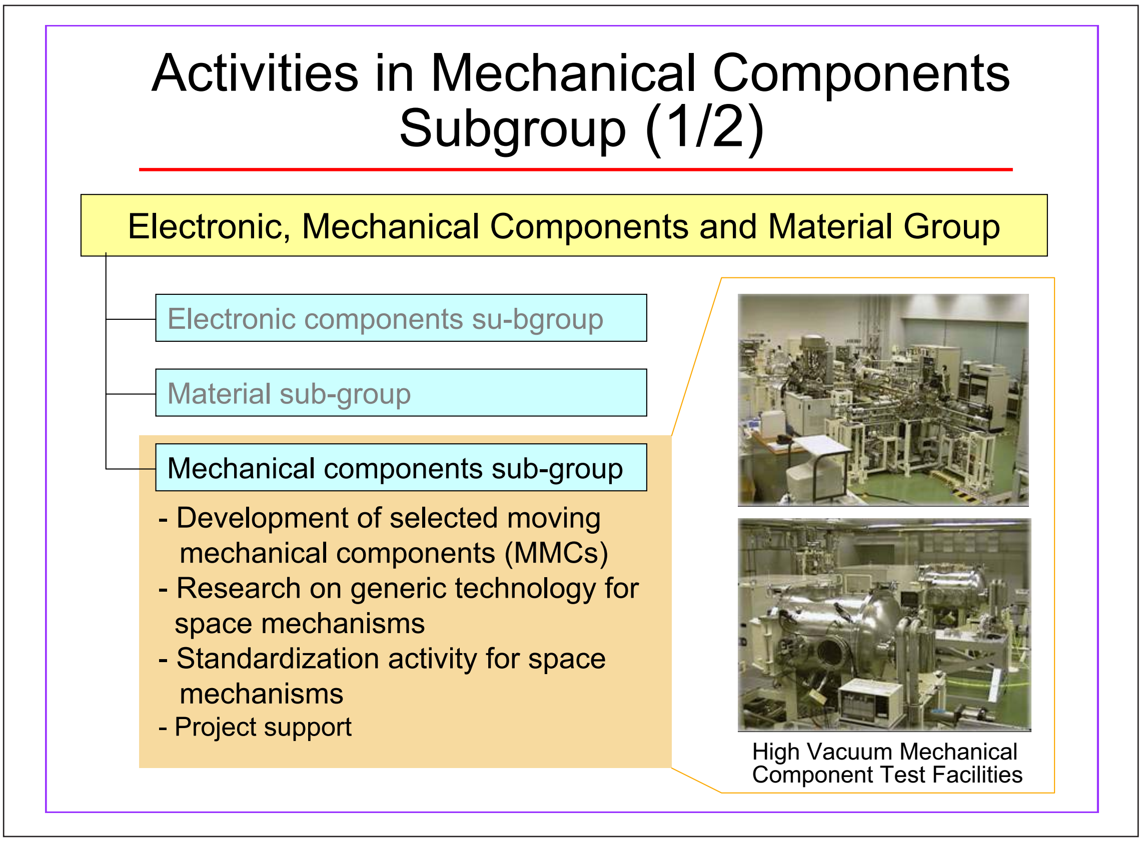
19th Microelectronics Workshop

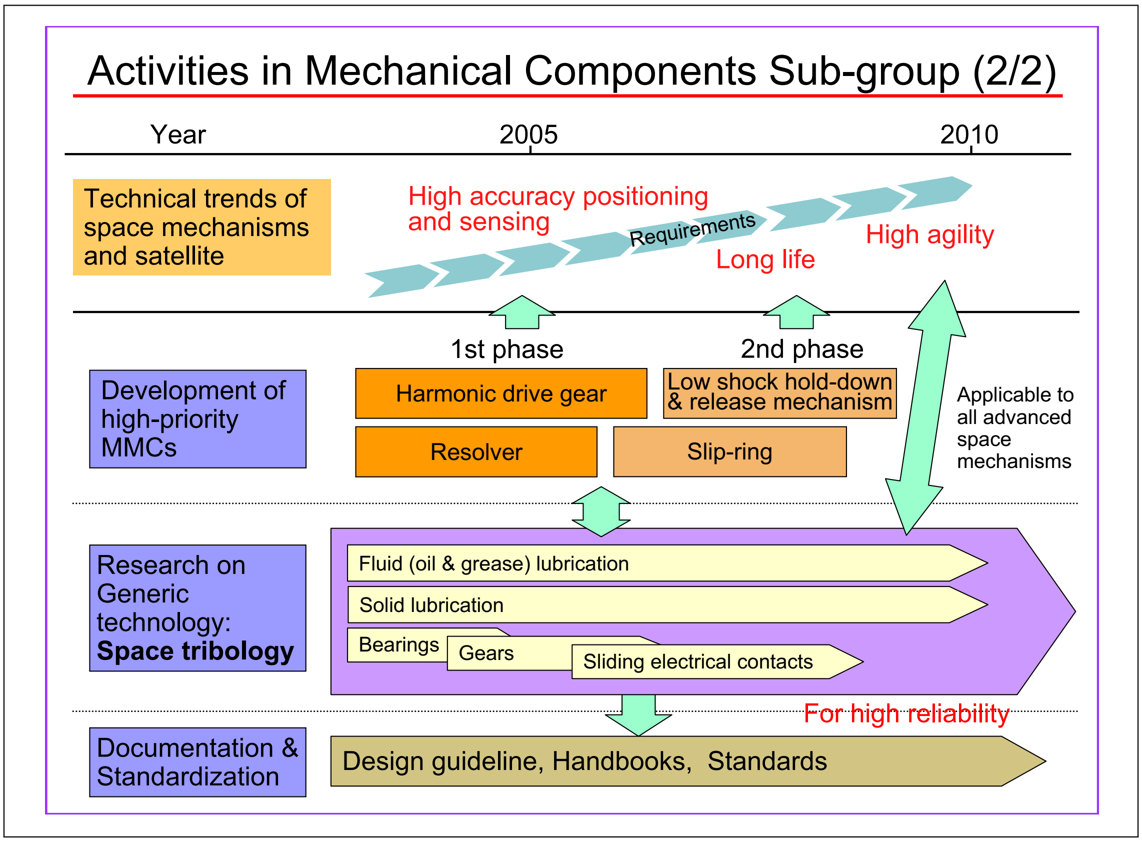
October 25-27, 2006 Tsukuba, Ibaraki, JAPAN

Shingo OBARA
Electronic, Mechanical Components and Material Group
Institute of Aerospace Technology
JAXA

Activities in mechanical components sub-group

- Outline
- Development of mechanical moving components
- Project support


Activities in Mechanical Components Subgroup (1/2)
Electronic, Mechanical Components and Material Group
Electronic components su-bgroup
Material sub-group
Mechanical components sub-group
- Development of selected moving mechanical components (MMCs)
- Research on generic technology for space mechanisms
- Standardization activity for space mechanisms
- Project support
High Vacuum Mechanical Component Test Facilities


Activities in Mechanical Components Sub-group (2/2)
Year
2005
2010
Technical trends of space mechanisms and satellite
High accuracy positioning and sensing
Requirements
Long life
High agility
1st phase
2nd phase
Development of high-priority MMCs
Harmonic drive gear
Low shock hold-down & release mechanism
Resolver
Slip-ring
Applicable to all advanced space mechanisms
Research on Generic technology: Space tribology
Fluid (oil & grease) lubrication
Solid lubrication
Bearings
Gears
Sliding electrical contacts
For high reliability
Documentation & Standardization
Design guideline, Handbooks, Standards

Development of selected MMCs

Committee on Space Component Technology, Space Mechanical Components & Materials Subcommittee

Selection of high-priority MMCs
- For solving availability problem
- To obtain higher performance
- For growing the market

Development: 1st phase (2003～)

(1) Resolver (Angular sensor)
- High accuracy < ±0.0015°
- High resolution 21 bit

(2) Harmonic drive gear
- Light weight & compact
- Long life > 10^6 rev.

Project Support

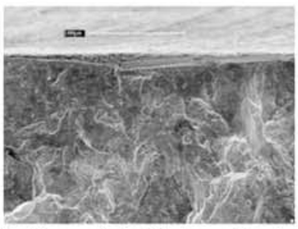
Performance verification test

Life evaluation test of ball bearings for GOSAT satellite

Failure analysis

SEM observation of fracture surfaces of H-II LE-7 engine

Failed FTP inducer



Starting point of fatigue fracture

Research on space tribology

- Fluid lubrication
- Solid lubrication

Fluid (oil & grease) lubrication

Fluid lubricants
・MAC (+additives)
・MAC based grease
・PFPE

Tribological characteristics of existing fluid lubricants
- Wear and friction coefficients
- Effect of additives

High-priority MMC related research
- Lubrication mechanism of harmonic drive gears

- To establish fluid-lubricating method for space applications
- To accumulate technical data of mechanical components

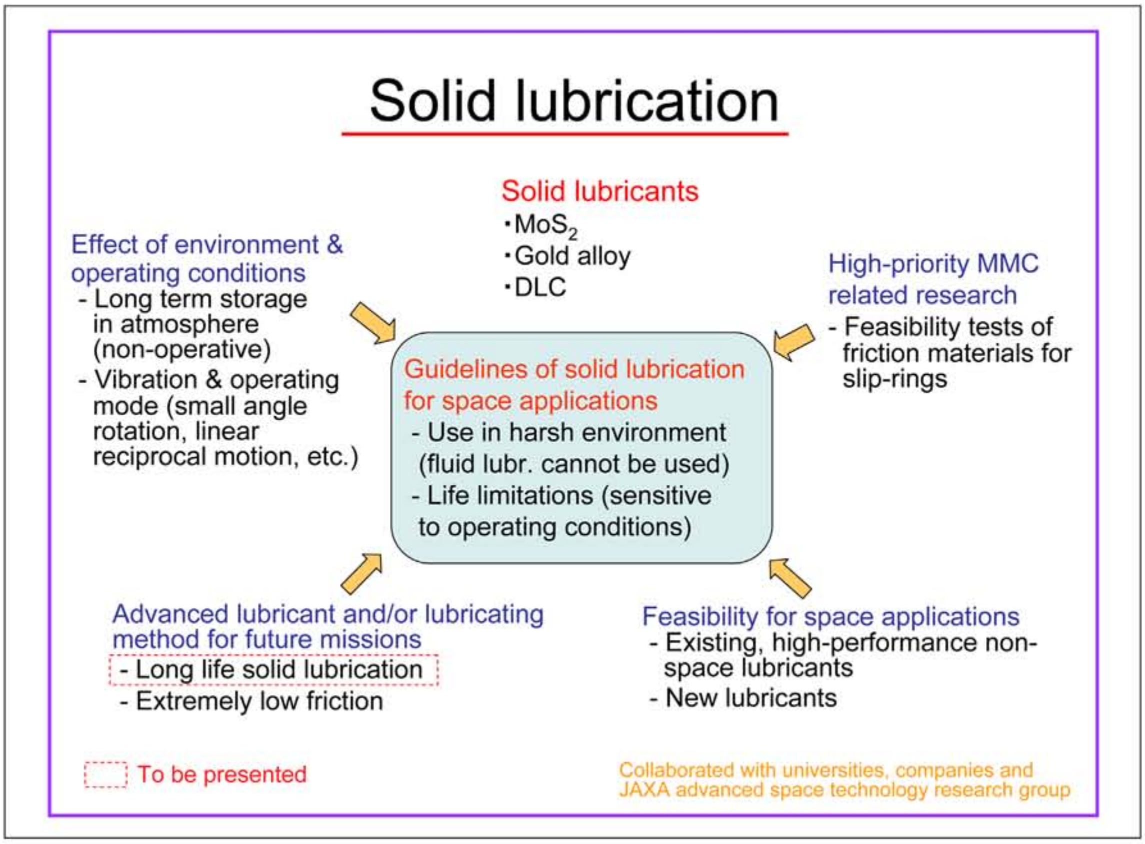
Feasibility of new lubricants
- Tribological characteristics

Ball bearing dynamics simulation
- Effect of gravity on bearing performance
- Retainer instability

Lubrication mechanism of ball bearings
- In-situ measurement of film thickness
- Tribological characteristics of oil-impregnated retainer
- Life tests

[dashed box] To be presented

Collaborated with universities, companies and JAXA advanced space technology research group



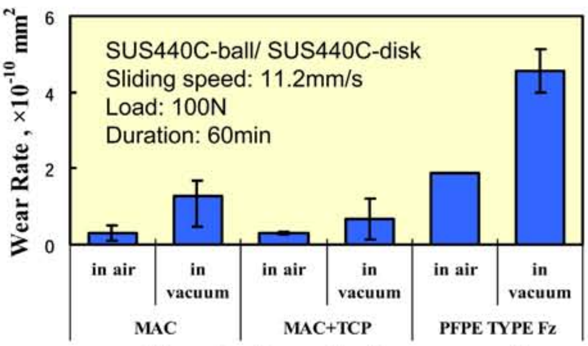
Tribological characteristics of space oils

－Collaboration with Tokyo Institute of Technology (TIT)－

* Friction and wear characteristics of promising oils for space use have been evaluated with a pin-on-disk tribometer.
  - MAC
  - PAO
  - PFPE
  - Mineral oil

* Effectiveness of inclusion of extreme-pressure additives and/or anti-oxidants in hydrocarbon oils is investigated.
  - TCP
  - Hindered phenols
  - Amines

Ball surfaces after the wear tests

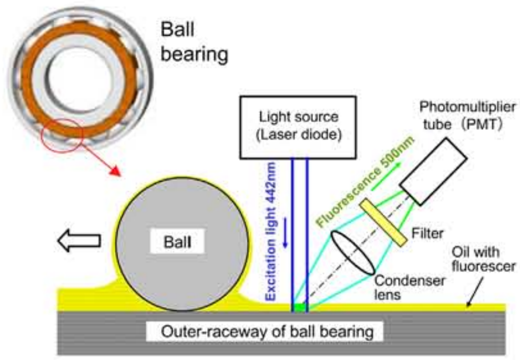


Wear test results for space oils

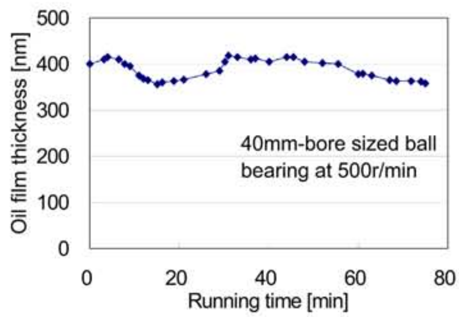
In-situ measurement of oil film thickness on ball bearing raceway

－Collaboration with TIT－

* Downsized, high-resolution Laser Induced Fluorescence (LIF) system was developed for measuring oil film thickness during ball-bearing operation.
* The film thickness on the raceway was decreased by repeated ball passings, and finally, a submicron scale thin film was left, contributing to hydrodynamic lubrication of the bearing.



In-situ measurement system using LIF



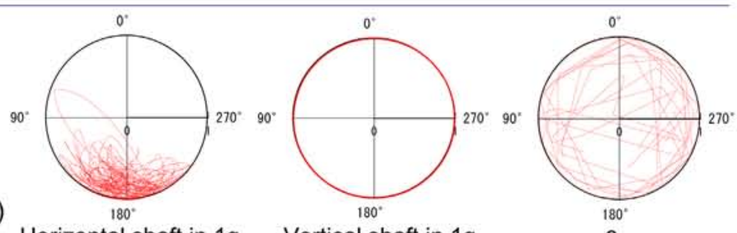
Result of film thickness measurement

Ball bearing dynamics simulation

Dynamic analysis code of ball bearings has been developed

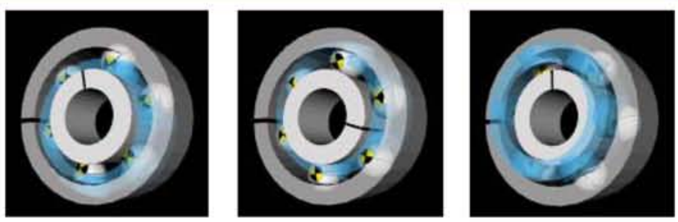
– for understanding the effect of gravity condition on bearing performance, and
– for rapid evaluation of key bearing design factors.

Effect of gravity condition on retainer motion.
(Mass centre loci of gyroscope bearing retainer at 9000 r/min)



Horizontal shaft in 1g Vertical shaft in 1g 0 g

3-D animation of unstable retainer motion.
(Gyroscope bearing at 9000 r/min. The retainer motion is exaggerated.)



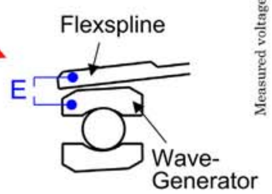
Lubrication mechanism of Harmonic Drive Gears

Generally, life of Harmonic Drive Gears (HDGs) in vacuum is remarkably shorter than that in air. Why ?

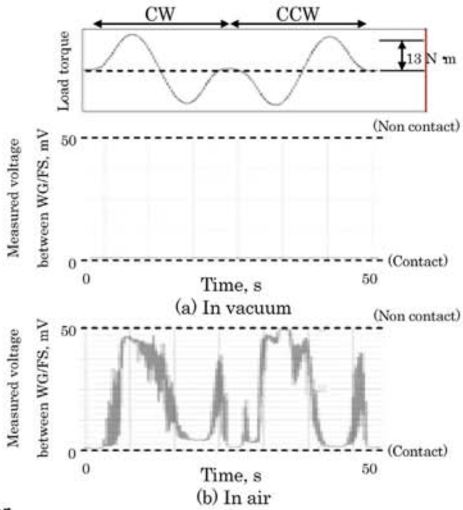
Electric resistance measurement among HDG elements

This is probably because the lubricant between Wave Generator (WG) and Flexspline (FS) is rapidly starved when HDG is operated in vacuum.

Harmonic Drive Gear



Measurement of voltage E between WG and FS



Measured voltage E (MAC-based grease, input rotational speed: 200 rpm)

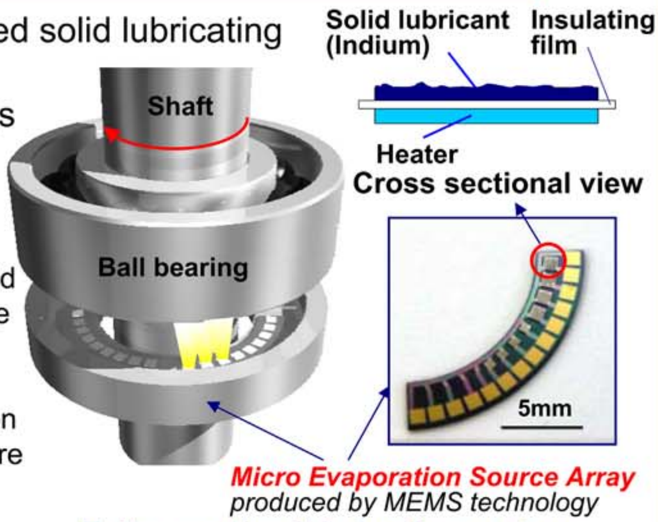
Long life solid lubrication of ball bearings by tribo-coating

－Collaboration with Tohoku University－

Applicability of advanced solid lubricating method called “tribo-coating” to ball bearings is investigated.

Tribo-coating:

- Periodic resupply of a solid lubricant to sliding surface by evaporation.
- Long lifetime over 10^7 revolutions and low friction coefficient under 0.02 were achieved in pin-on-disk experiments.



Tribo-coating lubrication system for ball bearing

Summary

Activities for moving mechanical components

- Development of selected moving mechanical components
- Research on space tribology
- Providing handbooks, guidelines and standards for space mechanisms

Space tribology research

- Key technology to develop future space mechanisms with high performance and high reliability.
- Continuing effort to gather technological data and to get perspective of phenomena involved.

Development of Strain Wave Gearing* for Space Flight Application

Harmonic Drive Systems, Inc.
HD Division / Research & Development

*Strain wave gearing is also known as "Harmonic Drive®"

"Harmonic Drive®" is a registered trademark that can be used only on products which are manufactured and sold by Harmonic Drive Systems, Inc.

FINE MECHANICS & TOTAL motion CONTROL

Corporate Profile

Harmonic Drive Systems Inc.

Business Location
Head Office: 6-25-3 Minami-Oi, Shinagawa-ku, Tokyo JAPAN
Hotaka Plant: 1856-1 Hotakamaki, Azumino-shi,Nagano JAPAN
Sales Office: 6 Business Offices in Japan

Founded
October 1970

Business Domain
Manufacturing and sales of precision speed reducers

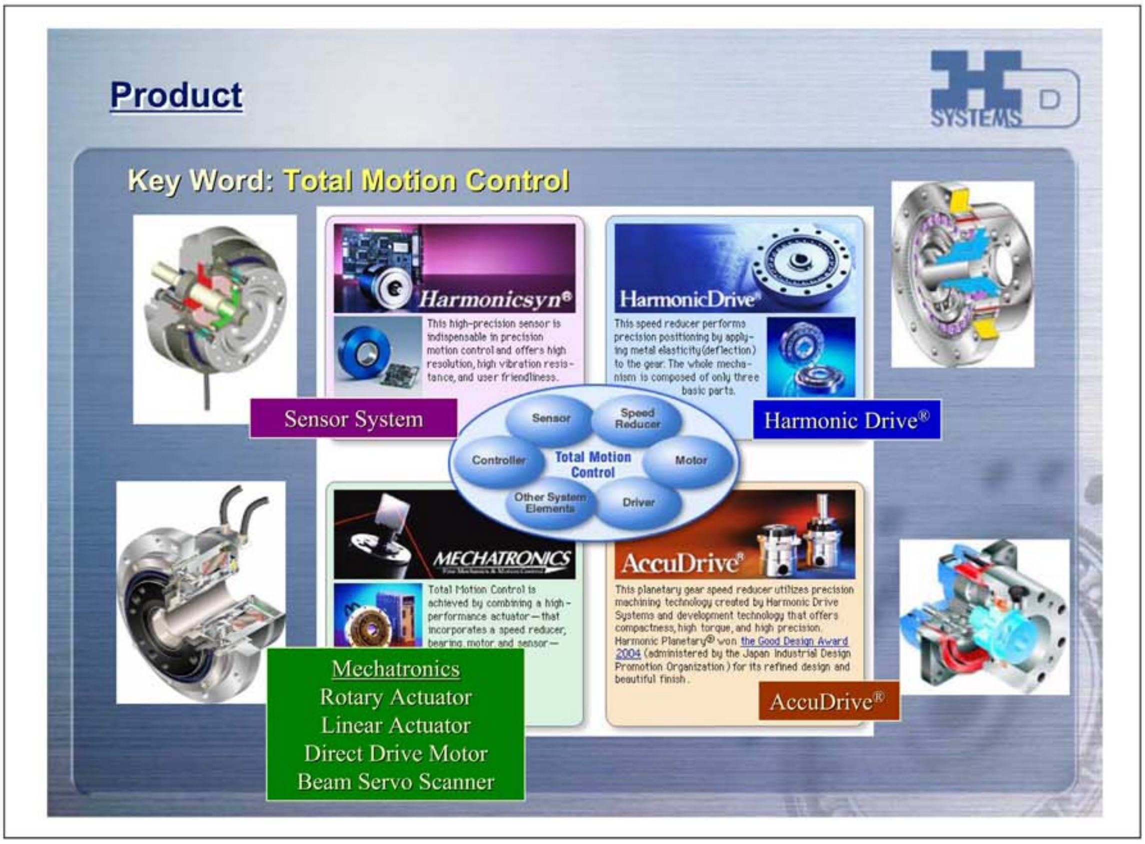
Capital
¥666.8 million

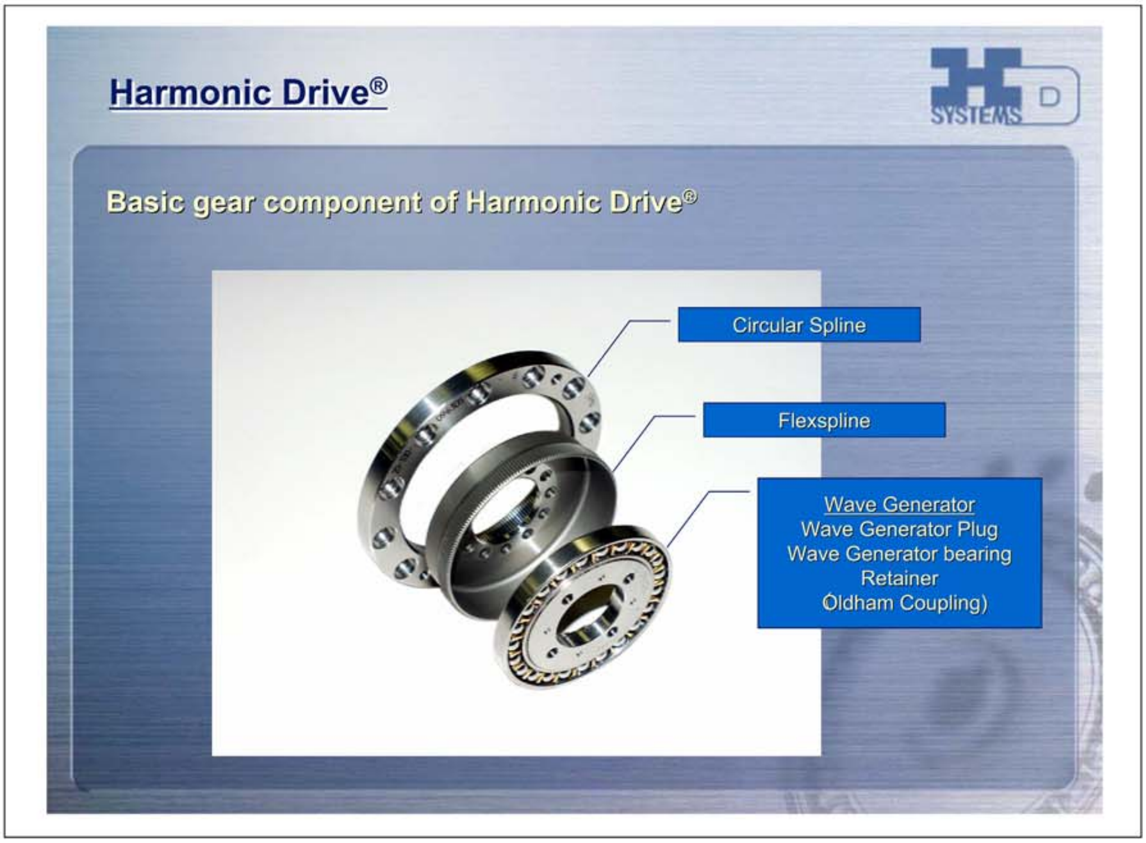
Net Sales
¥13,937 million (FY2005 ended March 31, 2006)

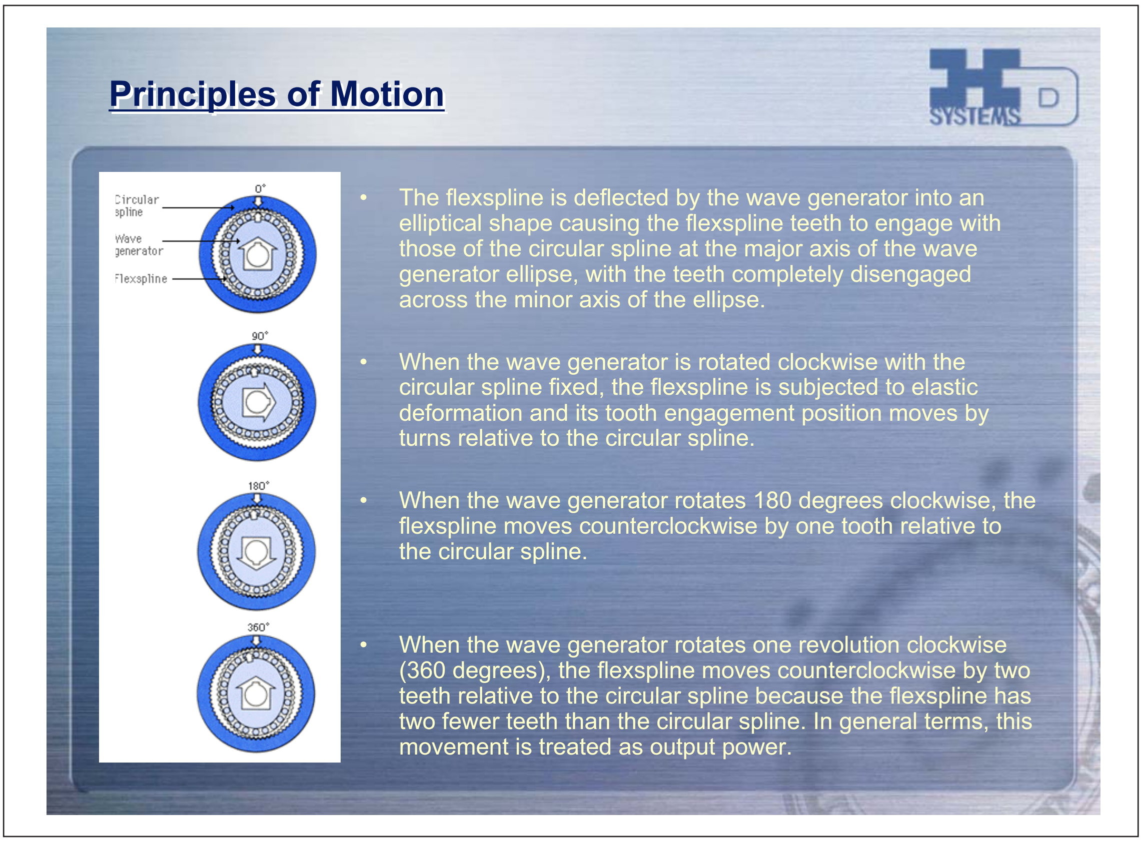
Employees
207 (as of March 31, 2006)

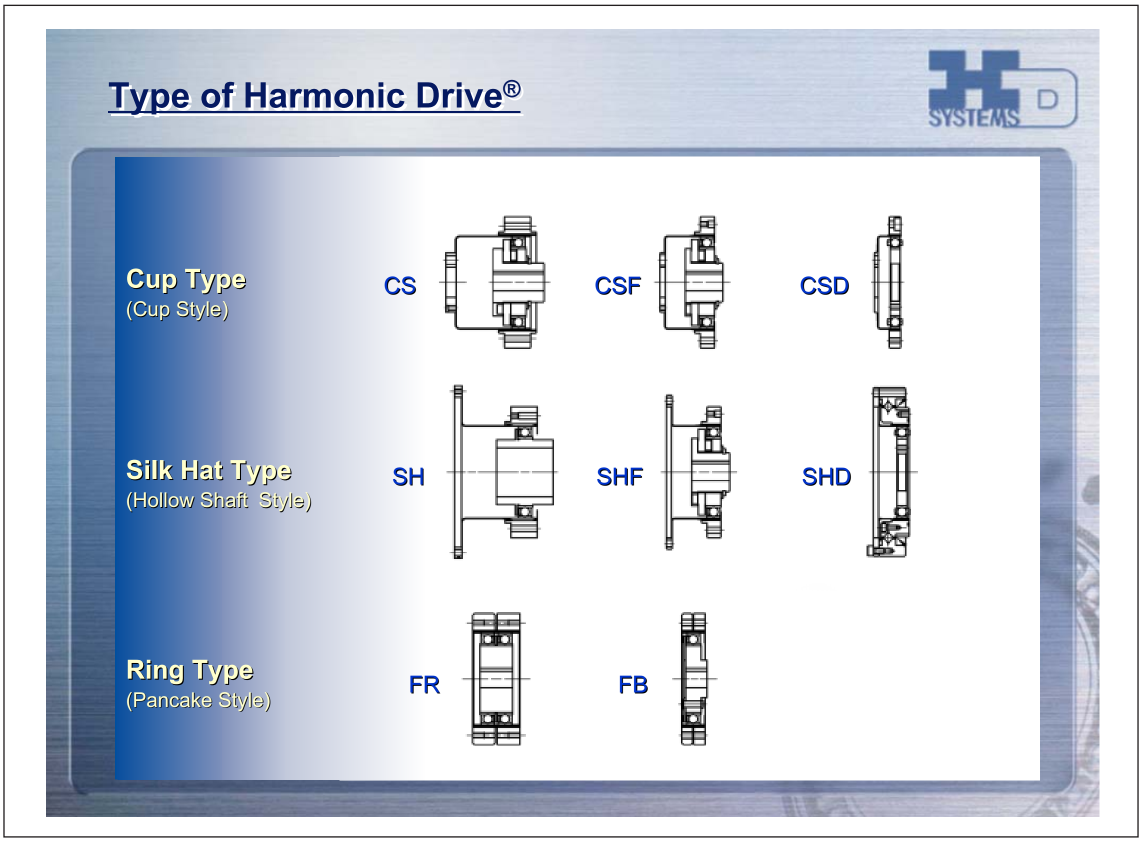
Domestic Subsidiaries
HD Logistics, Inc.
Harmonic Precision Inc.
Harmonic AD, Inc.

Overseas Subsidiaries and Affiliates
Harmonic Drive L . L . C . (Peabody, Massachusetts U.S.A.)
Harmonic Drive AG (Limburg a.d. Lahn GERMANY)


Product
SYSTEMS
Key Word: Total Motion Control
Harmonicsyn®
This high-precision sensor is indispensable in precision motion control and offers high resolution, high vibration resistance, and user friendliness.
HarmonicDrive®
This speed reducer performs precision positioning by applying metal elasticity(deflection) to the gear. The whole mechanism is composed of only three basic parts.
Sensor System
Harmonic Drive®
Sensor
Speed Reducer
Controller
Total Motion Control
Motor
Other System Elements
Driver
MECHATRONICS
Total Motion Control is achieved by combining a high-performance actuator—that incorporates a speed reducer, bearing, motor and sensor—
AccuDrive®
This planetary gear speed reducer utilizes precision machining technology created by Harmonic Drive Systems and development technology that offers compactness, high torque, and high precision. Harmonic Planetary® won the Good Design Award 2004 (administered by the Japan Industrial Design Promotion Organization) for its refined design and beautiful finish.
AccuDrive®
Mechatronics
Rotary Actuator
Linear Actuator
Direct Drive Motor
Beam Servo Scanner


Harmonic Drive®
SYSTEMS
Basic gear component of Harmonic Drive®
Circular Spline
Flexspline
Wave Generator
Wave Generator Plug
Wave Generator bearing
Retainer
Oldham Coupling)


Principles of Motion
Circular spline
Wave generator
Flexspline
0°
90°
180°
360°
The flexspline is deflected by the wave generator into an elliptical shape causing the flexspline teeth to engage with those of the circular spline at the major axis of the wave generator ellipse, with the teeth completely disengaged across the minor axis of the ellipse.
When the wave generator is rotated clockwise with the circular spline fixed, the flexspline is subjected to elastic deformation and its tooth engagement position moves by turns relative to the circular spline.
When the wave generator rotates 180 degrees clockwise, the flexspline moves counterclockwise by one tooth relative to the circular spline.
When the wave generator rotates one revolution clockwise (360 degrees), the flexspline moves counterclockwise by two teeth relative to the circular spline because the flexspline has two fewer teeth than the circular spline. In general terms, this movement is treated as output power.


Type of Harmonic Drive®
Cup Type
(Cup Style)
CS
CSF
CSD
Silk Hat Type
(Hollow Shaft Style)
SH
SHF
SHD
Ring Type
(Pancake Style)
FR
FB

Circumstance of Development Start

- The NASDA authorized parts for space application which make the base technology of space development decreases rapidly by authorization declining etc. (～2000)
- Task team for space application was organized, and the future parts for space application program was studied. (2001)
- In order to deal with in the long run and systematically, technical committee of parts for space application was established in NASDA. (2002)
- In the committee, HD was authorized as an important part, and the development support was decided. (2003)

Development of Harmonic Drive® for Space Flight Application

- Concept:
  - To develop strain wave gearing as a internationally competitive part for space flight application

Specification (Type, Size, Gear Ratio)

- Application: PDM, APM

  Request: long life, high positioning accuracy, hollow shaft design

Long Use Type

Type: SHF, Size: 20, Gear ratio: 1/160

(SHF-20-160-2A-GR-SP)

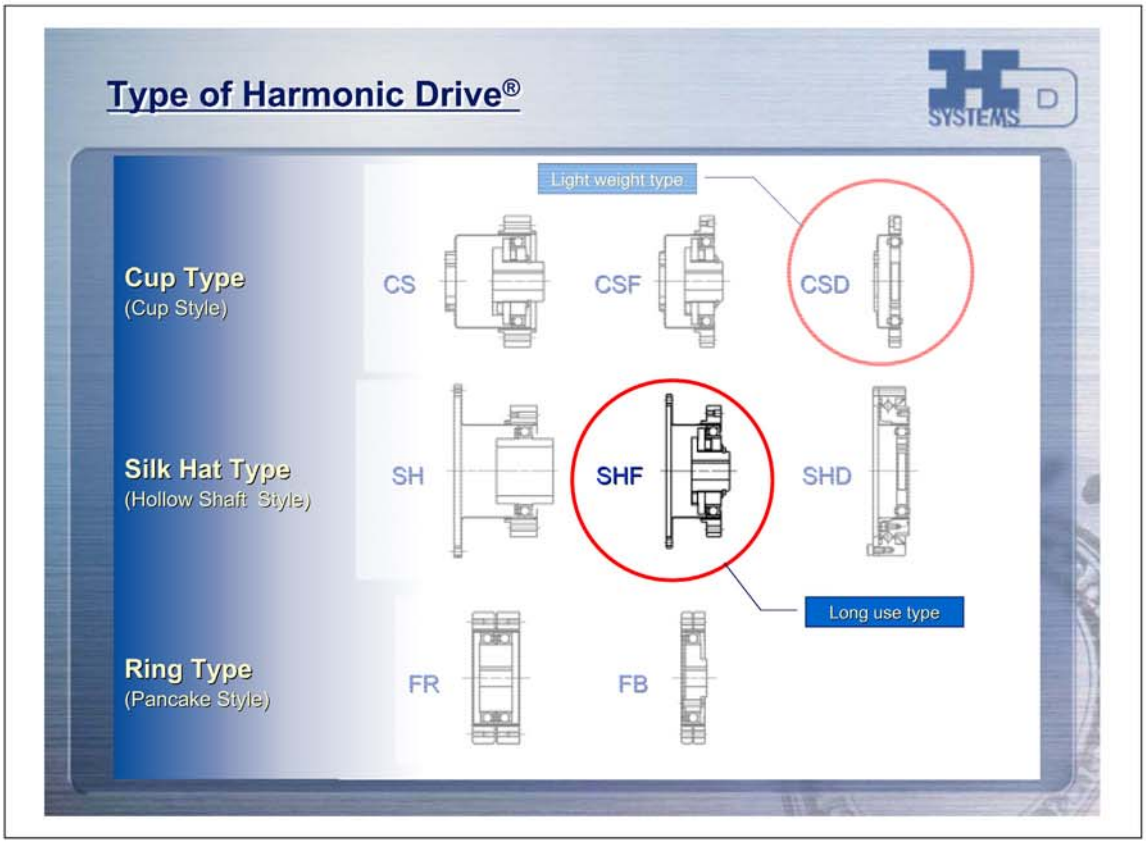
- Application: one shot mechanism

  Request: Light weight, Compact

Light Weight Type

Type: CSD, Size: 20, Gear ratio: 1/160

(CSD-20-160-2A-GR-SP)



Requirement

- Requirement

	Requirement	
	Long Use Type	Light Weight Type
Life	Output Revolution: 1×10^6 rev	100 Cycles 1 cycle: Within 360°
Lubrication	MAC Grease	
Transmission Accuracy	Less than 30 arc-sec	Less than 60 arc-sec
Spring Rate	K1 1.38×10^4 Nm/rad (minimum) (Load Torque: 7.0 Nm)	K1 1.10×10^4 Nm/rad (min.) (Load Torque: 7.0Nm)
Temperature Range	Operating：-10℃～+80℃ Un-operating：-40℃～+80℃	Operating：-30℃～+80℃ Un-operating：-60℃～+95℃
Vacuum Pressure	Less than 10^{-4} Pa	
Vibration	Sign Wave Vibration X, Y and Z axis 10～100 Hz 25G Random Vibration X, Y, and Z axis 5～20 kHz 21G RMS 180 sec.	

Development Flow

1. **Basic test and trial production**
   - Effect of grease quantity
   - Effect of input speed
   - Evaluation of processability
2. **Engineering model test**
   - Vibration test
   - Thermal vacuum test
   - Life test
3. **Qualification Model Test**
   - Vibration test
   - Thermal vacuum test
   - Life test

Result of Basic Test and Trial Production

- **Condition of Engineering Model test**
  - **Grease quantity**

Parts of grease application		Grease quantity
Wave Generator bearing		0.1g
Inside of Flexspline		0.4g
Teeth	Flexspline	0.3g
	Circular Spline	0.3g

  - **Input speed**
    500 r/min
- Evaluation of processability
  - Oil impregnation process
    It was established.
  - Domestic phenolic material for retainer
    It was evaluated that domestic material is equivalent to imported material.

Effect of Input Speed

- Surface of the Flexspline inside after endurance test

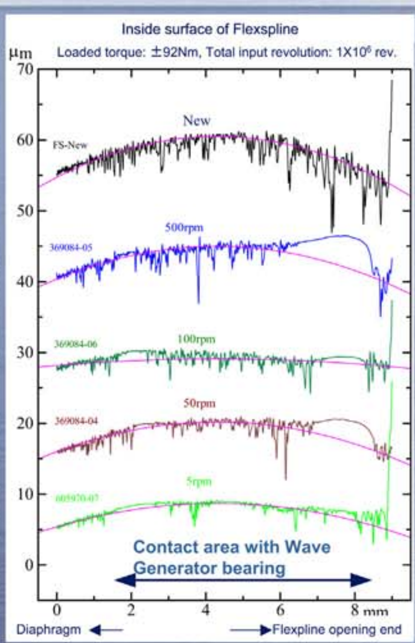
Wear is concentrate to the opening end side of Flexspline.

High Speed

Input speed

Low Speed

Wear is generated on the average.



Engineering Model Test

- Test flow

Test	Place	Test condition
Initial performance test	HDS Hotaka Factory	Starting Torque, Efficiency, Spring Rate, Transmission Accuracy Under atmospheric pressure
Vibration test	JAXA TSC	Sign Wave: X, Y, Z axis 5～100Hz, 0.6～25G, 2oct/min Random: X, Y, Z axis 5～2,000Hz 21G RMS 180 sec.
Thermal vacuum test	JAXA TSC	-10℃→+95℃ 1H hold 4cycle、 Vacuum pressure: 1×10^{-4}Pa (Max.) Measurement of Efficiency & starting torque on each cycle
Life test	JAXA TSC	Load Torque: 40 Nm, 20Nm one direction, continuous Input speed: 500 rpm Vacuum pressure: 1×10^{-4}Pa (Max.)

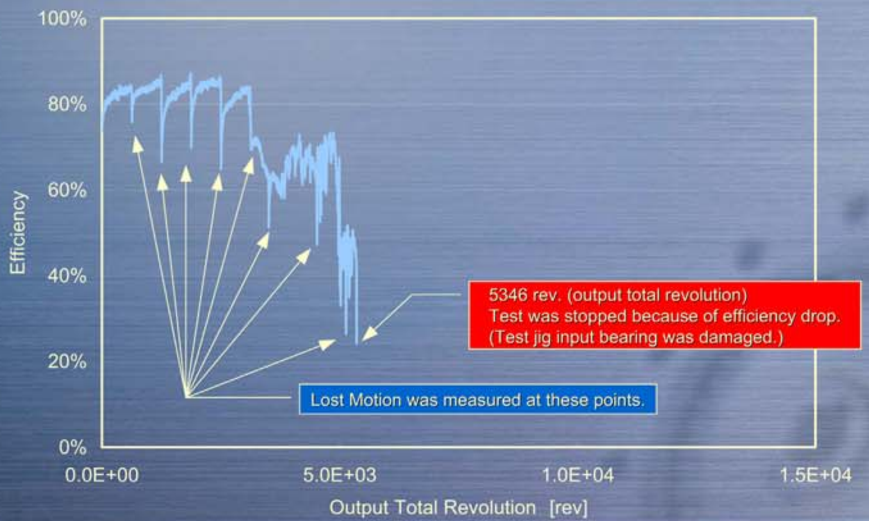
EM Test (Life Test)

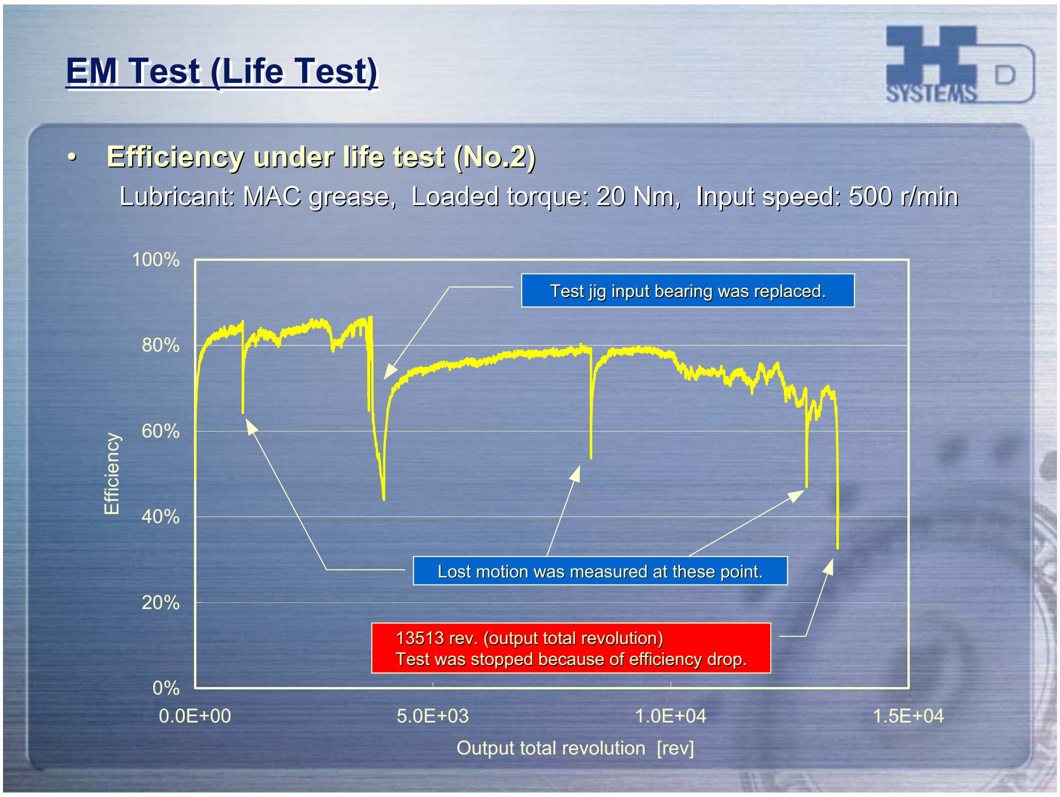
- Test Condition

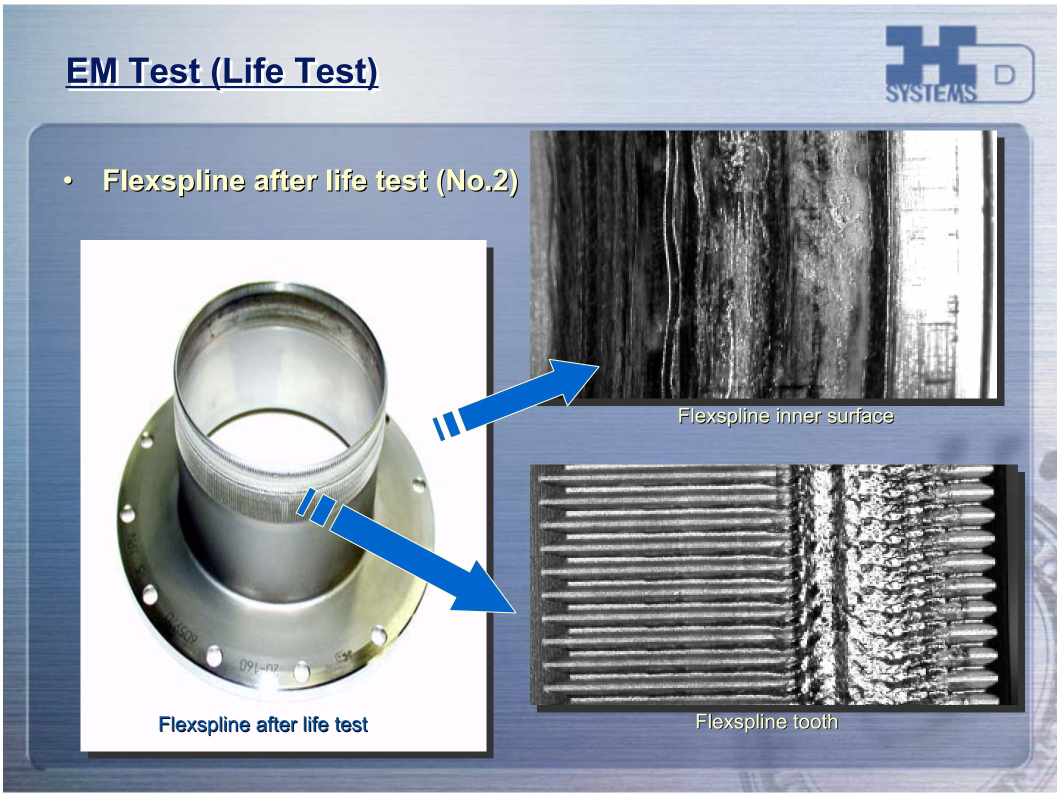
	No.1	No.2
Harmonic Drive®	Long Use Type (SHF-20-160-2A-GR-SP)	
Lubrication	MAC grease	
Input speed	500 r/min CW continuous	
Loaded torque	40Nm continuous	20Nm continuous
Temperature	Room temperature	
Vacuum Pressure	Less than $1X10^{-4}$Pa	
Verification	Efficiency、Increase of Lost Motion	
Requested life	$1X10^{6}$ rev. (output total revolution)	

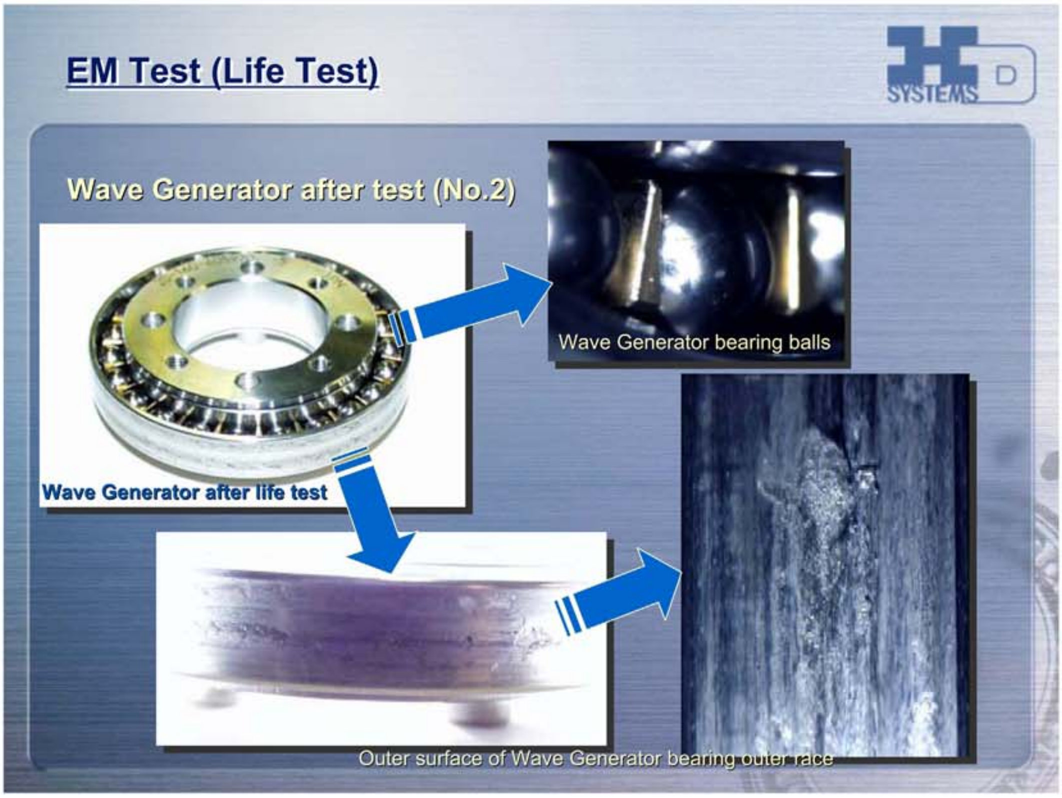
EM Test (Life Test)

- **Efficiency under life test (No.1)**
  Lubricant: MAC grease, Loaded torque: 40 Nm, Input speed: 500 r/min




EM Test (Life Test)
SYSTEMS
D
Efficiency under life test (No.2)
Lubricant: MAC grease, Loaded torque: 20 Nm, Input speed: 500 r/min
100%
80%
60%
40%
20%
0%
Efficiency
Test jig input bearing was replaced.
Lost motion was measured at these point.
13513 rev. (output total revolution)
Test was stopped because of efficiency drop.
0.0E+00
5.0E+03
1.0E+04
1.5E+04
Output total revolution [rev]


EM Test (Life Test)
SYSTEMS
D
Flexspline after life test (No.2)
Flexspline inner surface
Flexspline tooth
Flexspline after life test



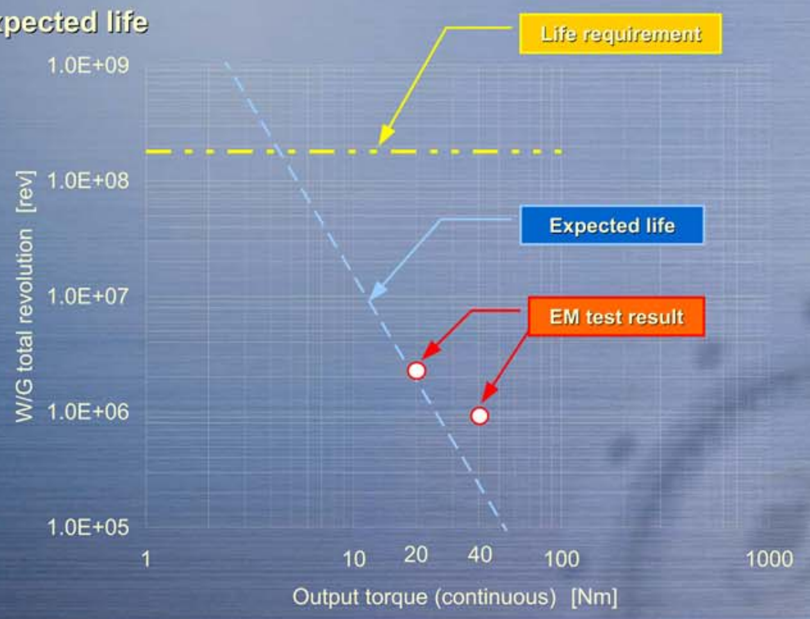
EM Test (Life Test)

- **Results of Life Test**

No.	Test condition	Output total revolution	Results
No.1	Output torque: 40Nm Input speed: 500 r/min	5346rev.) ※This test was stopped because of efficiency drop, but it found the cause was damage of jig bearing by investigation after test.	･The cause of efficiency drop was loss torque of input jig bearing. ･Harmonic Drive can still on operate though wear can be seen on the inside of Flexspline.
No.2	Output torque: 20Nm Input speed: 500 r/min	13513rev.	･The test was stopped because the efficiency drop rapidly. ･Remarkable wear can be seen on the Circular Spline teeth, Flexspline teeth and inside and outside of Wave Generator bearing outer race.

EM Test (Life Test)

- Expected life



Conclusion

- There is no damage of Harmonic Drive[R] under vibration test and thermal vacuum test.
- Lubrication under vacuum environment is a much tougher condition more than under atmosphere.
- To satisfy the life requirement, operating torque should be lowered.
- Process from wear start to the end of life should be investigate in future development.


株式会社 ハーモニック・ドライブ・システムズ
FINE MECHANICS & TOTAL motion CONTROL

Research activities of space materials sub-group

The 19th Microelectronics Workshop
JAXA
Electronic, Mechanical Components and Materials Engineering Group
Yugo Kimoto

Contents

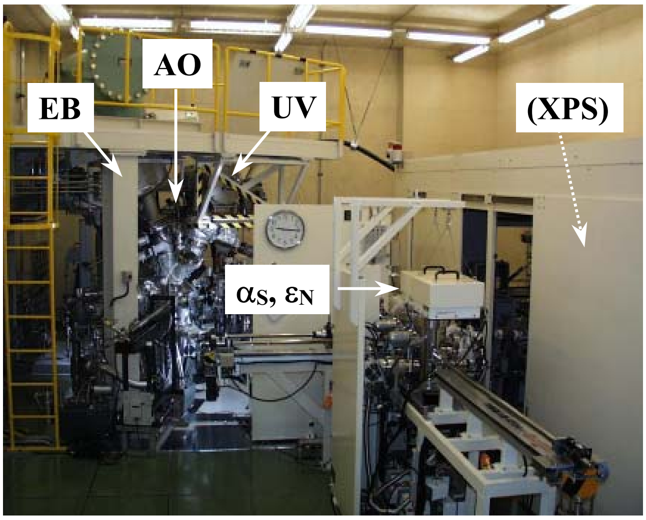
1. Research about the space materials
2. Research facilities in our lab
3. Material exposure experiment on the ISS and its highlight data
4. Outgas measurement test
5. Safety Verification Test
6. Materials Database System

1.Research about the space materials

- Research about the durability of the space materials
  - Establish and maintain the evaluation technology about space environment (space radiation, ultraviolet rays, atomic oxygen) for space materials applied to extra-surface of spacecraft.
    - Space material exposure experiment & its analysis
    - Irradiation service & consulting
    - Mutual evaluation of the space materials in cooperation with CNES
- Research about the advanced materials
  - Evaluation of the new materials superior durability in the space environment

2. Research facilities in our lab

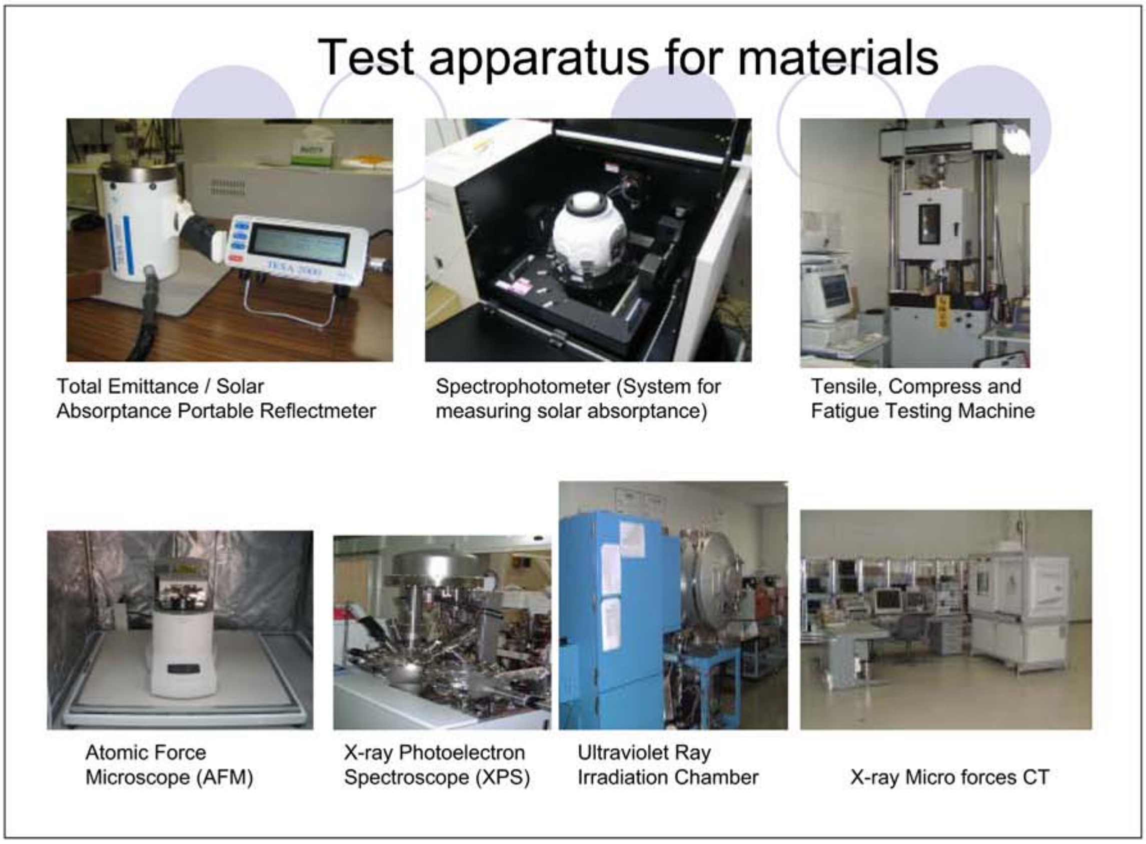
Combined Space Effects Test Facility

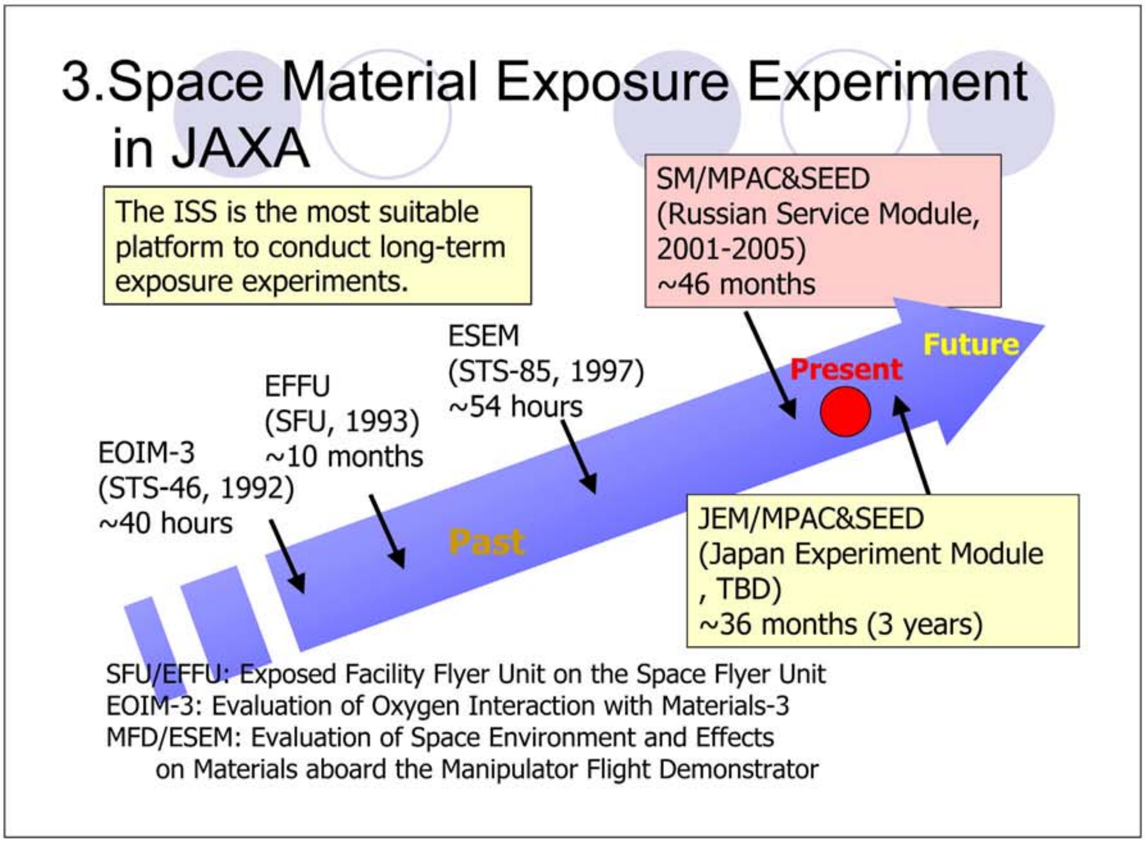


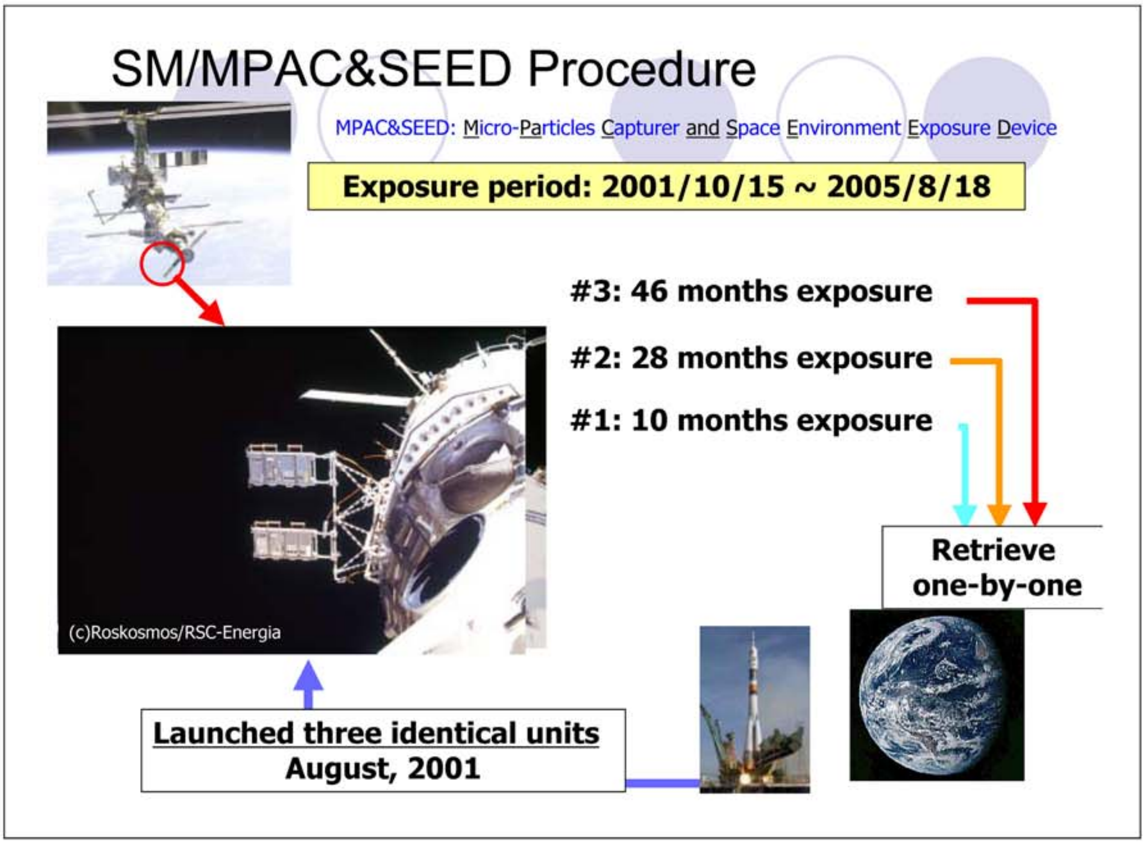
AO (PSI's FAST™ AO source)
Energy: 5 eV
Flux: 4E+15 atoms/cm²·s

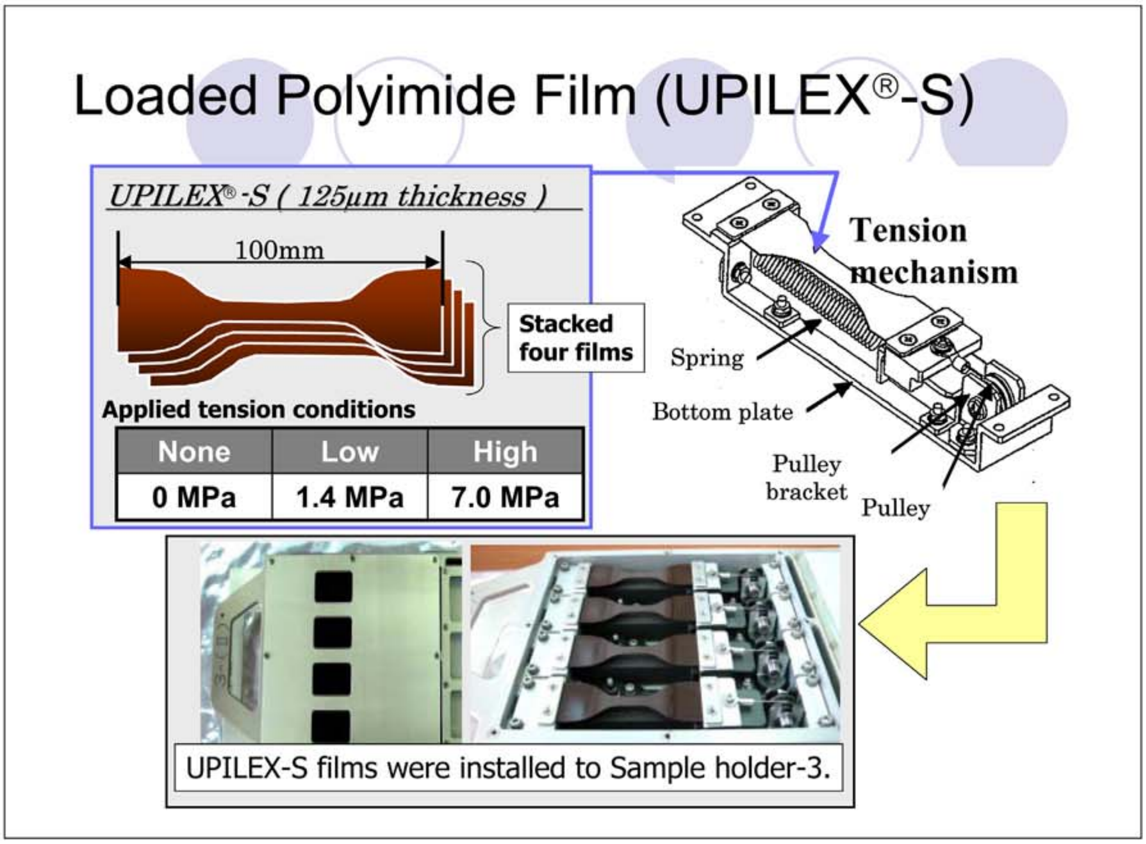
EB (Nissin-high voltage)
Acceleration voltage: 200~500 kV
Current: 0.2~2.0 mA

UV (Hamamatsu photonics)
Lamp: 48 deuterium lamps
Flux: 5 ESDs/day (120 nm - 200 nm)


Test apparatus for materials
Total Emittance / Solar Absorptance Portable Reflectmeter
Spectrophotometer (System for measuring solar absorptance)
Tensile, Compress and Fatigue Testing Machine
Atomic Force Microscope (AFM)
X-ray Photoelectron Spectroscope (XPS)
Ultraviolet Ray Irradiation Chamber
X-ray Micro forces CT


3.Space Material Exposure Experiment in JAXA
The ISS is the most suitable platform to conduct long-term exposure experiments.
SM/MPAC&SEED (Russian Service Module, 2001-2005) ~46 months
ESEM (STS-85, 1997) ~54 hours
EFFU (SFU, 1993) ~10 months
EOIM-3 (STS-46, 1992) ~40 hours
Past
Present
Future
JEM/MPAC&SEED (Japan Experiment Module , TBD) ~36 months (3 years)
SFU/EFFU: Exposed Facility Flyer Unit on the Space Flyer Unit
EOIM-3: Evaluation of Oxygen Interaction with Materials-3
MFD/ESEM: Evaluation of Space Environment and Effects on Materials aboard the Manipulator Flight Demonstrator

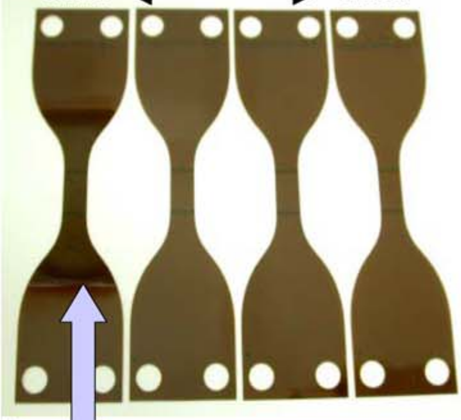

SM/MPAC&SEED Procedure
MPAC&SEED: Micro-Particles Capturer and Space Environment Exposure Device
Exposure period: 2001/10/15 ~ 2005/8/18
#3: 46 months exposure
#2: 28 months exposure
#1: 10 months exposure
Retrieve one-by-one
(c)Roskosmos/RSC-Energia
Launched three identical units
August, 2001


Loaded Polyimide Film (UPILEX®-S)
UPILEX®-S (125μm thickness)
100mm
Stacked four films
Applied tension conditions
None | Low | High
0 MPa | 1.4 MPa | 7.0 MPa
Tension mechanism
Spring
Bottom plate
Pulley bracket
Pulley
UPILEX-S films were installed to Sample holder-3.

Surface Condition of Retrieved UPILEX®-S

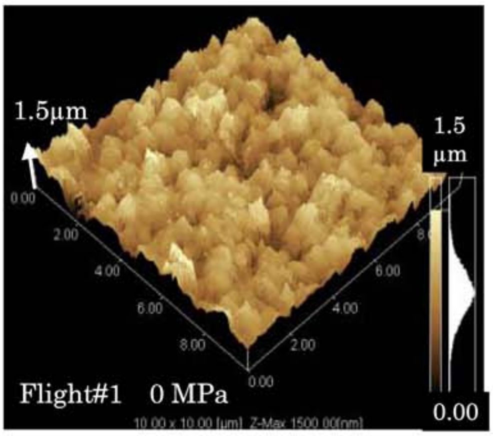
Surface Appearance

outer ↔ inner

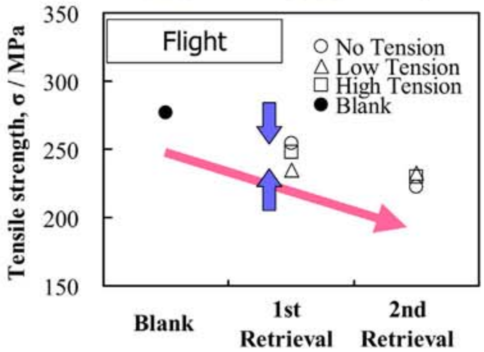


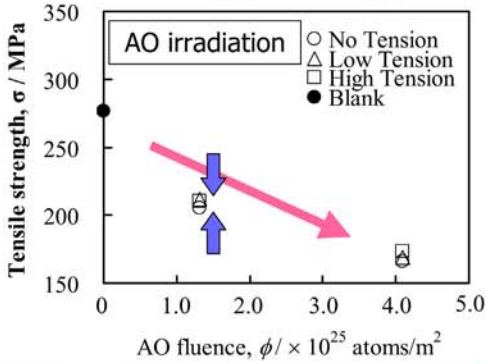
Bronzed only outermost layer.

Surface microstructure by Atomic Force Microscopy



Comparison of Flight and AO Irradiation Samples



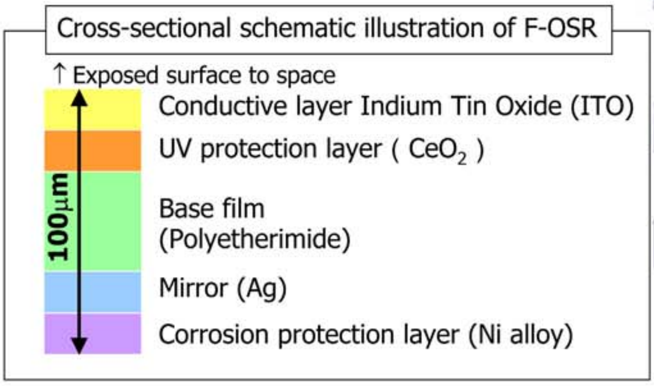


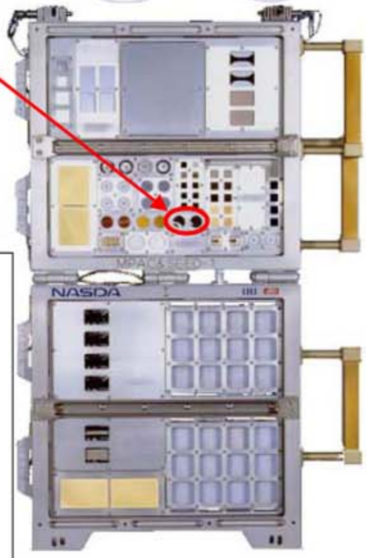
Decreases in tensile strength were observed on flight and ground AO- irradiated samples. ⇒ AO attack is a main factor of the degradation.

Applied tension of films during the exposure had no significant influence on their strength.

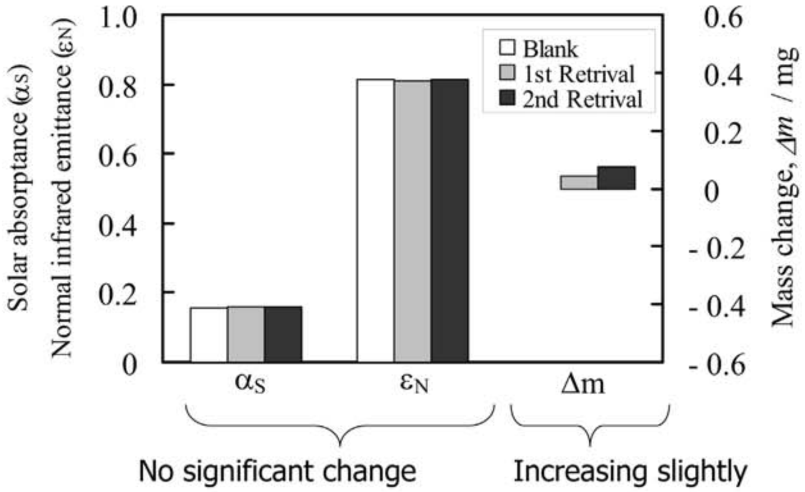
Flexible Optical Solar Reflector (F-OSR)

Dimensions : 25.4mmϕX0.1mmt
Exposure area : 20mmϕ



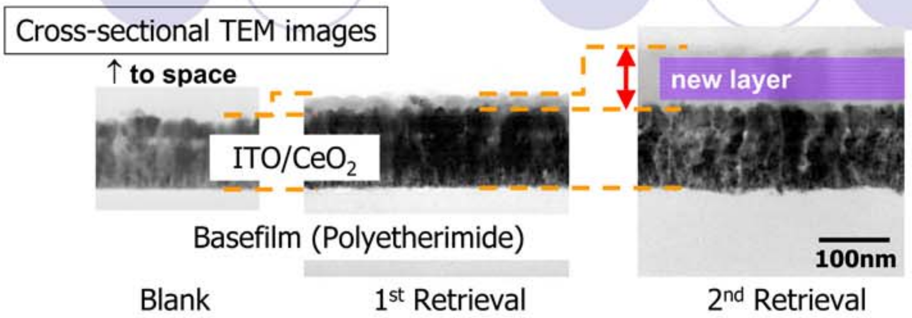


Thermo-optical property and mass change of F-OSR



High performance to a space environment exposure.

Cross-section microstructure of F-OSR



EDX analysis revealed that the new layer consists of silicon oxide (SiOx).

	Actual mass change ΔM (mg)	Condensed layer thickness (nm)	Calculated Condensed layer mass (mg) *
1st Retrieval	0.042	20	0.016
2nd Retrieval	0.071	80	0.065

* Calculated on the assumption that the condensed layer is whole SiO_2 (Density: 2.6 g/cm^3)

4. Outgas measurement test

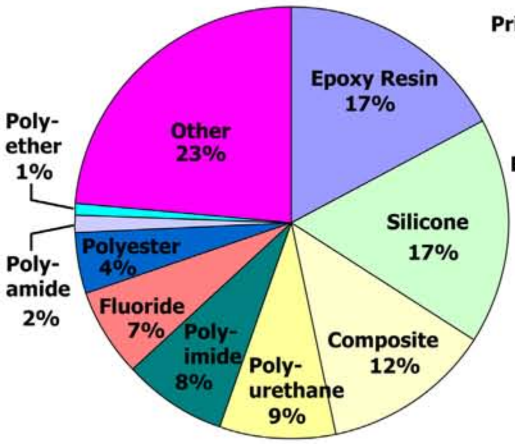
- ASTM E595
  "Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment"
  (American Society for Testing and Materials)

- Test Purpose
  - •To screen materials for space applications
  - •Obtain the outgas profile under thermal vacuum condition

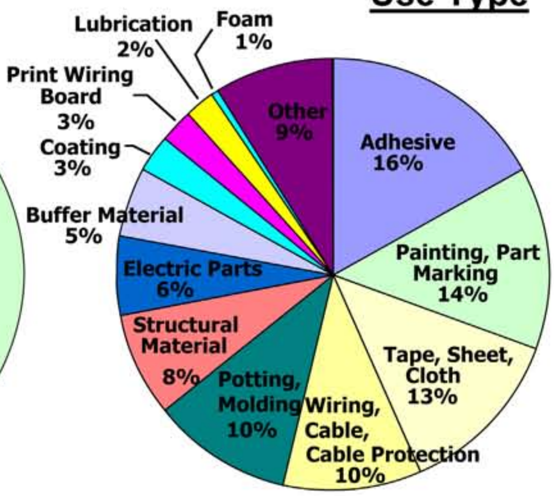
Outgas measurement test apparatus

JAXA Outgas Data (Approx.3300data 2005)

Material Type



Use Type



5. Safety Verification Test

Safety verification tests are tests required for payload equipment, parts and materials used in manned spacecraft such as the Japanese Experiment Module (JEM). A test consists of inflammability, odor and off gas tests. Since 1991, JAXA has been conducting tests, which are compliant with NASA document NHB8060.1C.

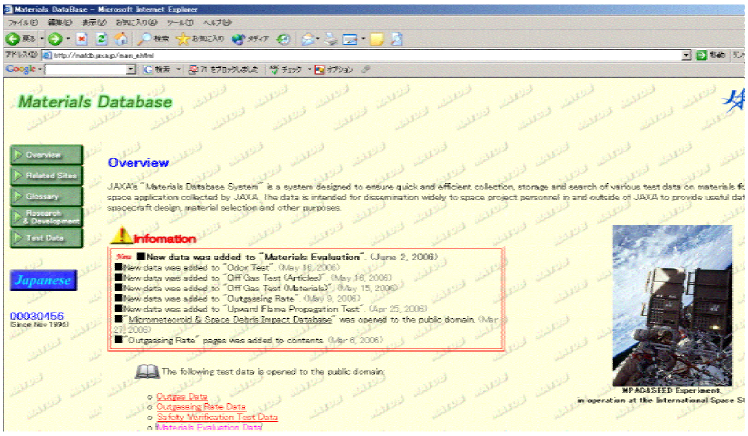
- Test1: **Upward Flame Propagation**
  - Incombustibility and self-extinguishing property of materials, as well as scattering retarding characteristic of combustion fragments that would ignite nearby materials, when a material is ignited by a standard flame source
- Test3: **Flash Point of Liquids**
  - A flashing point of a liquid
- Test4: **Electrical Wire Insulation Flammability**
  - incombustibility and self-extinguishing property when an electric wire insulating material is ignited by an external flame source and inflammability by an electrical load.
- Test6: **Odor Assessment**
  - An odor generated by a material or equipment
- Test7: **Determination of Offgassed Products**
  - Evaluation of compositions and amounts of offgases generated by a material or equipment
- Test8: **Flammability Test for Materials in Vented or Sealed Containers**
  - Whether or not a sealed or unsealed container withstands a flame in and outside of the container
- Test18:**Arc Tracking**
  - Resistance to arc tracking of an electric wire insulating material

Fire temperature and fire height measurement

Odor panel qualification Test

6. Materials Database System http://matdb.jaxa.jp

- ✓Test data on materials for space application collected by JAXA.
- ✓The following test data is opened to the public domain:
  - ✓Outgas Data
  - ✓Outgassing Rate Data
  - ✓Safety Verification Test Data
  - ✓Materials Evaluation Data (UV, AO, EB)
  - ✓Space Experiment Data (Space material exposure experiment, Micrometeoroid & space debris impact data)



Evaluation on Wire Covering Degradation (Investigation of ADEOS-II Malfunction)

Electronic, Mechanical Components
and Materials Engineering Group
Institute of Aerospace Technology
Japan Aerospace Exploration Agency (JAXA)

Junichiro Ishizawa
Naoko Baba

Introduction

Midori-II (Originally called the Advanced Earth Observing Satellite-II (ADEOS-II)) stopped supplying observation data due to an electrical power failure.

Fault Tree Analysis (FTA) suggested that a break or short circuit in the power-supply harness between the solar array paddle subsystem and the electrical-power subsystem was the most probable cause.

Each phase of the failure scenario was tested and analyzed, and then material degradation was evaluated for failure verification.

In October 2003, a solar paddle on Midori-II (ADEOS-II) ceased providing electrical power.

FTA determined that the most probable fault locations were the power system and the wiring harness.

Our evaluation determined that the wire insulator had the highest possibility of triggering the failure.

Supposed scenario of malfunction

[Before power supply failure]
1)Multi layer insulation (MLI) charging
(Ungrounded MLI was charged while in the shadow or aurora zone.)

2)A cut on the wire insulator of the harness

3)Trigger arc between the MLI and the harness
/Single arc between damaged harnesses

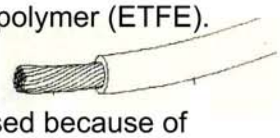
[Break out power supply failure]
4)Continuous discharging between a pair of harnesses

5)Arc spreading to an adjacent harness
→ A pair of harnesses develops a short or open circuit from heat damage caused by continuous discharging, a common occurrence.

Wire insulator

- MLI wrapped harness of 106 cables.

- Raychem Spec 55/ AWG22 (outer diameter: 1.09mm)
  Strand wire (silver-coated copper wire)
  Radiation cross-linked ethylene-tetrafluoroethylene copolymer (ETFE).
  Wall thickness : 0.15mm



Cf. Polyimide or Fluoropolymers (e.g., PTFE) are often used because of their heat resistance.
ETFE is inferior to PTFE in heat and arc tracking, and greatly superior to PTFE in formability.

Radiation cross linking or cross linking agent are used to increase the mechanical properties of ETFE at elevated temperature, causing the ETFE to become rubbery and preventing it from melting.

Raychem 55/ is cross-linked by an electron beam after the wire is covered.

Evaluation philosophy

Raychem 55/ wire has been proven robust in many flights.
→ The main factor in its degradation :
Midori-II's unique high-temperature cycle,
reaching the crystalline melting point of ETFE
(far beyond the derated temperature).

- Highest temperature (estimation): 230℃±10～15℃
- Thermal endurance (Spec.)：200℃, 10,000hr
- Crystalline melting point： 236℃ （measured by DSC）

Evaluation of discharge

Single wire

Discharging test after heat-cycle test

→ No discharging was observed.

Tied harness (Midori-II configuration)

Discharging was occurred after the heat-cycle test.

Discharging caused cracking, with charring and blackening of the wire insulator.

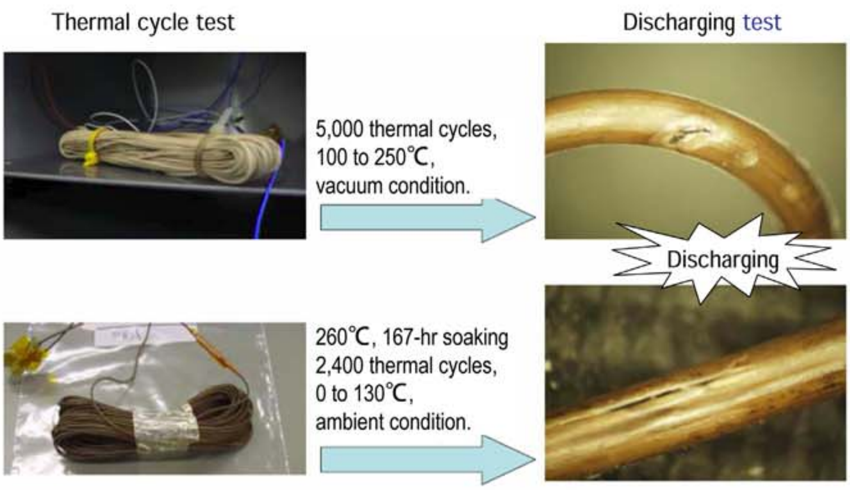
Possible scenarios:

Reduced insulation, damage to covering caused by discharging,

or

insulator damage causing discharging.

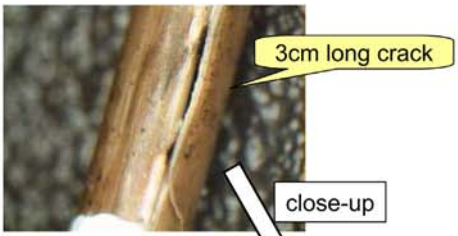
Thermal cycle tests on tied harness



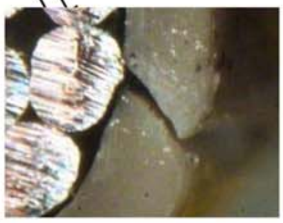
Discharging was observed.
Cracks were visible on insulator after discharging.

Visual observation of cracks


Crack A



Crack B



Crack opening :
large, long, smooth
Cracks differed from the fractured surface on normal polymeric materials.
The depressed area included abrasions.
There seems to be little possibility of such a large heat strain for the heat-cycle conditions based on estimates from Midori-II telemetry data.
→ We determined that the crack morphology is peculiar to this material.

Fracture morphology

- Fractured surfaces were similar to those of rubber material in tensile stress.

Cross linking was the source of rubber-like elasticity in polymers.

- Radiation cross-linked ETFE：

Rubbery state near the crystalline melting point.
Visible cracks after the discharging test occurred near the crystalline melting point.

- Some radiation cross-linked material:

Shape recovery phenomenon above the crystalline melting point.
Anomalous cracks seems to be related to this phenomenon.

Soldering iron test (preliminary experiment)

Heating the covering with a soldering iron

Covering cracked after heating with soldering iron

Crack: Lengthwise or oblique direction, smooth and open.

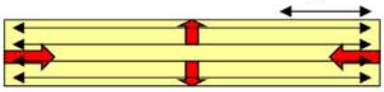
Wire insulator：Remaining stress or oriented texture in lengthwise direction.

【Stress relaxation】 Lengthwise direction : Compressive

Circumferential direction: Tensile

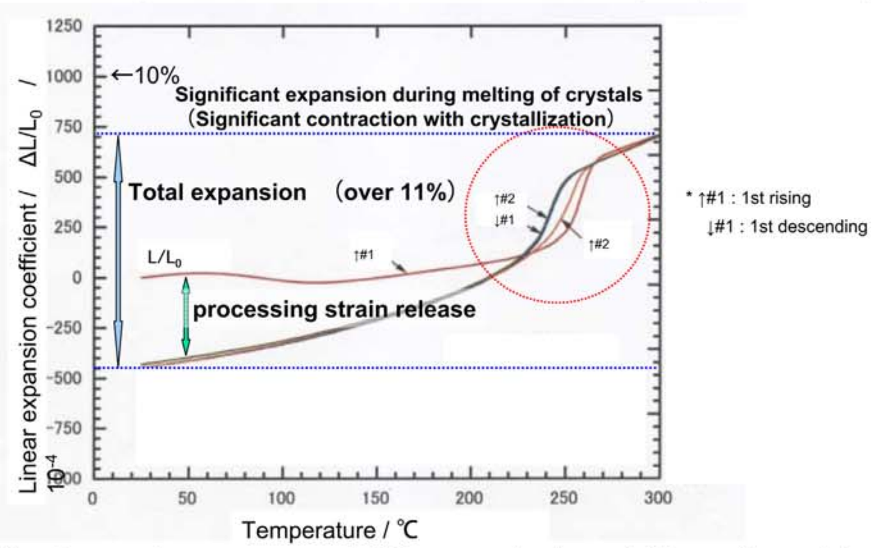
For confirmation

: Tensile tests and thermal expansion measurements in circumferential direction.



Thermal expansion measurements in the circumferential direction

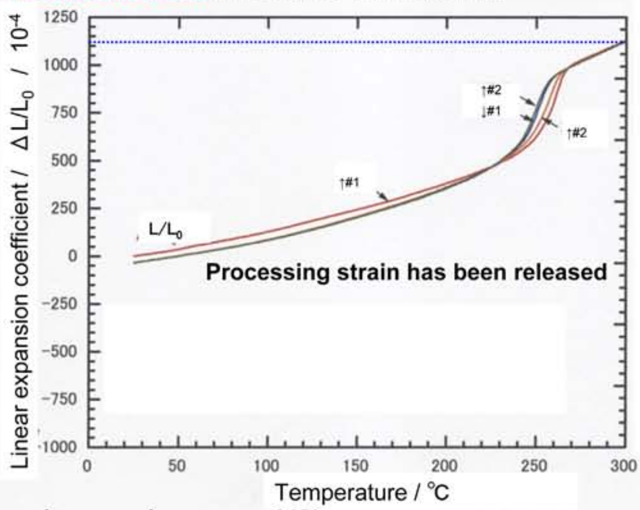
TMA （Non-heated specimen） TMA : Thermo-mechanical analysis (Tension mode)



Significant expansion was measured at the approximate crystalline melting point.

Thermal expansion measurements in the circumferential direction

TMA（Heated specimen : 245℃, 169-hr in vacuum）

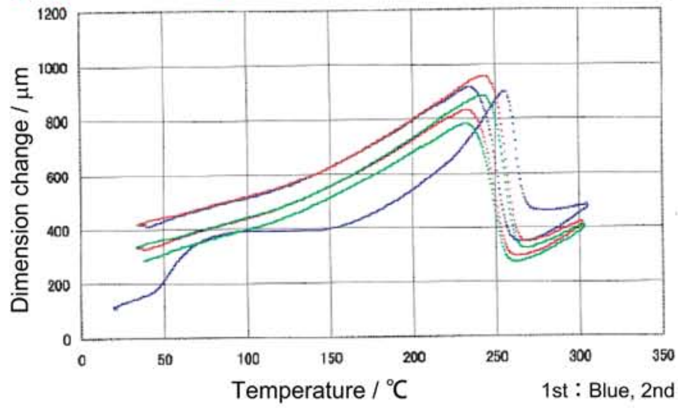


* ↑#1 : 1st rising
↓#1 : 1st descending

Thermal expansion : over 11%
Significant expansion was measured at the approximate crystalline melting point.

Thermal expansion measurements in the lengthwise direction

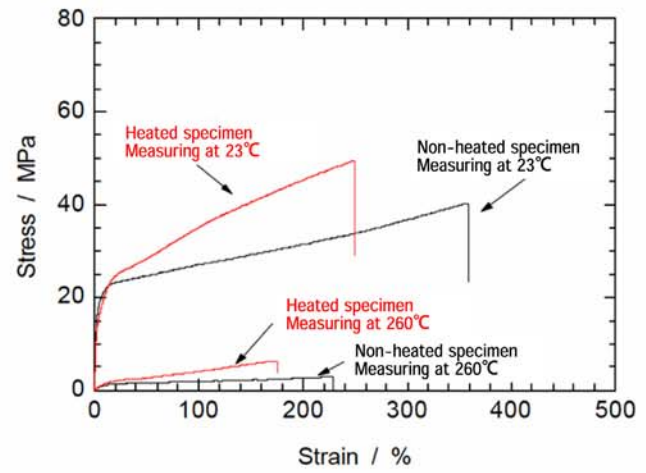
TMA （γ-ray irradiatied specimen : 10 months exposure Midori-II ）



1st : Blue, 2nd : Red, 3rd : Green line

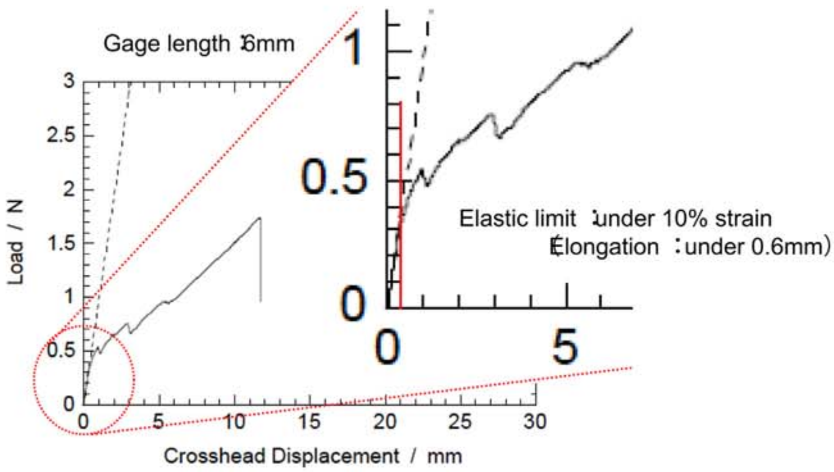
Opposite behavior (Expansion, Contraction) from the circumferential direction at the approximate crystalline melting point.
Inverse strain and ablation probably occurred at the crossing points of the cable of the tied harness in the Midori-II thermal-cycle environment.

Tensile tests in the circumferential direction



Insulator materials reduced in elongation by 169-hr exposure at 260℃.
Maximum stress and strain decreased at 260℃.

Tensile tests in the circumferential direction



Thermal expansion (over 11%) > Elastic limit (under 10%)
Possibility of plastic deformation
(Additional testing is required for more credible assurance.)

Mechanism of crack formation

Crack-forming mechanism

At cable crossing points in tied harness:

- **Cracks with abrasion were observed after thermal-cycle tests.**
- **Tied harness bonded together at temperatures greater than 230℃. (Other test results)**

- **Bonding points prevent stress relief of the harness in the thermal cycle.**
- **Abrasions could occur that would cause cracks and reduced thickness.**

Thermal cycle

↓

Abrasion and thickness reduction of cable-covering material

and

repetitive thermal strain, including significant expansion and contraction around the crystalline melting point

↓

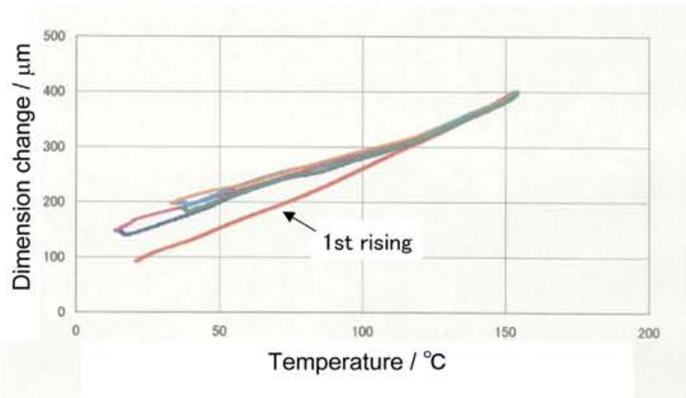
Crack (Initiation and extension)

In addition, electron-beam exposure and a vacuum environment of high temperatures for an extended time possibly contributed to the damage of the materials.

Temperature conditions for safe use

Thermal strain from 150 to 250 ℃, 3cycles

DMA（Dynamic Mechanical Analysis）on Raychem spec55/ AWG22 cable covering



Only 2% strain were measured.

Modest heat strain from room temperature to 150℃.

Summary on Midori-II verification

- Verification studies conducted for the cable failure in Midori-II (ADEOS-II) showed that at high temperatures, approximately at the crystalline melting point, significant expansion and contraction occurred in the insulator material.
- Due to total heat strain reaching the plastic range, repetitive plastic deformation and abrasion likely damaged the covering materials.
- Significant expansion and contraction were not detected for thermal cycles below 150 ℃ (at maximum temperature).

→ Raychem 55/ wire could be used at temperatures up to 150℃

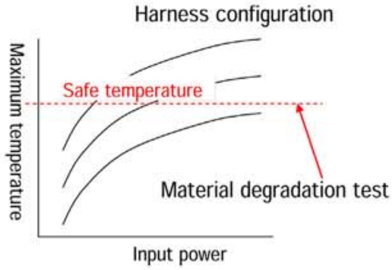
Standards for satellite design

- JAXA is revising standards for satellite design.

Derating for harness (Power and signal line)

- Material degradation test: temperature limit
- Temperature rise test using continuous current

→ Derating standards for satellite harness



COTS Reliability
All COTS Devices Are Not Created Equal

- Author ; Christine Pollock, Maria Petkova and Alan Devoe
  from Presidio Components, Inc.

- Speaker ; Hiroaki Yamamoto （山本博章）
  From PTM Corporation

PRESIDIO COMPONENTS, INC.

Outline

- **Present Test Data for BME/PME COTS Part 0805 / .1 uF / 50 volt rated**
- **Discuss Mil Qualification Requirements**
- **Examine 125C Performance In Detail**
- **Examine Other Performance Factors**
- **Discuss Differences Between BME/PME**

PRESIDIO COMPONENTS, INC.

Part Selection .1 uF/50 Volt Rated

Attributes	COTS	Presidio	QPL
Case Size	0805	0805	CDR04 (1712) CDR33 (1209)
Electrode System	Ni (X7R)	PdAg (X7R)	PdAg (BX)
Dielectric Thickness	.4-.5 mils	.9 mils	1.5 mils 1.1 mils
Dielectric Material	K=2500	K=4000	K=2600
TC (-55/+125C)	+/-15%	+/-15%	+/-15%
VTC (-55/+125C)	-60% @ 50 V	-40% @ 25 V	-25% @ 50 V
Insulation Resistance 125C	0.6 – 6 GΩ	10 GΩ	50 GΩ
Voltage Breakdown	675 - 2650	1100	>2000
Qualification Basis	Not Standard	Std Mil-PRF-55681 Testing	Established Reliability S Level
Cost	¢	¢¢	$$
Delivery	2 Weeks	10 Weeks	26 Weeks

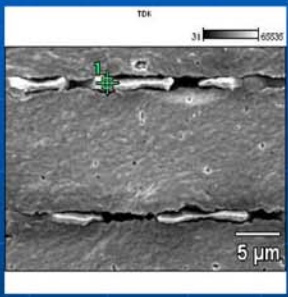
PRESIDIO COMPONENTS, INC.

Dielectric Performance

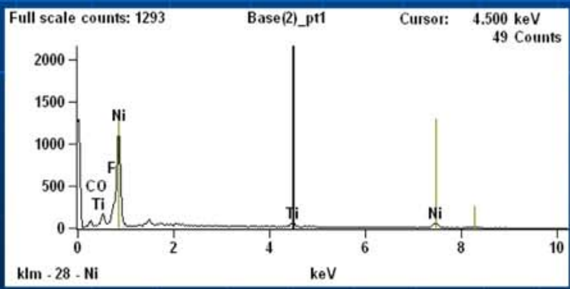
- X7R
  - Temperature Range -55 to +125C
  - IR At 25C 10GΩ
  - IR At 125C 1GΩ
- X5R
  - Temperature Range -55 to +85C
  - IR At 25C 5GΩ
  - IR At 85C .5 GΩ

PRESIDIO COMPONENTS, INC.

Typical Construction



BME-D
Excellent Microstructure
No Defects Noted In DPA
All Ni Electrodes
All Lots Fail Life Test



PRESIDIO COMPONENTS, INC.

Comparison of Properties and Life Test Performance

	Dielectric Thickness	Voltage Breakdown	Initial IR 125C	Failures At 0 Hours Life	Final IR 125C	Failures IR 125C At 2000 Hours Life	Acc Hours (Millions)
Specified Limit			1 GΩ		0.3 GΩ		
BME-A	0.49	2642	6.2	0/130	2.20	31/130	2.080
BME-B1	0.58	674	2.2	0/130	1.80	21/130	2.080
BME-B2	0.58	1207	2.6	0/130	0.1	118/130	2.080
BME-C	0.49	2324	1.5	0/130	1.6	4/130	2.080
BME-D	0.49	1732	1.8	2/130	0	130/130	2.080
BME-E	0.49	1806	0.6	130/130	0.25	99/130	2.080
BME-F	0.39	1496	0.8	78/78	0.75	0/78	1.248
BME-G1	0.49	1257	2.8	0/130	2.50	1/130	2.080
BME-G2	0.49	unknown	3.5	0/49	2.50	3/49**	0.784
BME-H	0.58	923	1.1	48/130	0.55	3/130	2.080
PME	0.90	1112	10.2	0/197	12.0	0/197	11.50***

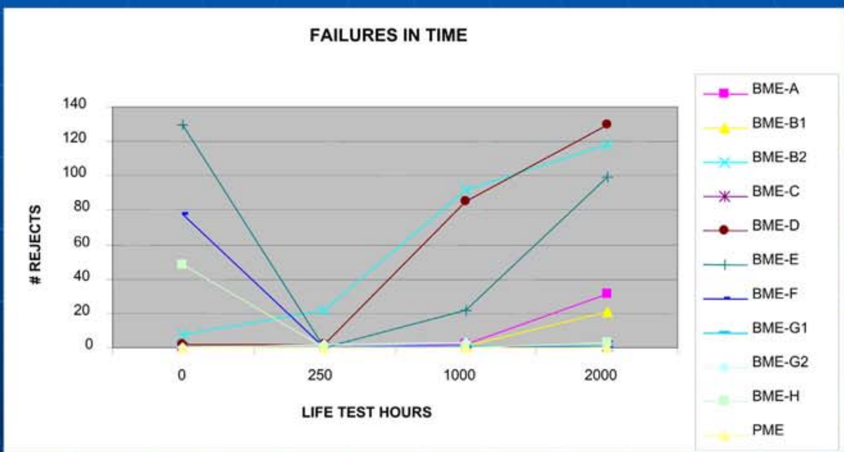
PRESIDIO COMPONENTS, INC.

Min/Max IR

	Before Life		After Life	
	Low	High	Low	High
BME-A	4.4	7.2	0	15
BME-B	1.0	3	0	3.0
BME-C	1.7	2.6	0.1	2.1
BME-D	1.5	2.9	0	0.02
BME-E	0.3	0.7	0	0.3
BME-F	0.5	1	0.5	2.5
BME-G	1.5	5.0	0.1	2.5
BME-H	0.7	4.6	0.2	0.6
PME	>10		>30	

PRESIDIO COMPONENTS, INC.

Life Test Results



PRESIDIO COMPONENTS, INC.

Mil-PRF-123 Look Alike

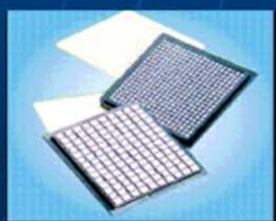
Extended Range For NASA

- Replaced 1808 .1uF With 0805 .1uF
- Tested IAW Mil-PRF-123
- Mil-PRF-123 Does Not Allow BME

PRESIDIO COMPONENTS, INC.

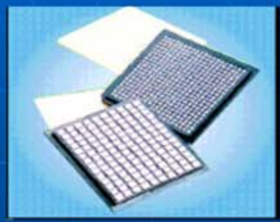
DSCC Extended Range

- DSCC Drawings
  - DSCC 03028……….0603 Size
  - DSCC 03029……….0402 Size
  - DSCC 05006……….0805 Extended Cap
  - DSCC 05007……….1206 Extended Cap
- Does Not Specify Electrode Type
- Group C Optional – Customer Specified



PRESIDIO COMPONENTS, INC.

BME Summary

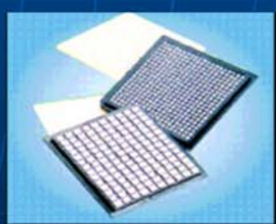


- BME does not meet X7R requirements at 125C
- Currently no part number differentiation between BME/PME
- Fallout not due to infant mortality
- No standard qualification routine
- Not suitable for military applications

PRESIDIO COMPONENTS, INC.

PME Summary

- PME does meet X7R requirements at 125C
- Fallout is due to infant mortality
- Standard qualification routine
- Suitable for military/space applications



PRESIDIO COMPONENTS, INC.

19th Microelectronics Workshop

Non-Destructive Inspection Method of BGA Using X-ray Systems for High-Density Mounting Space Applications

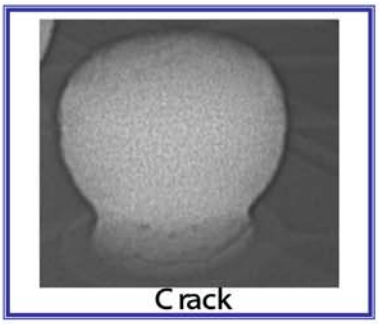
Masao Nakamura○, Hirotaka Azuma,
(Nippon Avionics Co., Ltd.)
Toshiyuki Yamada
(Fukushima Avionics Co., Ltd.)
Tsuyoshi Nakagawa, Norio Nemoto, Koichi Shinozaki
(Japan Aerospace Exploration Agency)

October 27, 2006

1

Outline

- Background
- Major Defects of BGA
- Inspection Method
- Results
- Summary
- Tasks



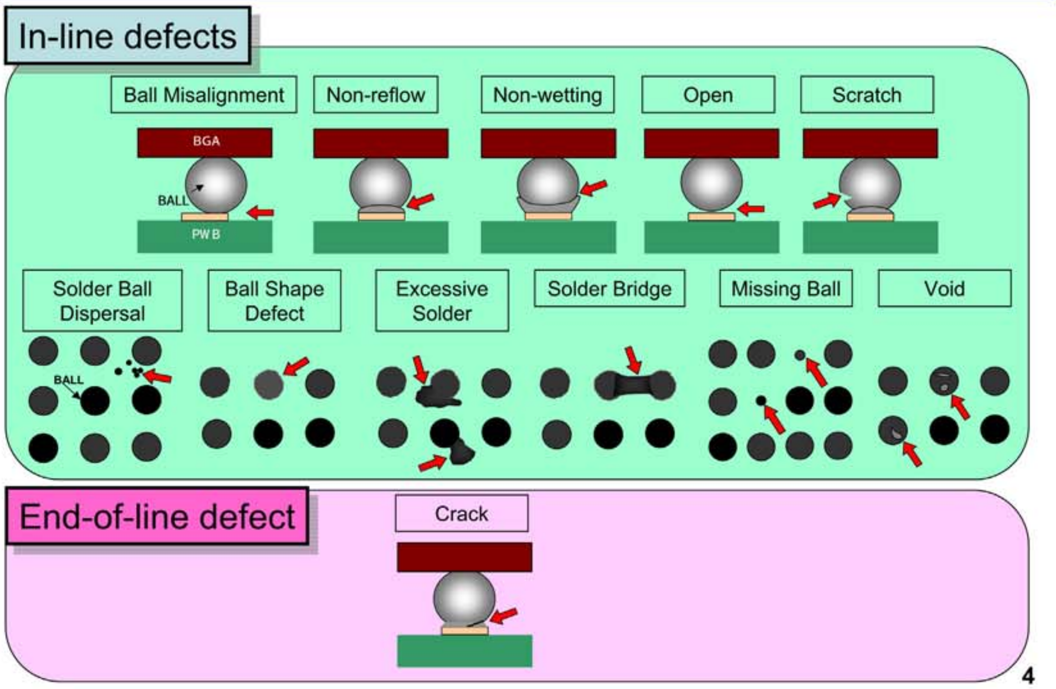
2

Background

- Recently, demands of high-density mounting technique for miniaturization of space applications have increased.
- We are considering to apply BGA packages to space applications as a solution of high-density mounting.
- A critical issue of BGA package is that inner balls cannot be inspected by a conventional visual inspection method.
- In these circumstances, we focus on inspection methods of BGA using X-ray systems.

3

Major Defects of BGA

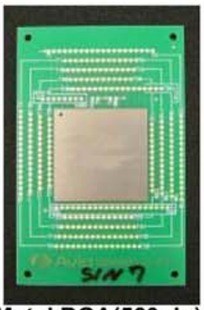


4

Inspection Method

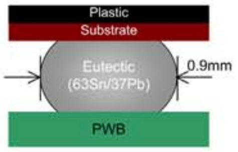
BGA Samples

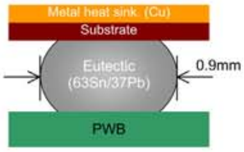
Plastic BGA (388pin)

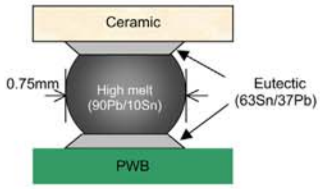


Metal BGA(560pin)

Ceramic BGA (400pin)







- **Number of Layers** : **Six Layers**
- **Pattern** : **Daisy Chain**
- **Pitch** : **1.27mm**
- **PWB Material** : **FR-4**
- **PWB Size** : **77.5mm(W) X 120mm(D) X 1.6mm(T)**

5

Inspection Method (cont.)

Specification of X-Ray Systems

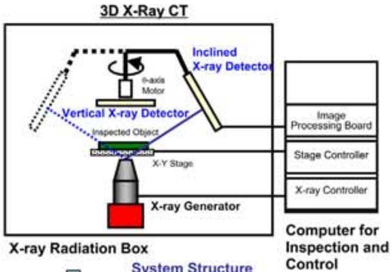
Apparatus	Microfocus X-ray(I.I.)	Microfocus X-ray(FCR*)	Microfocus X-ray(FPD**)	3-D X-ray CT
X-ray tube	Sealed X-ray tube	Sealed X-ray tube	Open type X-ray tube	Open type X-ray tube
X-ray detector	Image Intensifier (I.I.)	Imaging Plate (IP)	Flat panel (Six megapixels)	Flat panel (Six megapixels)
Detector Gray-scale	256 gray-scale	1024 gray-scale	4096 gray-scale	4096 gray-scale
Condition	Focal spot size :7um Tube voltage :150kV Tube current : 66μA	Focal spot size :7um Tube voltage :150kV Tube current : 66μA Irradiation time :40s	Focal spot size :1-4um Tube voltage :100-120kV Tube current : 100-150μA	Focal spot size :1-4um Tube voltage :100-120kV Tube current : 100-150μA
Image processing	Digital image processing	Digital image processing	Digital image processing	Digital image processing

* FCR : Fuji Computed Radiography (FUJI PHOTO FILM CO.,LTD)
**FPD : Flat Panel Detector

FCR System

(Non-Destructive Inspection Co., Ltd.)

3D X-Ray CT



System Structure

http://www.oe.nagoya-denki.co.jp/contents/products/nlx/NLX5000e_forweb.files/index.html

6

Results

Result

No.	Defect Item	Apparatus I.I.	FCR	FPD	3-D X-ray
1	Ball Misalignment	***	***	---	---
2	Non-reflow	***	***	***	***
3	Non-wetting	***	***	***	***
4	Open	***	***	---	---
5	Scratch	***	***	---	---
6	Solder ball dispersal	**	***	---	---
7	Ball shape Defect	***	***	---	---
8	Excessive Solder	***	***	---	---
9	Solder Bridge	***	***	---	---
10	Missing Ball	***	***	---	---
11	Void	**	***	**	***
12	Crack(CeramicBGA)	*	**	**	***
	Crack(Plastic/MetalBGA)	*	*	*	***

Items 1–11: In-line defects
Item 12: End-of-line defects

*** :Detectable, ** :Depend on position, * :Undetectable

--- :N/A

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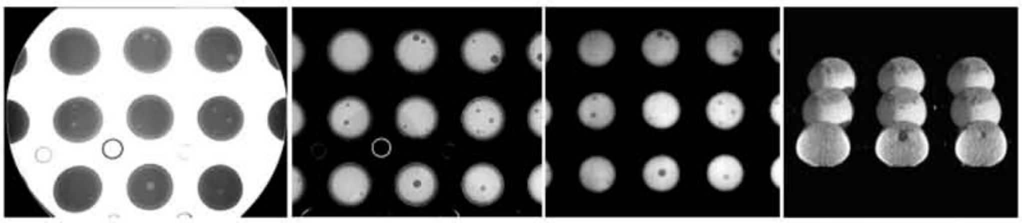
Results (cont.)

Example of In line Defects (cont.)

- Void (Plastic BGA)

Detectable | Detectable | Detectable | Detectable



Microfocus X-ray(I.I.) | Microfocus X-ray(FCR) | Microfocus X-ray(FPD) | 3-D X-Ray CT

It is possible to know the void position using 3-D X-ray CT.

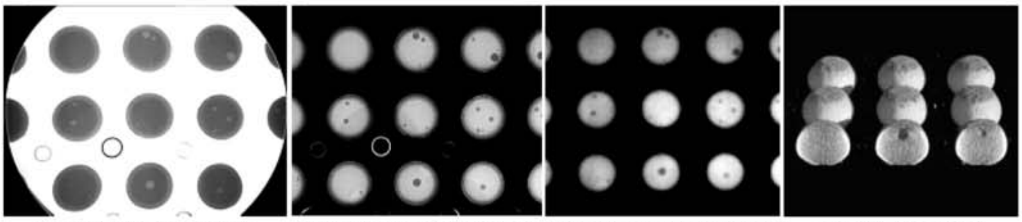
9

Results (cont.)

Example of In line Defects (cont.)

- Void (Plastic BGA)

Detectable | Detectable | Detectable | Detectable



Microfocus X-ray(I.I.) | Microfocus X-ray(FCR) | Microfocus X-ray(FPD) | 3-D X-Ray CT

It is possible to know the void position using 3-D X-ray CT.

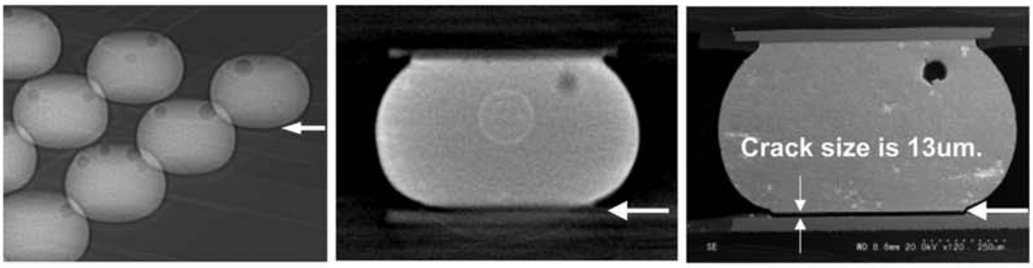
9

Results (cont.)

Example of End-of-line Defect

- Crack(Plastic BGA)

Undetectable | Detectable



Microfocus X-ray(FCR) | 3D X-ray CT | DPA

3-d X-ray CT allows us to detect the crack which is undetected by microfocus X-ray.

10

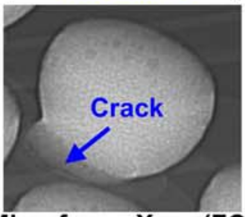
Results (cont.)

- **Crack of Ceramic BGA**

Undetectable

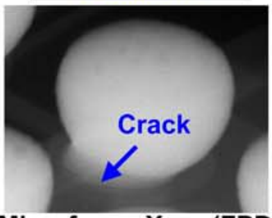
Microfocus X-ray(I.I.)

Detectable



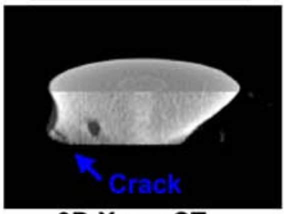
Microfocus X-ray(FCR)

Detectable

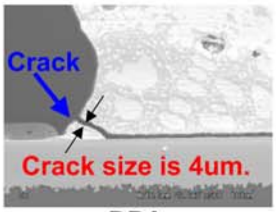


Microfocus X-ray(FPD)

Detectable



3D X-ray CT



DPA

Crack of Ceramic BGA was detected by both microfocus X-ray and 3-D X-ray CT .

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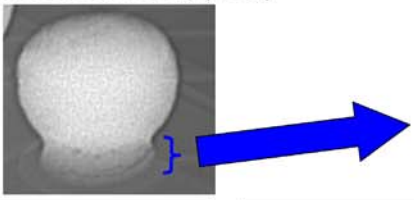
Results (cont.)

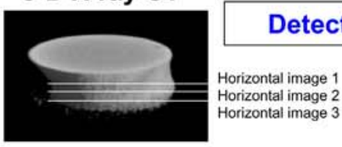
- **Capability of 3D X-Ray CT System**

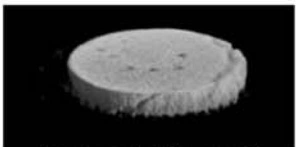
Microfocus X-ray(FCR)



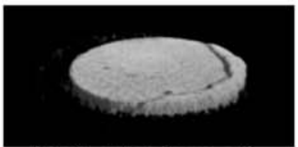
3-D X-ray CT

Detectable

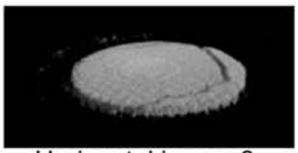




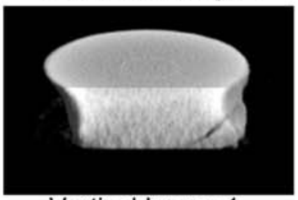
Horizontal image 1



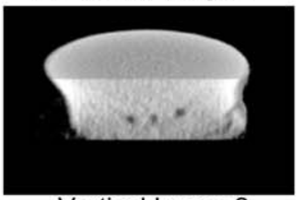
Horizontal image 2



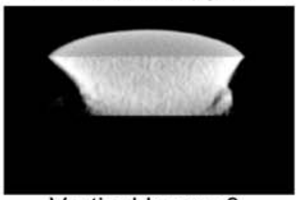
Horizontal image 3



Vertical Image 1



Vertical Image 2



Vertical Image 3

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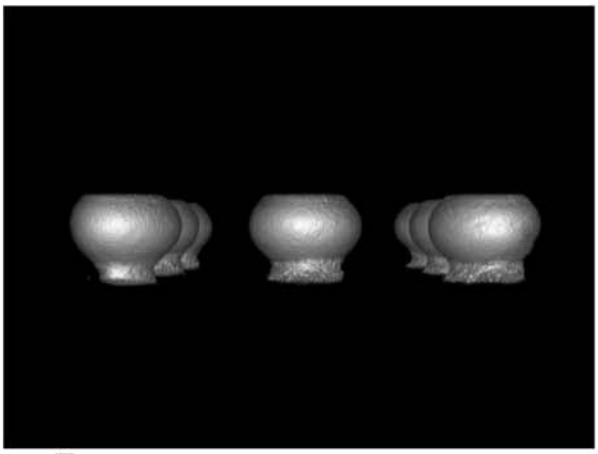
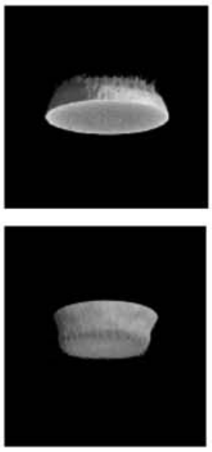
Results (cont.)

- **Capability of 3D X-Ray CT System (cont.)**

3D image at this study





http://www.oe.nagoya-denki.co.jp/contents/products/nlx/NLX5000e_forweb.files/index.html

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Summary

- **In-line defects of BGA can be detected by microfocus X-ray(I.I./FCR/FPD) or 3-D X-ray systems.**
- **It is possible to detect solder cracks by 3-D X-ray CT system.**
- **We hope that X-ray inspection is an effective way to evaluate the quality of BGA assembly when applied for space applications.**

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Tasks

- Evaluation of X-ray inspection capability on an actual flight module or a test vehicle.
- Upgrading and expanding of our design rules of PWB for BGA mounting.

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今回報告したBGAの非破壊検査技術をまとめた技術資料がございます。ご興味のある方は下記メールアドレスに①氏名、②会社名、③住所、④連絡先（電話、FAX、E-mail）、⑤ご意見・ご要望等をお送りください。

宇宙航空研究開発機構　安全・信頼性推進部

E-Mail : HDMTECH@jaxa.jp

Consideration of RoHS issues and Evaluation of Hot Solder Dipping Method for Tin Whisker

October 2006

Safety and Mission Assurance Department
Electronic, Mechanival Componets and Materials Engineering Group
Japan Aerospace Exploration Agency (JAXA)

1

1. Background

EU has enacted two directives, RoHS and WEEE, that prohibit the use of Pb, Cd, Cr^{6+}, Hg, PBB and PBDE in products for the EU consumer market since July 2006. One of the key elements in these directives is Pb, which had been widely used in electric components such as solder and parts terminations. Although these regulations only affect products for sale in the EU, many manufacturers in the world have shifted to lead-free products.

1. JAXA continue to use parts containing SnPb for space applications.
2. Purchase of the parts and materials that contains lead is becoming difficult.
3. Reliability problems of lead-free parts and materials may surface in space applications.

***1:RoHS(Restriction of the use of certain Hazardous Substance in electrical and electronic equipment)：**
http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf
WEEE(Waste Electrical and Electronic Equipment)：
http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00240038.pdf

2

2. Effects of RoHS in Consumer Market

【Trend】

- RoHS & WEEE directives prohibit the use of lead in consumer products in EU after July 2006.
- In several states in the U.S., a similar "green" law has enacted.
- In China, a similar directive to RoHS will be enacted in March 2007.
- Many parts manufacturers in the world have shifted to lead-free products.
- In Japan, "JIS C 0950; J-MOSS" that is not similar to RoHS was enacted in Dec. 2005.
- J-MOSS does not prohibit the use of lead, but requires to indicate the usage of lead.*
- Many Japanese parts manufacturers also shifted to lead-free products.

* http://www.meti.go.jp/policy/recycle/main/3r_policy/policy/j-moss.html

3

3. Effects of RoHS in Aerospace Market

At present, the products for military and aerospace usage are outside the RoHS directives. But lead-free parts are widely sold in the market along with lead-containing parts. This could induce misuse of the parts and result in a failure in space applications.

【NASA】
- ◆Lead-free problem such as tin whisker is being researched
- ◆**Use of lead-free parts for space applications has been forbidden.**
- ◆The roadmap to lead-free parts usage for space applications is not specified.

【ESA】
- ◆**Use of lead-free parts for space applications has been forbidden.**
- ◆The roadmap to lead-free parts usage for space applications is not specified.

【JAXA】
- ◆**Use of lead-free solder for space applications has been forbidden.**
- ◆The roadmap to lead-free parts usage for space applications is not specified.

Purchase of lead containing parts for space applications is becoming increasingly difficult because of the consumer market shift to lead-free parts.

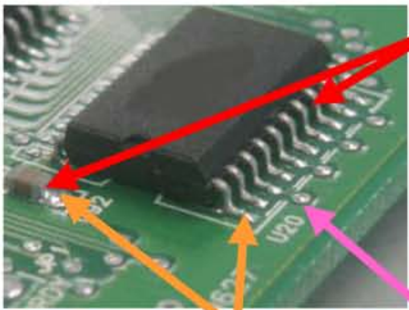
Management Required!!

The community to address lead-free parts issues is established in 2006 by JAXA

4

4. Effects of Shift to Lead-Free Parts

A typical lead-free parts related problems are shown below.



①Tin whiskers

Lead containing electrode

↓

Lead-free electrode ex: Tin, Tin copper

Tin whiskers

*1 :NASA/GSFC Tin Whisker Homepage

③Leaching of copper substrate

SnPb

↓

Lead-free solder

ex :SnAgCu

KYODEN CO.,LTD.

②Electrical termination of PWB

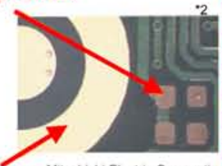
Solder plating

↓

Lead-free plating

ex :Gold plating

High-heat-resistant preflux



preflux

Gold

*2 Mitsubishi Electric Corporation

5

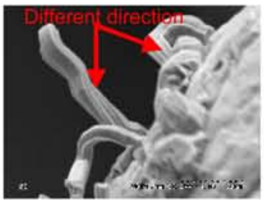
5. Summary of JAXA Basic Assessment

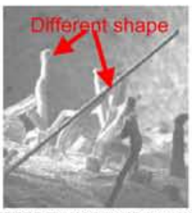
In the basic assessment carried out by JAXA, the following were observed regarding the Tin whiskers of the pure Tin electrode. The Tin whisker growth mechanism not well understood and the research is continued globally.

1. Tin whisker are different even among the same type device.【Photo1】
2. Tin whisker shape and direction are different even among the same part.【Photo2】
3. Hot Solder Dipping (HSD) is one of key methods for Tin whisker mitigation or control.【Photo 3】

Photo1-1 Company A

Photo1-2 Company B





NASA/GSFC Tin Whisker Homepage

Photo 2 Different shape

Photo 3-1 Pure Tin electrode

Photo 3-2 HSD electrode

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6. Basic Assessment

【Purpose】

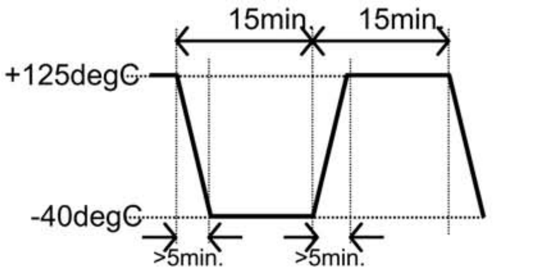
1. Assess effects of Tin whisker control by Hot Solder dipping (HSD)
2. Assess effect of Tin whisker control by the assembly methods

【Test Condition】

Test type : Thermal shock

Temperature: -40 deg. C to +125 deg C

Shock cycle : maximum 2,000 cyc.



7

7. Sample (Chip Ceramic Capacitors)

Table 1 Test Sample

Sample	Lead-free Type A	Lead-free Type B	Lead-free Type C
P/N	GRK39CG331J50	GRK39B103k50	SC0603-TIN
Dimension	1.6 x 0.8 mm	1.6 x 0.8 mm	1.6 x 0.8 mm
Electrode	Sn100 (5.1, 3.8, 2.7μm) Ag/Ni barrier metal	Sn100 (3.9μm) Cu/Ni barrier metal	Sn100 (8.0μm) Ag/Ni barrier metal
Photo			

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8. Summary of HSD result and Tin whisker result(1/2)

No.	Sample	HSD condition		Tin whisker			
		Temp.	Times	0cyc	500cyc	1000cyc	2000cyc
A	Lead-free Type A (Sn/Ni/Ag: Sn=3.8μm)	230℃	1	non	non	non	non
B			2	non	non	non	non
C			3	non	non	non	non
1		240℃	1	non	non	non	non
2			2	non	non	non	non
3			3	non	non	non	non
4		250℃	1	non	non	non	non
5			2	non	non	non	non
6			3	non	non	non	non
7		260℃	1	non	non	non	non
8			2	non	non	non	non
9			3	non	non	non	non

non :Tin whisker growth was not observed, yes :Tin whisker growth was observed

- Projections of solder was observed at 230 deg. C.
- Surface of hot solder bath was oxidized at 260 deg. C.
- Tin whisker was not observed at all HSD condition.

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8. Summary of HSD result and Tin whisker result(2/2)

No.	sample	HSD condition	Tin whisker			
			0cyc	500cyc	1000cyc	2000cyc
10	type A (Sn/Ni/Ag: Sn=5.1μm)	non-HSD	non	Yes	Yes	Yes
11		250℃, twice	non	non	non	non
12	type A (Sn/Ni/Ag: Sn=3.8μm)	non-HSD	non	Yes	Yes	Yes
13		250℃, twice	non	non	non	non
14	type A (Sn/Ni/Ag: Sn=2.7μm)	non-HSD	non	Yes	Yes	Yes
15		250℃, twice	non	non	non	non
16	type B (Sn/Ni/Cu: Sn=3.9μm)	non-HSD	non	Yes	Yes	Yes
17		250℃, twice	non	non	non	non
18	type C (Sn/Ni/Ag: Sn=8.0μm)	non-HSD	non	Yes	Yes	Yes
19		250℃, twice	non	non	non	non

non :Tin whisker growth was not observed, yes :Tin whisker growth was observed

(pink) : Short Tin whisker was observed, (red) : Long Tin whisker was observed

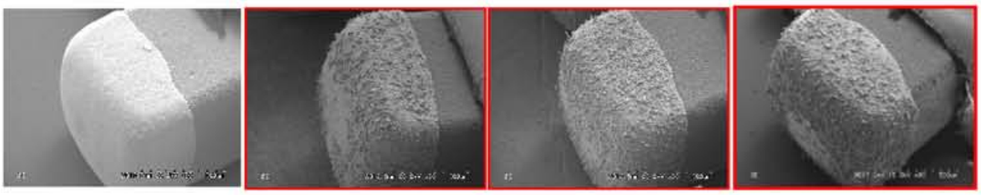
- Tin whisker was observed in non-HSD samples
- Tin whisker grows as Tin plating thickness increases.

10

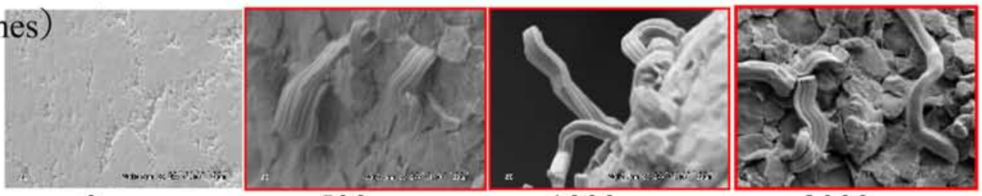
9. Result of thermal shock cycle test(1/2)

・Type C capacitor （Sn/Ni/Ag, Sn=8.0um, No.18）, Non-HSD

Electrode（９０ times）



Surface（１５００ times）



0 cyc | 500 cyc | 1000 cyc | 2000 cyc

- Tin whisker was observed at 500 cycle.
- Tin whisker grows as thermal shock cycle increases.
- The number of Tin whisker increases as thermal shock cycle increases.

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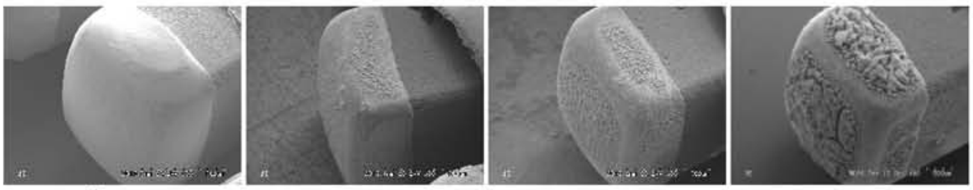
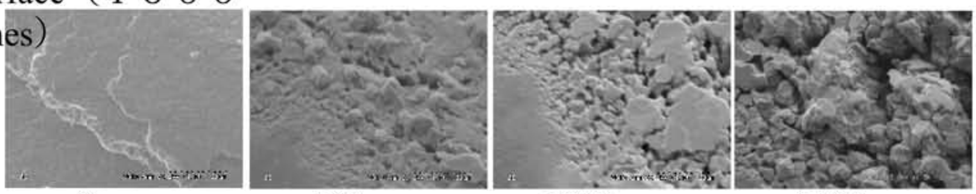
9. Result of thermal shock cycle test(2/2)

・Type C capacitor （Sn/Ni/Ag, Sn=8.0um, No.19）,
HSD sample (250 deg. C, twice)

Electrode（９０ times）



Surface（１５００ times）



0 cyc | 500 cyc | 1000 cyc | 2000 cyc

·Tin whisker was not observed

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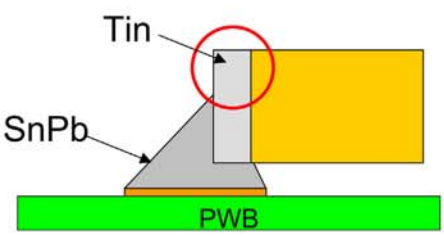
10. Assembly Method Evaluation

【Purpose】

To evaluate the effect of tin whisker control by assembly methods.

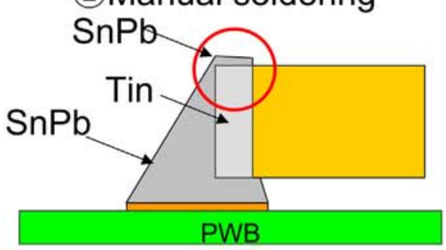
Assembly Methods:
1. Reflow soldering (SnPb solder)
2. Manual soldering (SnPb solder)

①Reflow soldering



Top of the chip capacitor is not covered with SnPb solder

②Manual soldering



Top of the chip capacitor is covered with SnPb solder

13

11. Summary of Assembly Method Effects

Type	HSD condition	Method	Tin whisker			
			0cyc	500cyc	1000cyc	2000cyc
Type A (Sn/Ni/Ag: Sn=3.8μm)	non-HSD	reflow	non	yes	yes	yes
		manual	non	non	yes	yes
	250℃, twice	reflow	non	non	non	non
		manual	non	non	non	non
Type C (Sn/Ni/Ag: Sn=8.0μm)	non-HSD	reflow	non	yes	yes	yes
		manual	non	non	yes	yes
	250℃, twice	reflow	non	non	non	non
		manual	non	non	non	non

non : Tin whisker growth is not observed, yes :Tin whisker growth was observed
(pink box): Small Tin whisker was observed, (red box) : Long Tin whisker was observed

- Tin whisker was not observed in every assemble method using HSD sample.
- Tin whisker was observed in every assembly method, even if top of the capacitor was covered with SnPb solder by manual soldering.

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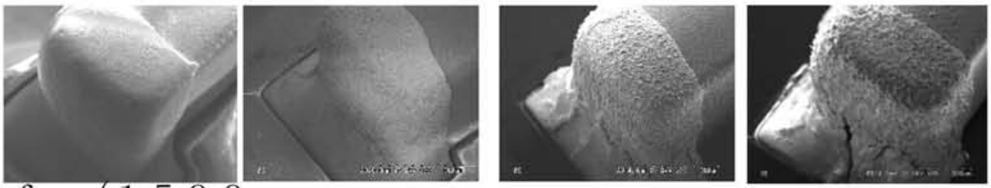
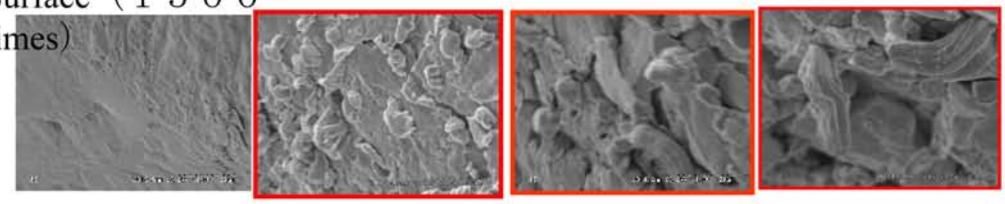
12. Result of assemble method effect(1/2)

・Reflow soldering method,
Type C capacitor (Sn/Ni/Ag, Sn=8.0um, No.26), non-HSD

Electrode (９０ times)



Surface (１５００ times)



0 cyc | 500 cyc | 1000 cyc | 2000 cyc

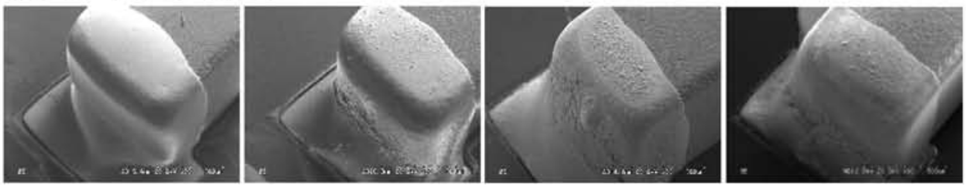
- Tin whisker was observed at 500 cycle.
- Tin whisker grows as thermal shock cycle increases.
- The number of tin whisker increases as thermal shock cycle increases.

15

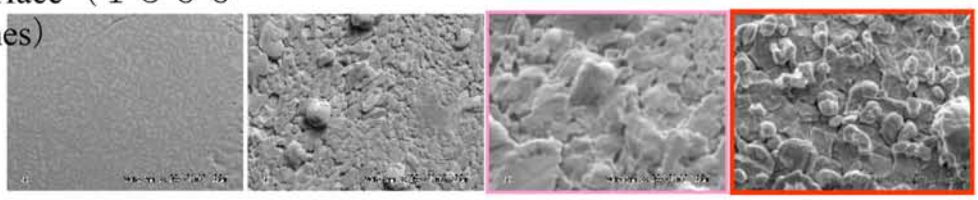
12. Result of assemble method effect(2/2)

・Manual soldering method,
Type C capacitor (Sn/Ni/Ag, Sn=8.0um, No.26), non-HSD

Electrode (９０ times)



Surface (１５００ times)



0 cyc | 500 cyc | 1000 cyc | 2000 cyc

・Tin whisker was observed at 1000 cycle.
・Tin whisker was observed even if top of the capacitor was covered with SnPb solder by manual soldering.

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13. Summary

EU enacted RoHS and WEEE directives, that restrict the use of Pb et.al. for EU consumer products after July 2006.

1. Purchase of the parts and materials that contains lead is becoming difficult.
3.Reliability problems of lead-free parts and materials may surface in space applications.

JAXA established the community to address lead-free parts issues and started basic assessment of the issues.

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プロジェクト承認部品データベース

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第19回 MEWS 2006.10.27

プロジェクト承認部品データベース(PAPDB)

・現状

・プロジェクトにおける承認部品リスト(APL)
システムメーカは、PDRの段階でAPLを作成しJAXAへ提出。
その後、CDR、維持設計と進むに合わせ維持改定をしている。

・非標準部品の使用申請(NSPAR)
電気･電子･電気機構(EEE)部品プログラム標準(GBA-99010C)を基にしたプロジェクトの部品基準書により審査。

・この時のAPLの確認、NSPARの申請、審査、承認は全て紙ベースで行われている。

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第19回 MEWS　2006.10.27

プロジェクト承認部品データベース(PAPDB)

・PAPDBの目的

1.これまでプロジェクト単独に用いられてきたこれらのデータを一元化し、できるだけ共通に利用できるデータは相互利用を図る。
2.申請手続きをWEBを利用したものに置き換え、効率化と利便性を増進させる。→紙ベースの申請が不要になる。
3.現在運用している認定部品に関するデータベースとあいまって部品に関する総合的な情報源となるべく運用しプロジェクト支援を強化する。
4.「プロジェクトで発生した不具合の他プロジェクトへの影響について一次評価を実施 (定常運用移行後。プロジェクト参画の一環)」

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第19回 MEWS　2006.10.27

プロジェクト承認部品データベース(PAPDB)

・PAPDBの機能

1. JAXAの衛星プロジェクトに使用されるEEE部品の部品リスト（APL）に関するデータをWEBベースで登録でき、このデータを利用して非標準部品申請（NSPAR）に関するデータをWEBベースで申請、審査、承認、登録できる 。
2. データを一元的に蓄積し、相互利用を図るユーザフレンドリーを指向

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プロジェクト承認部品データベース(PAPDB)

・PAPDBの特徴

1. 管理することを目的にするのではなく、ユーザフレンドリーなデータベースとすることにより双方(管理者及びユーザ)が最大の利益を享受できる。
2. APLを本データベースで提出、管理できる。
3. 既存のAPLのEXCEL形式(CSV)から入力(データ移行)、登録ができる。
4. これまでのプロジェクトのAPLデータを再利用して新規プロジェクトのAPLが作成可。
5. 蓄積されたデータの統計分析機能により、部品の技術動向から重要部品の国産開発候補や国産／輸入部品、及び／又は標準／非標準部品の傾向を把握し、部品プログラムの計画立案に資することが可。
6. 信頼性技術情報、プリアラート、アラート情報に該当する部品の使用の有無が容易に確認でき、水平展開作業が効率化できる。

5

	入力項目	APL	NSPAR	一般に開示	備考
1	登録会社	○			NEC東芝スペース、三菱電機、・・・その他(記入)
2	申請番号		○		
3	申請日		○		
4	改定日／改定符号		○		
5	申請会社		○		NEC東芝スペース、三菱電機、・・・その他(記入)
6	プロジェクト名	○	○		
7	部品の種類	○	○	○	GBA-99010記載の20種から選択
8	部品番号	○	○	○	
9	一般部品番号	○	○	○	記入又は-
10	部品の機能(概略仕様)	○	○	○	MPU、FPGA、積層セラミックコンデンサなど記入
11	パッケージ	○	○	○	14Pin、DIPなど、その他(内容記入)
12	仕様書番号/版数	○	○	○	
13	製造業者	○	○	○	
14	供給業者	○	○	○	
15	選定区分	○	○	○	標準品、実績のあるNSPAR品など
16	使用実績(プロジェクト／用途、NSPAR No.)	○	○		
17	品質保証レベル	○	○	○	クラスⅠ、クラスⅡ、その他(内容記入)
18	使用機器	○	○		TTC、TCU,など、複数指定可、その他(記入)
19	設計･構造		○		クラスⅠ、クラスⅡ、その他(内容記入)
20	構造解析データ		○		CAデータ有、DPAデータ有、DPA実施予定、無
21	製造プロセス管理		○		クラスⅠ、クラスⅡ、その他(内容記入)
22	スクリーニング		○		クラスⅠ、クラスⅡ、その他(内容記入)

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	入力項目		APL	NSPAR	一般に開示	備考
23	認定試験			○		クラスⅠ、クラスⅡ、その他(内容記入)
24	品質確認試験			○		クラスⅠ、クラスⅡ、その他(内容記入)
25	供給性管理			○		単一ロット生産、短期生産、継続生産
26	申請理由			○		
27	ESD耐性レベル			○	○	
28	耐放射線性レベル(TID)		○	○	○	10Krad、20Krad、・・・、その他(内容記入)
29	耐放射線性レベル(SEE)		○	○	○	SEU、SEL、SET、SEB後説明をタイプイン
30	耐放射線性試験			○		認定時のみ、ロット毎、代表ロット、その他
31	補足説明			○		
32	備考		○			
33	添付資料	仕様書		○		有、無:有の場合は電子ファイルを添付
34		構造解析データ		○		有、無:有の場合は電子ファイルを添付
35		認定試験データ		○		有、無:有の場合は電子ファイルを添付
36		ESD試験データ		○		有、無:有の場合は電子ファイルを添付
37		耐放射線試験データ		○		有、無:有の場合は電子ファイルを添付
38	連絡先	担当会社/部署		○		
39		役職		○		
40		氏名		○		
41		住所		○		
42		電話番号		○		
43		Email		○		
44	不具合の有無		○	○		
45	NSPARの要、不要の別		○			

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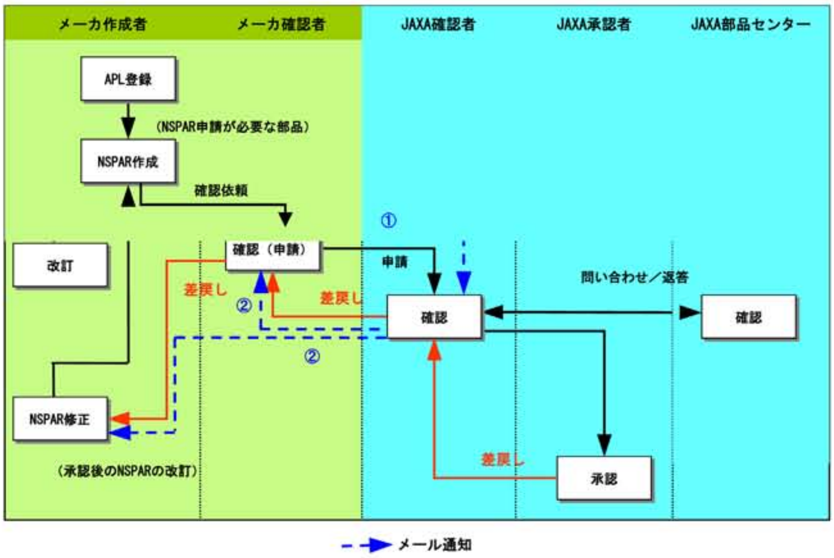
プロジェクト承認部品データベース(PAPDB)

PAPDBのワークフロー



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プロジェクト承認部品データベース(PAPDB)

・今後の方針

1.新規プロジェクトから利用を推進

2.プロジェクト及びシステムメーカに対する説明会の実施

19th MEWS October 27, 2006

JAXA Project Approved Parts Database

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1

The 19th MEWS October 27, 2006

JAXA Project Approved Parts Database (PAPDB)

▪ Current Status

- **JAXA Project Approved Parts List (APL)**

  A system manufacturer prepares APL at the time of preliminary design review and submit it to JAXA.

  As the project proceeds to critical design review and liaison engineering process, the list is revised.

- **Non-Standard Parts Approval Request (NSPAR)**

  Review is conducted using the project's parts procurement statements based on Standards for Electrical, Electronic and Electromechanical (EEE) Parts Program (GBA-99010C).

- **Verification of APL, application, review and approval of NSPAR is currently conducted by paper-based method.**

2

The 19th MEWS October 27, 2006

JAXA Project Approved Parts Database (PAPDB)

・Purpose of PAPDB

1. To unify data independently used by project for mutual utilization.
2. To improve efficiency and convenience by introducing on-line application. → Leads to paperless application
3. To assume a role as comprehensive information source for space parts and enhance project support with existing database of JAXA certified parts.
4. To implement preliminary evaluation for effects of a failure occurred in a project on other projects.

3

The 19th MEWS October 27, 2006

JAXA Project Approved Parts Database (PAPDB)

▪ Features of PAPDB

1. PAPDB enables manufacturers to compile a list of EEE parts (APL) used for JAXA satellite projects in the database on the Web. These data can be utilized for application, review, approval and registration of NSPAR on the internet.

2. User-friendly system with mutual accessibility by unifying all data.

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The 19th MEWS October 27, 2006

JAXA Project Approved Parts Database (PAPDB)

・Merits of PAPDB

1. Both an administrator and a user can share the maximum benefit as designed not as administrator-sided but as user-friendly database.
2. Submitting and administrating APL is capable through PAPDB.
3. Data migration and registration can be implemented using existing CSV files.
4. APL for a new project can be prepared reusing APL's for previous projects.
5. Statistical analysis function helps parts program planning by predicting possible critical parts for domestic development and grasping tendency of domestic/foreign-made parts or standard/non-standard parts from parts technology trend.
6. Users can easily check usage of parts relevant to reliability information, pre-alert, or alert information for efficient lateral spread.

5

	Item	APL	NSPAR	Public disclosure	Remark
1	Registrant company	○			NEC TOSHIBA Space Systems, Ltd., Mitsubishi Electric Corporation, or others (keyboard input)
2	Application number		○		
3	Application date		○		
4	Revision date/revision letter		○		
5	Application company		○		NEC TOSHIBA Space Systems, Ltd., Mitsubishi Electric Corporation, or others (keyboard input)
6	Project name	○	○		
7	Part type	○	○	○	Selection from 20 types listed in GBA-99010
8	Part number	○	○	○	
9	Generic part number	○	○	○	Keyboard input or put "-"
10	Function (specification outline)	○	○	○	Keyboard input e.g. MPU, FPGA, multi-layer ceramic capacitor etc.
11	Packaging	○	○	○	14 Pin, DIP, or others (keyboard input)
12	Specification number/issue	○	○	○	
13	Manufacturer	○	○	○	
14	Supplier	○	○	○	
15	Classification	○	○	○	Standard part, non-standard parts which have been used in the past etc.
16	Approval history (project, use application, NSPAR No.)	○	○		
17	Quality level	○	○	○	Class I , Class II, or others (keyboard input)
18	Subsystem	○	○		Multiple selections, e.g. TTC, TCU, or others (keyboard input)
19	Design and construction		○		Class I, Class II, or others (keyboard input)
20	DPA data		○		Criticality analysis, DPA data, DPA planned, None
21	Production process control		○		Class I , Class II, or others (keyboard input)
22	Screening		○		Class I , Class II, or others (keyboard input)

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	Item		APL	NSPAR	Public disclosure	Remark
23	Qualification test			○		Class I, Class II, or others (keyboard input)
24	Quality conformance inspection			○		Class I, Class II, or others (keyboard input)
25	Supply control			○		Single lot, short-run production, or continuous production
26	Reason for request			○		
27	ESDS level			○	○	
28	Total ionization doze (TID)		○	○	○	10Krad, 20Krad... or others (keyboard input)
29	Single-event effect (SEE)		○	○	○	SEU, SEL, SET, or SEB and its details
30	Rad-hardness test			○		QT only, each lot, sample lot, or others
31	Supplemental information			○		
32	Remark		○			
33	Attachments	Specification		○		Yes or no: If yes, attach the applicable file.
34		C/A data		○		Yes or no: If yes, attach the applicable file.
35		QT data		○		Yes or no: If yes, attach the applicable file.
36		ESD test data		○		Yes or no: If yes, attach the applicable file.
37		Rad-hardness test data		○		Yes or no: If yes, attach the applicable file.
38	Contact point	Company/department		○		
39		Appointment		○		
40		Name		○		
41		Address		○		
42		Telephone		○		
43		Email		○		
44	Presence of failure		○	○		
45	Necessity of NSPAR		○			

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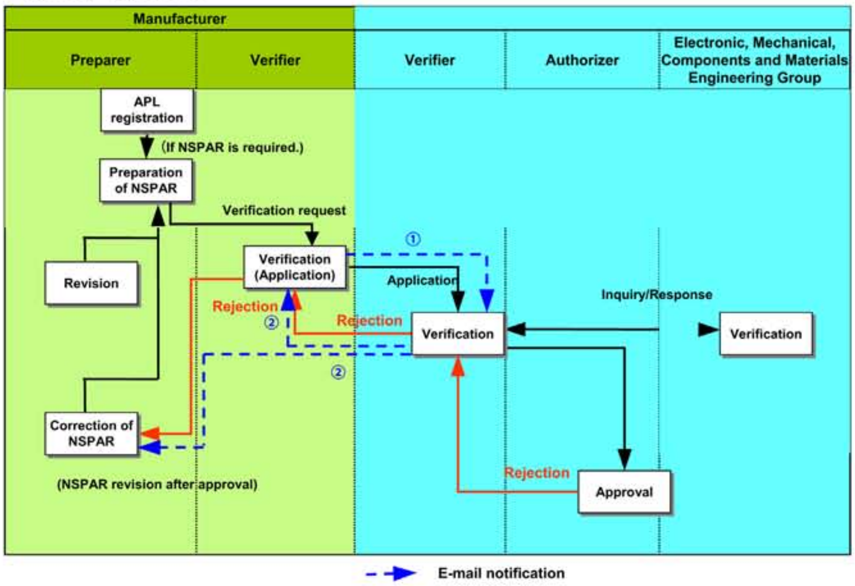
JAXA

JAXA Project Approved Parts Database (PAPDB)

PAPDB workflow



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The 19th MEWS October 27, 2006

JAXA Project Approved Parts Database (PAPDB)

・Future Plan

1. **Pursuing real utilization of PAPDB from new projects**

2. **Holding presentation meetings of PAPDB for projects and system manufacturers**

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The 19th Microelectronics Workshop at JAXA/TKSC

Wrap-up Report

Oct. 27, 2006
Takashi Tamura
Electronic, Mechanical Components and Materials Engineering Group
Institute of Aerospace Technology(IAT), JAXA

1

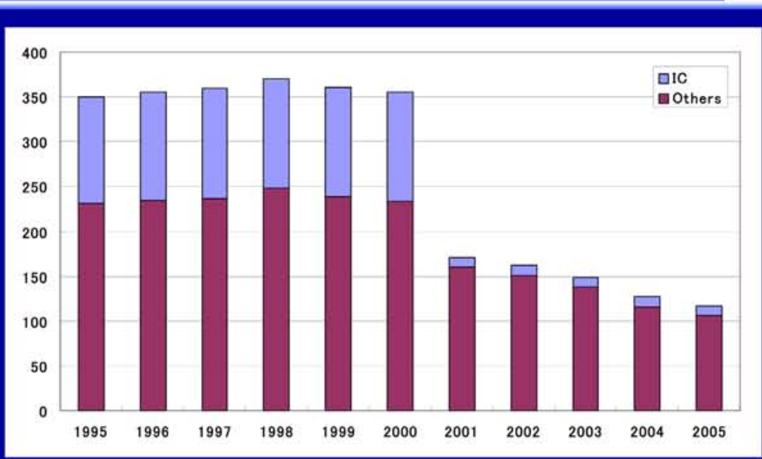
Overview

【Theme】
Ensuring Stable Supply and Quality of Space Components and Materials
-Strategy for Components & Materials in Aerospace & Automobile Industries-

Recent Parts/Components Issues:
- Significance of Parts Failure
- Increasing Complexity/Advanced System/ Decreasing Reliability?
- Lead-Free Electronics : Whisker Growth
- Lessons Learned from Other Industries such as Auto Industry
- Strategic Parts/Components Program
  -Europe/US/Japan
- International Cooperation
- Future Parts/Components for Advanced Space Systems
- Summary and Comments

2

Background



The number of JAXA qualified products has been drastically decreasing in the last 5 years.

Stable Supply of Space Parts/Components is a primary concern

Significance of Parts Failure

FPGA:

- **FPGAs are used in many electronic components.**
- **Concerns in FPGA will have significant impact(Cost/Schedule)**

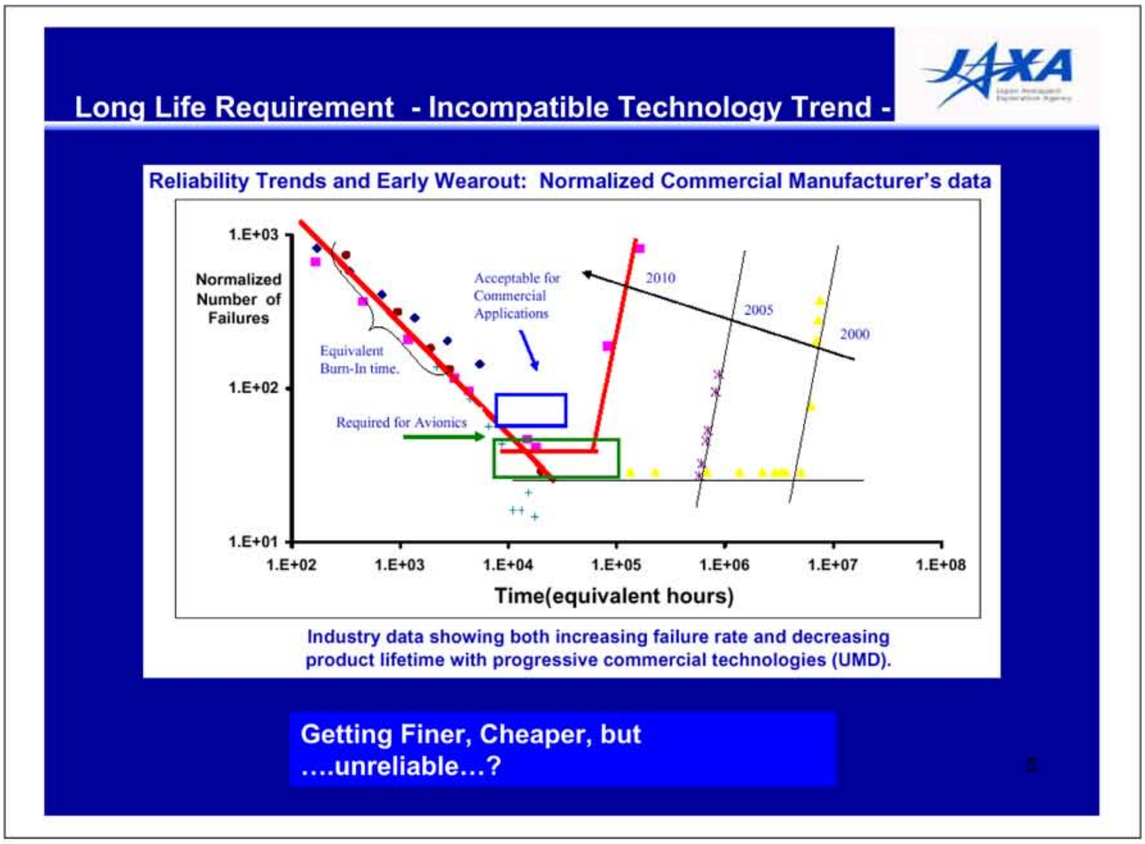
Ex)Issues of FPGA maturity contributed more than half of the total loss cost in 2004.

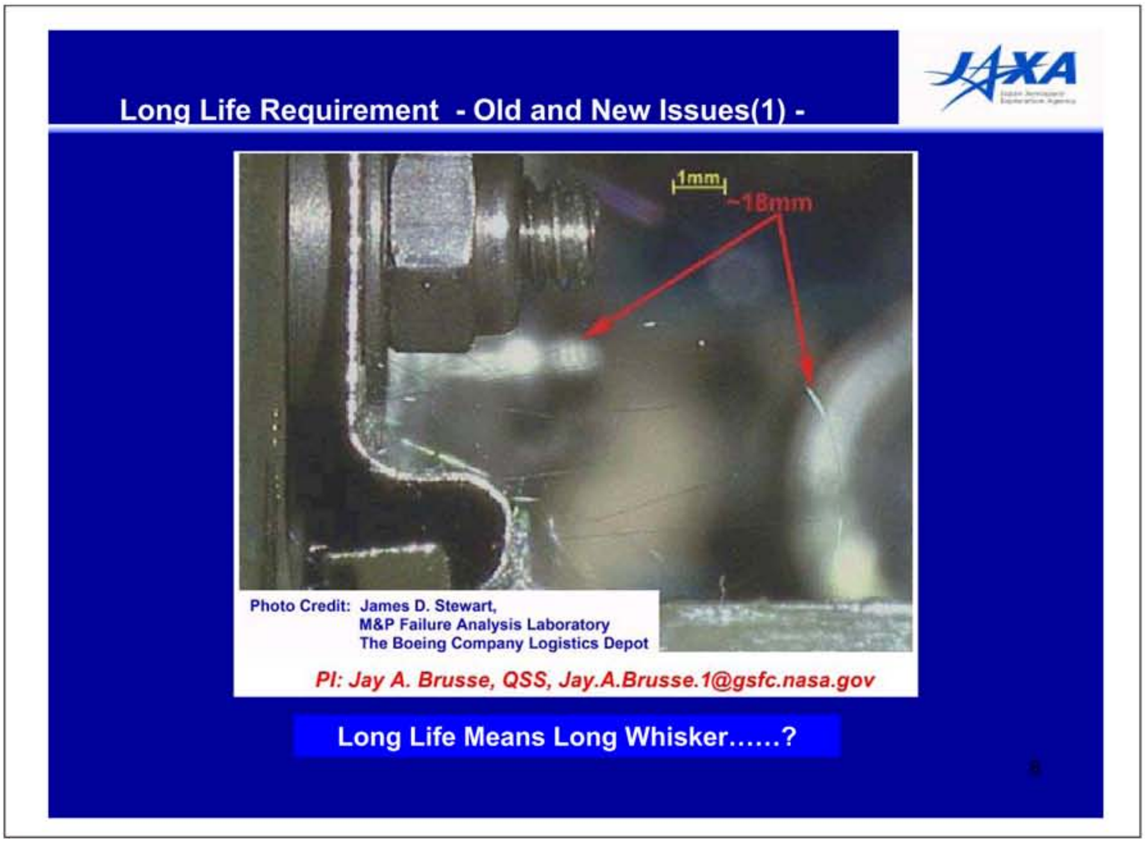
- **Reliability/ Quality is the No.1 Priority**

On the other hand…….

Moore's Law: 2x performance improvement every 18 months

- **Most semiconductor devices are designed with 3-10 years Service Goal!**
- **Space Operators request 10-15 years life in orbit!**


Long Life Requirement - Incompatible Technology Trend -
JAXA
Reliability Trends and Early Wearout: Normalized Commercial Manufacturer's data
Normalized Number of Failures
1.E+03
1.E+02
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Time(equivalent hours)
Acceptable for Commercial Applications
Equivalent Burn-In time.
Required for Avionics
2010
2005
2000
Industry data showing both increasing failure rate and decreasing product lifetime with progressive commercial technologies (UMD).
Getting Finer, Cheaper, but ….unreliable…?


Long Life Requirement - Old and New Issues(1) -
JAXA
1mm
~18mm
Photo Credit: James D. Stewart,
M&P Failure Analysis Laboratory
The Boeing Company Logistics Depot
PI: Jay A. Brusse, QSS, Jay.A.Brusse.1@gsfc.nasa.gov
Long Life Means Long Whisker……?

Long Life Requirement - Old and New Issues(2) -

- Need Materials Evaluation
- Need Physics of Failure
- Need Standardization
- Need Good Database

Lessons Learned from Other Industries

Good Design

◆Understand Risk

◆Risk Avoidance

Good Design Review

◆Joint Quality Design Review

◆Understand Risk

◆Risk Avoidance

Good Discussion

◆Good Relationship with Parts Industries

◆Know with each other

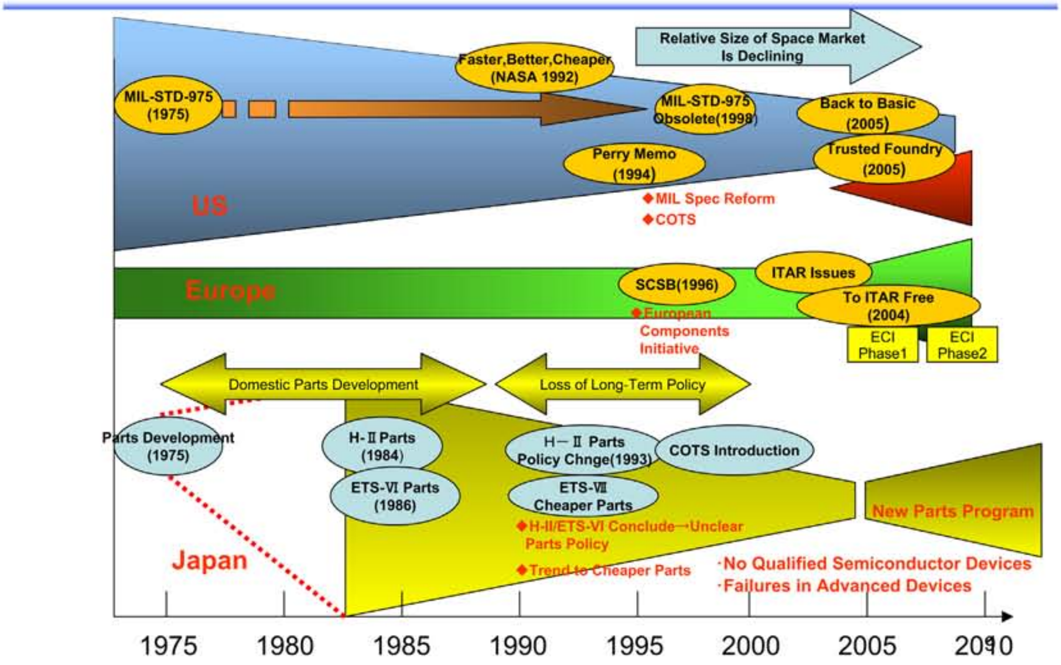
◆Share Information

Joint quality DR

① New design/construction
② Process control/inspection system
③ Past failures
④ Conformance to process at DENSO

･Weaknesses
･Issues

Report ⇒ Corrective actions

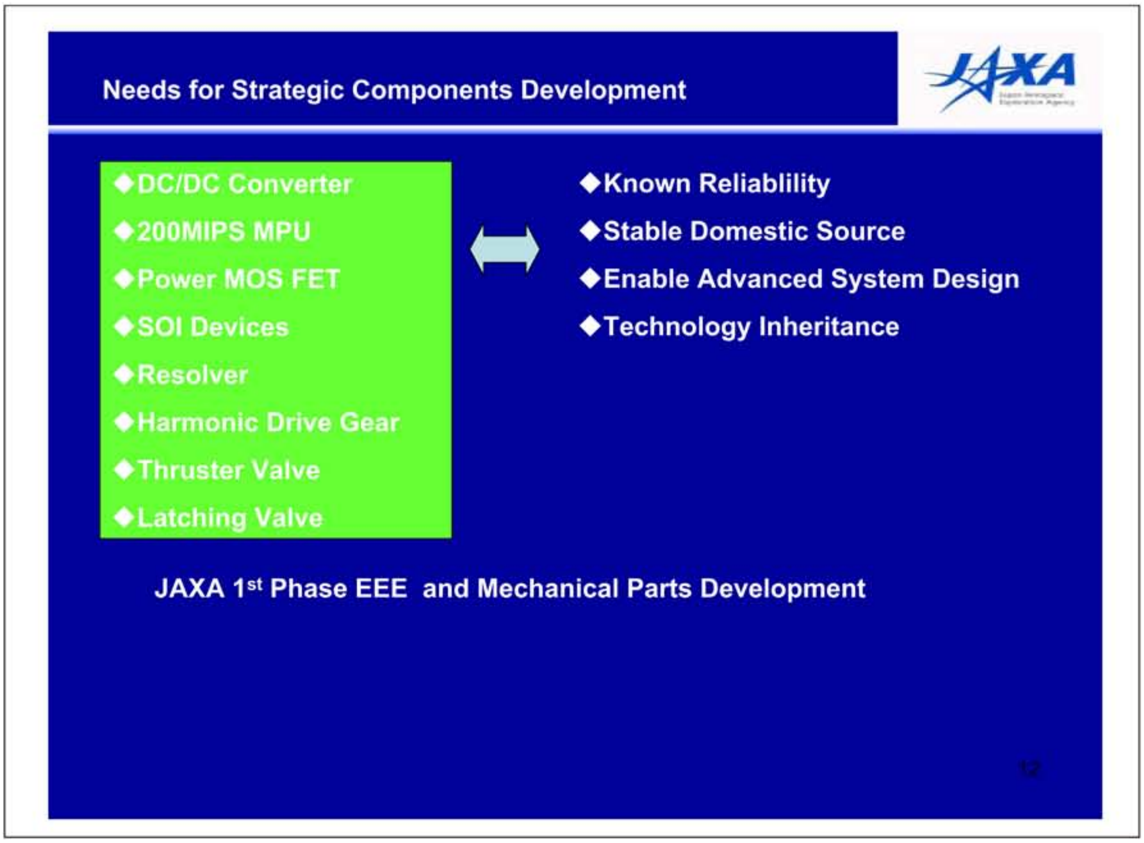


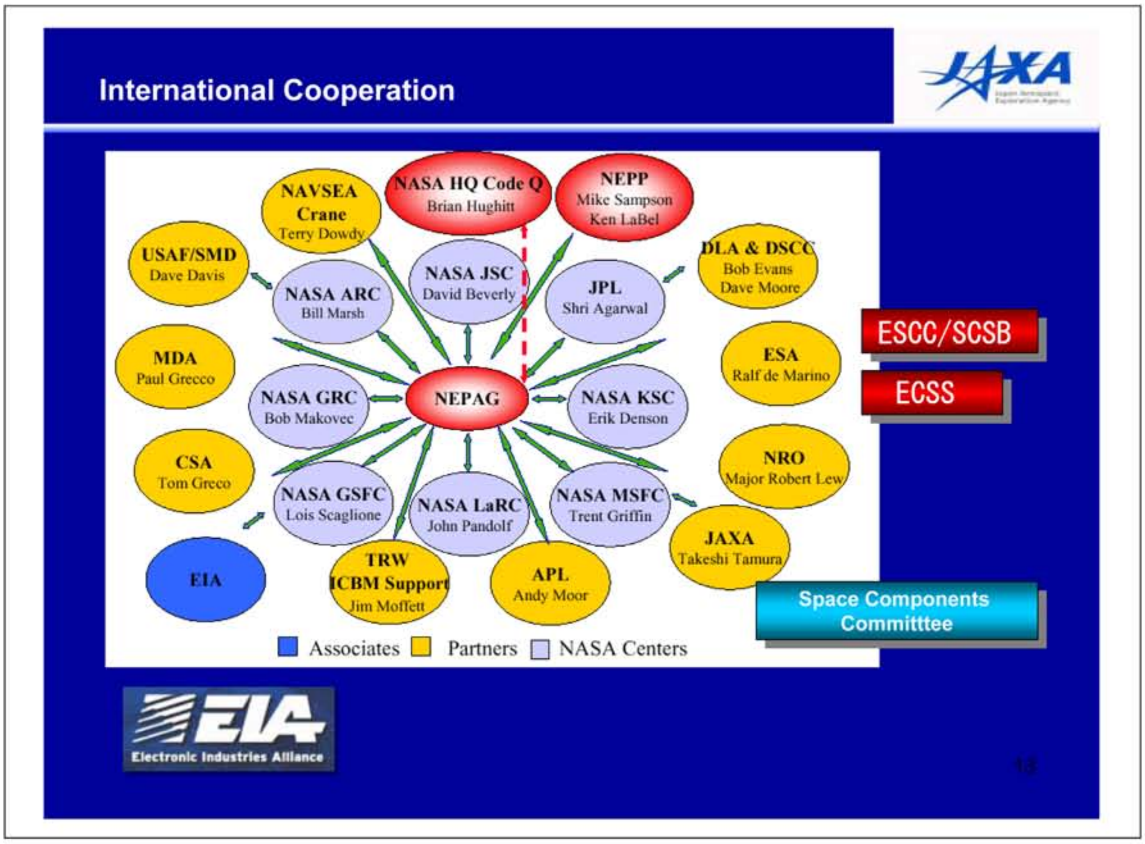
Strategic Parts/Components Program

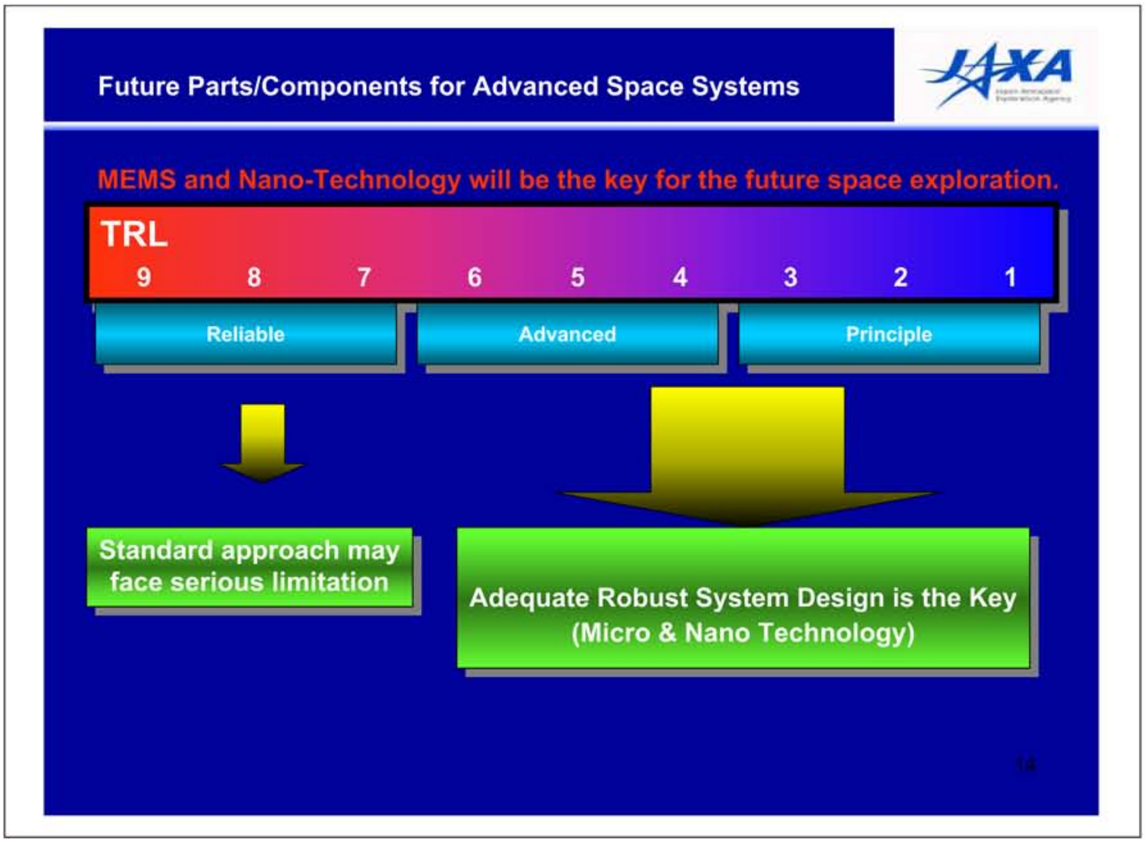
European Components Initiative

- To contribute to the European non dependence
  - Avoid possible embargo (ITAR restriction, …),
  - Increase the share of European components in our projects
  - Reduce the procurement schedules and prices
  - Improve the quality assurance by the use of the ESCC standard
  - Contribute to the exploitation of the European capabilities in terms of space components
  - Propose, in time state of the art technologies and components with a good readiness level and at a reasonable cost.
- To contribute to the space industry competitiveness
- Equipment manufacturers
  - Allow the space industry to have access to state of the arts components
  - Increase systems and equipment performances
  - Be able to propose new applications
- Component manufacturers
  - Develop a production capacity of HiRel radiation hardened components to a reduced number of component manufacturers
  - Develop as much as possible their products portfolio in order for them to be attractive and get back a significant revenue => Assurance of their commitment to the space business

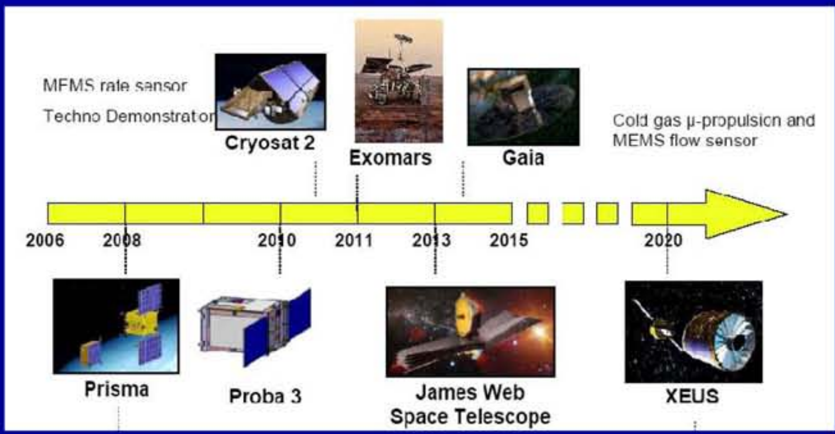

Trend of Parts/Components Strategy
esa
DLR
cnes
ECI Initiative
ITAR Free
Phase1: since 2004
Rad-Hard
$80 Million/yr
Trusted Foundry
$60-80 Million/yr
BAE SYSTEMS
Honeywell
IBM
Shift to Domestic Prod.
・IBM:2005FY～
・BAE:2002FY～
Availability of Core Devices may become difficult


Needs for Strategic Components Development
◆DC/DC Converter
◆200MIPS MPU
◆Power MOS FET
◆SOI Devices
◆Resolver
◆Harmonic Drive Gear
◆Thruster Valve
◆Latching Valve
◆Known Reliablility
◆Stable Domestic Source
◆Enable Advanced System Design
◆Technology Inheritance
JAXA 1st Phase EEE and Mechanical Parts Development

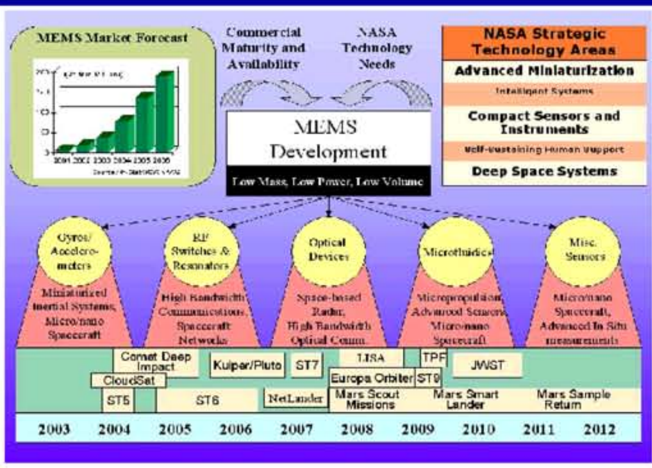

International Cooperation
JAXA
NASA HQ Code Q
Brian Hughitt
NEPP
Mike Sampson
Ken LaBel
NAVSEA
Crane
Terry Dowdy
USAF/SMD
Dave Davis
NASA JSC
David Beverly
NASA ARC
Bill Marsh
JPL
Shri Agarwal
DLA & DSCC
Bob Evans
Dave Moore
MDA
Paul Grecco
ESA
Ralf de Marino
NASA GRC
Bob Makovec
NEPAG
NASA KSC
Erik Denson
CSA
Tom Greco
NRO
Major Robert Lew
NASA GSFC
Lois Scaglione
NASA LaRC
John Pandolf
NASA MSFC
Trent Griffin
JAXA
Takeshi Tamura
EIA
TRW
ICBM Support
Jim Moffett
APL
Andy Moor
Associates
Partners
NASA Centers
ESCC/SCSB
ECSS
Space Components
Committtee
EIA
Electronic Industries Alliance


Future Parts/Components for Advanced Space Systems
JAXA
MEMS and Nano-Technology will be the key for the future space exploration.
TRL
9 8 7 6 5 4 3 2 1
Reliable
Advanced
Principle
Standard approach may
face serious limitation
Adequate Robust System Design is the Key
(Micro & Nano Technology)

Micro & Nano Technology - ESA -



Micro & Nano Technology –NASA-



Alignment of potential MEMS technology capabilities with NASA needs and technology development focus areas(Technology Plan, Section 4: "Strategic Technology Areas," updated August, 2001)

Summary and Comments

- Today's space systems Design rely more and more on advanced technology
- Declining space share
- Long Life Requirements

- Need Collaboration/Discussion
  - Between International Organizations
  - Between Parts Manufacturers and Users
  - Between Organization for Standardization
  - Between Industries(Space, Aeronautics, Auto,...)

Thank You!

17

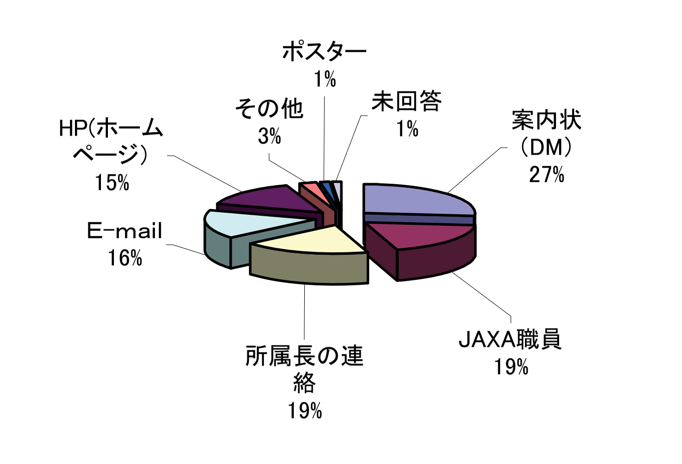
第19回マイクロエレクトロニクスワークショップ（MEWS19）アンケート調査結果

（1／3）

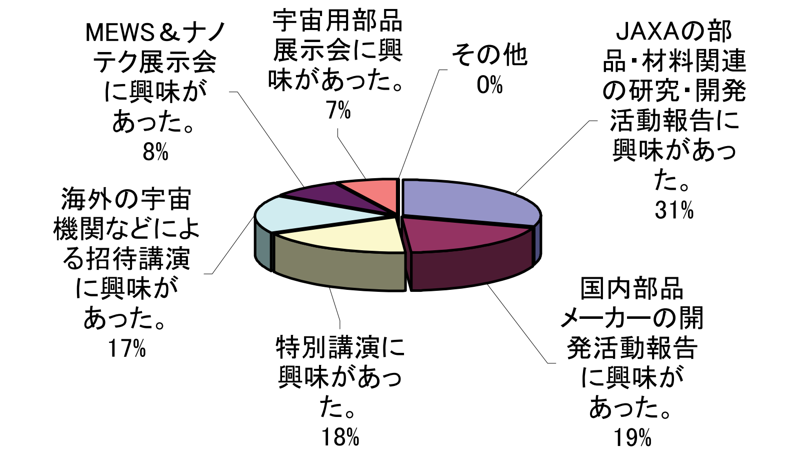
回答総数70、回収率28%。

平成18年10月31日作成

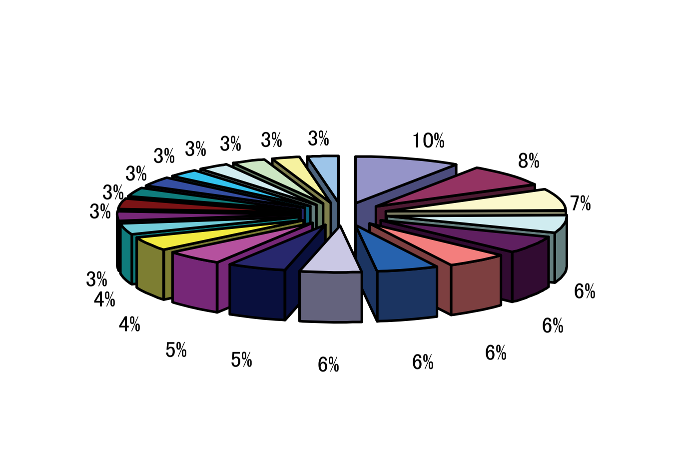
Q1 MEWS-19開催を何で知りましたか？　（回答数：75件）



Q2 参加の動機となったプログラムの項目は何ですか？(複数回答)
（回答数：153件）



Q3 聴講されて、興味を引かれた講演・発表は何でしたか？(複数回答)（回答数：378件）



順	興味を引かれた講演・発表ベスト5	占有率
1	車載用電子部品の品質向上活動	10
2	LSIプロセス診断	8
3	JAXA　RoHS対応の動きとHSDの評価結果	7
4	放射線応用に向けた完全空乏型SOI技術	6
4	MEMS and Micro-Structures in Aerospace Applications	6
4	Status of main CNES activities with regard to strategic technologies and components in the domain of silicon Ics.	6
4	NASA EEE Parts and Packaging Program(NEPP), An Overview of Current and Future Activities.	6
4	X線システムを用いたBGAの非破壊検査法	6
5	Micro & Nano Technologies at the European Space Agency	5
5	電子部品の開発状況報告	5

(2/ 3)

Q4 ワークショップの講演・発表内容に関して、お気づきの点やご感想をお聞かせください。

（主要5項目）

1 開発最新情報が聞けて有益。現状方式で今後も続けて欲しい。（4件）
2 スライド量が多すぎる発表が多い。減らすと同時通訳内容も充実するのではないか。(2件）
3 前刷集があり助かった。デンソー資料はフルで欲しかった。(2件）
4 鉛フリーに関するテーマは継続して欲しい。(1件）
5 MEMSとの同時開催は避けて欲しい(1件）

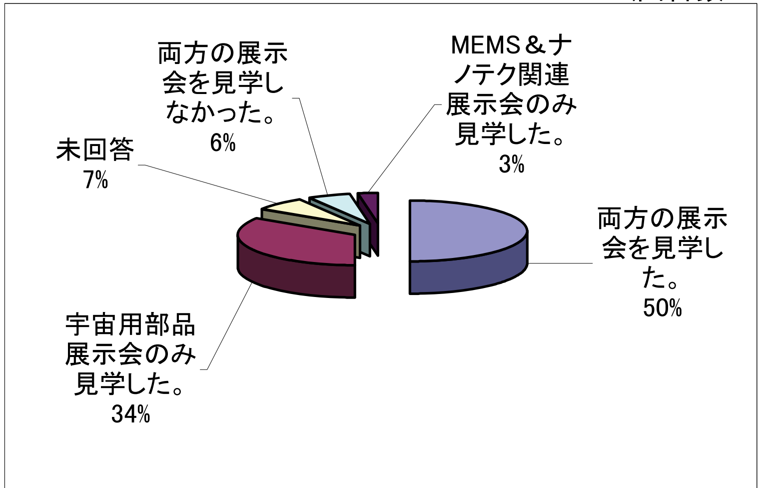
Q5 今後、どのようなテーマ、どのような内容の講演・発表を希望されますか？

（主要5項目）

1 RoHS対応の動向、評価試験進捗を発表して欲しい。特集のセッションを設けても良いのではないか。(3件）
2 部品だけの内容ではなく、プロジェクト活動の今後、JAXA戦略、JAXA方針も発表して欲しい。(3件）
3 部品に関する不具合内容(アラート）などの情報も発表して欲しい。(2件）
4 部品の評価技術手法や品質保証水準などに発表して欲しい。(2件）
5 半導体関連、車載用電子部品、民生部品、部品コストについての発表をして欲しい(1件）

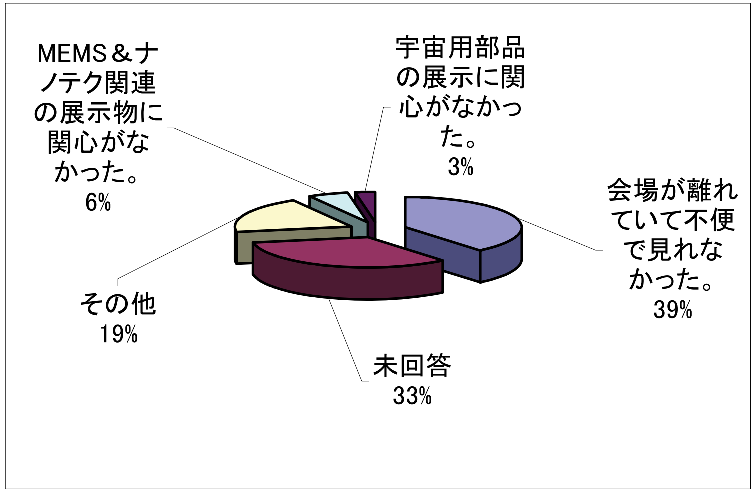
Q6 宇宙用部品展示会（会場：宇宙実験棟）とMEWS＆ナノテク展示会（会場：総合開発推進棟）を見学されましたか？

（回答数：70件）



Q7 〔Q6〕で1以外に〇を付けた方にお聞きします。片方又は両方の展示会を見学されなかった理由は何ですか？

（回答数：36件）



Q8 宇宙用部品展示会で興味を引いた企業又は部品が有りましたらご記入ください。 （3/ 3）

	企業名(上位3社)	
1	富士エレクトロニクス	4
2	HIREC	3
3	エイト工業	3
	その他	12
	計	22

	部品名(上位5品目)	
1	64bitMPU、200MIPSMPU （HIREC）	3
2	HIC、PROM、FPGA など（富士エレクトロニクス	3
3	コネクタ （ITTキャノン）	2
4	DC/DCコンバーター （日本アビオニクス）	2
5	CIC基板、CCC基板（オーケープリント）	2
	その他	12
	計	24

Q9 MEWS＆ナノテク展示会で興味を引いた企業又は部品が有りましたらご記入ください。

	企業名	
1	群馬大学	3
2	三菱電機	3
3	PLOX(株)	1
4	東地大	1
5	STマイクロテクノロジ	1
	計	9

	部品名	
1	可変インダクタ （群馬大学）	1
2	Analog （群馬大学）	1
3	フラーレン （PLOX（株））	1
4	表面分子サンプリング用ARMプローグ （東地大　江	1
5	リニア加速度センサ （STマイクロテクノロジー）	1
	計	5

Q10 両展示会に関して、お気づきの点やご感想などをお聞かせください。
（主要5項目）
1 ワークショップ会場とMEMS会場が離れすぎている。(3件)
2 出展企業数が少なすぎる。新技術を含む充実化を図って欲しい(3件)
3 MEMS&ナノテク展示会はもう少し規模拡大してもらいたい。(2件)
4 JAXAを支える部品メーカーをこれからも広く紹介して欲しい。(１件)
5 興味深い項目が多く有益だった。(1件)

Q11 MEWS-19全体に関して、お気づきの点やご感想などをお聞かせください。
（ワークショップの運営、前刷り集、同時通訳、開催場所、時間など）
（主要10項目）
1 前刷り集は日本語で用意して欲しい。英語では理解度が低く役に立っていない(4件)
2 前刷り集は目次と頁を表示し欲しい、もっと大きく印刷して欲しい。プレゼン資料に文字が多すぎる(3件)
3 前刷り集は前もって見れないのか(2件)
4 通訳が有ってとてもよかった。助かりました。(2件)
5 同時通訳の音声が切れることが有ったので改善して欲しい。(1件)
6 会場は東京、関西地区を希望、遠くて朝がが大変。(3件)
7 後刷り集の公開を期待する(2件)
8 若い技術者/研究者の参加が少ないように思う。(1件)
9 引き続き定期開催をお願い致します。(1件)
10 運営の段取りが悪い(1件)

以上

画像紹介

宇宙航空研究開発機構（JAXA）は平成18年10月25～27日の3日間、筑波宇宙センター宇宙実験棟において「第19回マイクロエレクトロニクスワークショップ」を開催しました。

本ワークショップは、主題「宇宙開発を支える部品材料の安定供給と品質の確保」の下に、副題「航空宇宙・自動車業界の部品材料戦略」として、MEMS（Micro Electro Mechanical System）&ナノテクの専門家を交えて、従来の電子部品に加えて、部品材料の開発状況・新技術、部品調達状況・民生部品の適用状況について、内外の宇宙機関、システムメーカ及び部品メーカ等、3日間でのべ約340名が参加して議論を深めました。

10月25～27日は部品展示会も開催し、国内外の部品メーカ、商社からの部品展示と技術紹介等を行いました。ここでは、そのようすを画像でご紹介します。

Workshop（1日目）

Workshop（1日目）

講演風景（講演順）


坂田 公夫 理事・本部長


渡辺 篤太郎 執行役


Dr. Robert Osiander


大沢 博昭 室長


Michael Sampson


Mark Porter

講演風景（講演順）


Laurent Marchand


Jean-Louis Venturin


大西 一功 教授


本田 登志雄 部長

Workshop（２日目）

Workshop（２日目）

講演風景（講演順）

久保山 智司 技術領域リーダ

浦野 幹彦 副主任技師

井田 次郎 部長

田中 大起 氏

小原 新吾 主幹開発員

上浦 啓次 マネージャー

講演風景（講演順）

山本 博章 代表取締役社長

中村 正夫 主任

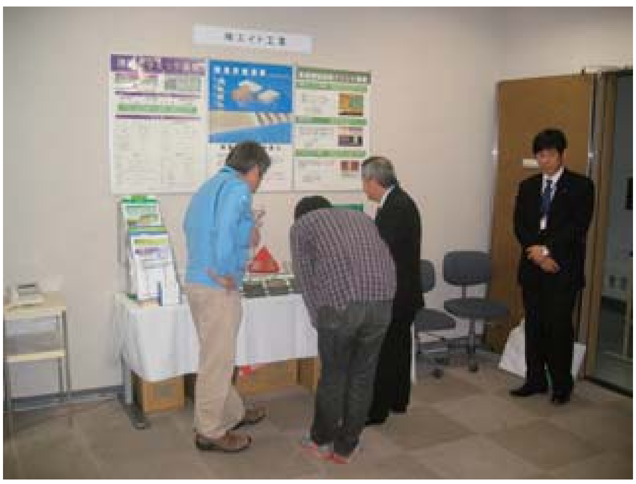
根本 規生 主任開発員

松岡 毅 主任開発員

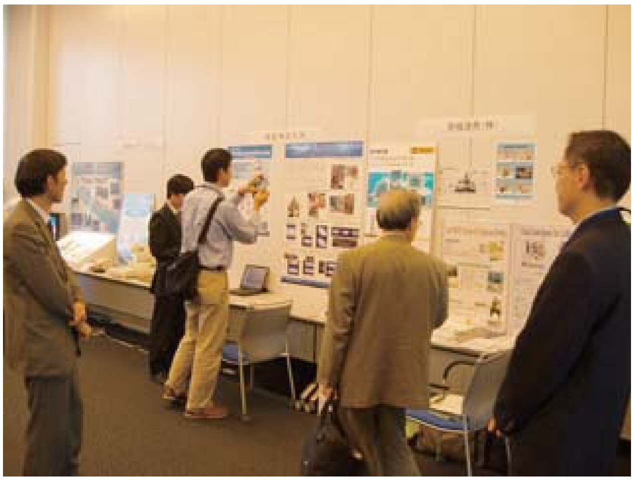
田村 高志 グループ長

Exhibition（平成18年10月25 ～ 27日、展示会）

出展企業名一覧（申込み順）
日本アビオニクス株式会社／株式会社フジ電科／エアロスペースリサーチ株式会社／丸文株式会社／株式会社アイティティキャノン／ピーティーエム株式会社／富士エレクトロニクス株式会社／ディーディーシーエレクトロニクス株式会社／株式会社エイト工業／HIREC 株式会社／田中貴金属販売株式会社／株式会社オーケープリント／ AVEX AEROSPACE Corp.



Exhibition（平成18年10月25～26日、MEMS & ナノテク展示会）



宇宙航空研究開発機構特別資料 JAXA－SP－07－010

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	URL:http://www.jaxa.jp/
印刷・製本	ケーティエス情報(株)

本書及び内容についてのお問い合わせは、下記にお願いいたします。
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〒305-8505 茨城県つくば市千現 2-1-1
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宇宙航空研究開発機構
Japan Aerospace Exploration Agency

本書は再生紙を使用しております。