Electronic Components Group
Non-volatile Memory for Space
October 2013
Agenda

- TCS Background & Services
- History and current usage
- Emerging technologies
- Questions
A distinguished history of serving both domestic and international aerospace customer for nearly 40 years

1976
TRW Components International (TRWCI) was formed by TRW, Inc., to supply parts management, engineering services and custom packaging solutions to the international space and military communities.

1999
TRWCI merged with Cubic Memory to form Vertical Circuits, Inc. (VCI)

2007
The space and military arm of VCI became Trident Space & Defense

2011
Trident Space & Defense is acquired by TeleCommunication Systems, Inc, to become TCS Space & Component Technology

“Same people, different names…TRW heritage and structure has been maintained since 1976”
Total Parts and Life Cycle Management

Engineering Services
- Design Assistance
- Parts Selection & Qualification
- Radiation Support
- Obsolescence Management
- Counterfeit Parts Detection
- Up-screening

Supply Chain
- Manufacturer Selection
- Supply all EEE Part Types
- Supply of Hardware & Materials
- Procurement Consolidation
- Die Procurement & Qualification

Manufacturing Support
- Materials Review
- Customer Source Inspection
- Product Assurance Testing
- Die Banking
- Unique Device and Obsolete Part Manufacturing

Quality Assurance
- Visual & Mechanical Inspection
- Quality Data Review
- Prohibited Materials Analysis (XRF)
- DPA
- GIDEP & ESCC Alert Tracking

Export Compliance
- Review of Regulation & Policies prior to contract
- Nearly 40 Years Experience with US regulations and all major jurisdictions

After Delivery Services
- Long term storage
- Assembly, Integration & Test Support
- Warranty Management
- Kit to BOM

A Full Spectrum of Services to Ensure Mission Success
SCT Value Proposition

COMPLETE SUPPLY CHAIN SOLUTIONS

- Consolidated procurement and long term storage
- Quality assurance
- Supplier qualification and management
- Pre-cap and final source inspection
- Dedicated program management
- Bill of material kitting
- Customer inventory management
- FAR compliance
- Order expediting and status reporting
- End-to-end parts project management

ENGINEERING SERVICES

- Component/RF/Mechanical Engineering
- Qualification testing
- Specification preparation
- Thermal and Stress analysis
- Source inspections
- Failure analysis
- BOM review/Obsolescence management
- Counterfeit parts detection
TCS has developed a broad network of US and European suppliers, laboratories and test facilities for all of your EEE parts and management needs.
As the need for lower-cost, higher-density storage increases, space users may be required to look to towards nonvolatile memories such as NAND flash and solid state drives. While it may be tempting to look to commercial off-the-shelf solutions, because of the harsh environment and radiation effects, there are many factors to consider when looking for the best solution, to ensure mission success.

This presentation summarizes memories that have been used in the past in space, along with new technologies that hold promise for future manned and deep-space missions.
The types of digital storage devices can be divided into two very broad categories:

- **Volatile memory** describes devices that must remain powered on for storage to persist. Examples include the DRAM and SRAM used in computers that only remember information while a computer is turned on.

- **Nonvolatile memory** devices can retain stored data without application of power. Examples include punch cards, magnetic tape, PROMs and EEPROMs, hard drives, solid-state drives, and flash drives.
Typical Space Requirements

Many storage technologies are not practical for space because of the particular requirements for satellites and space probes:

- Low mass
- Small volume
- Low power consumption
- Must be able to function in zero gravity
- High reliability (repairs not possible)
- Low error rate
- Long life: 5 – 15 years with no maintenance
- Operating range of -55°C to +125°C
- Radiation-hard: requirements vary considerably by application
  - Total dose
  - Dose rate upset
  - Dose rate survivability
  - Neutron
  - Proton
Nonvolatile Technologies

• EEPROM
• Tape and Magnetic Disk
• Flash memory—solid-state drives
  ➢ NOR
  ➢ NAND
  ➢ Solid-state drives
• Modified SRAM
  ➢ Battery-backed SRAM (BBSRAM)
  ➢ Nonvolatile SRAM (nvSRAM)
• Phase-change RAM (PCM, PRAM, C-RAM, or chalcogenide RAM)
• Ferroelectric RAM (FRAM or FeRAM)
  ➢ Conventional FRAM
  ➢ Polymer-printed FRAM
• Magnetoresistive RAM (MRAM)
  ➢ Conventional
  ➢ Spin-transfer torque (STT-MRAM)
  ➢ Thermal-assisted switching (TAS-MRAM)
  ➢ Vertical transport (VMRAM)
Legacy Technology: Mechanically Addressed Systems

- These use a contact structure (a “head”) to read and write on a storage medium. Capacity is limited primarily by the amount or size of the storage medium available, such as the length of magnetic tape.

- Hard disk drives use a rotating magnetic disk to store data. The cost per stored data bit is very low and it has the advantage of speed and no need to rewind… but does not work in space.

Early space probe missions Galileo (Jupiter, 1989) and Magellan (Venus, 1989) used magnetic tape storage, with nearly 2 km of tape for a capacity of 2 GB.
Solid State Recorders in Space

- Cassini (Saturn, 1997) was the first NASA deep space mission to use a radiation-tolerant solid-state recorder—2 Gb, using 4-Mb DRAM upscreened by TCS (formerly TRWCI)
- Mars landers and rovers, Stardust (comet Wild 2, 1999), Genesis (space dust, 2001), and Juno (Jupiter, 2011) all used a 2-Gb flash data card, using devices no longer in manufacture
- Because of Jupiter’s heavy radiation environment, Juno is the first spacecraft to use a radiation-shielded “electronics vault,” a box with 1-cm-thick titanium walls, to protect its electronics; it weighs 180 kg and cuts the expected 11-Mrad total-dose radiation exposure of the mission to 25 krad, low enough for vehicle electronics qualified to 50 krad
Solid State Recorders in Space

- Mars Global Surveyor (1996 – 2006) used four 750-Mb solid-state recorders
- DAWN (asteroid Vesta and dwarf planet Ceres, 2007) has 8 GB of solid-state memory in its CPU
- Curiosity (Mars, 2011) has 2 GB of flash memory in its CPU, and each mast camera has 8 GB of its own flash memory
- New Horizons (Pluto, 2006 – 2026) has redundant 8-GB banks of flash memory

*NAND-based solid-state recorders can do the job most of the time, but can be subject to single-event effects such as latchup*
Flash Memory—Solid-State Drives

• NAND logic
  - Can be written and read in blocks of bytes
  - Has shorter erase and write times
  - Needs less die area per cell (therefore lower cost per MB)
  - Has longer endurance (more write/read cycles)
  - NAND architecture is inherently more susceptible to total ionizing dose damage than the NOR architecture

• Solid-state drives
  - Combine a flash memory (usually NAND) with a controller as an interface to the host computer
  - Controller can include functions such as error correction, encryption, rapid erase, etc.
  - Greater density, lower power, and lower cost than SRAM/DRAM solid state recorders
Flash Memory—Radiation Susceptibility

- Writing and erasing require high voltages to push electrons across a dielectric layer, to be stored on one terminal of a transistor. These high voltages are built up in a charge pump.
- The charge pump is the circuitry most susceptible to radiation damage.
- As topographies shrink, the overall total dose capability of devices increases—when there is less dielectric, there is less of a chance for an ion or photon to become trapped in it and cause leakage.
- Single-event latchup performance is typically good.
- Single-event upset performance is typically not good.
- Because NAND is rad-tolerant, and not rad-hard, it is critical to implement proper mitigation techniques, such as shielding (TID only), over-provisioning, EDAC, anomaly detection and redundancy.
Radiation-Tolerant NAND Flash

- TCS is developing a single 8-Gb (1024Mx8) die in a 48-lead ceramic package, configured as an asynchronous NAND flash
- Hermetic package: 22.38 mm x 15.69 mm x 4.48 mm (body only)
- Operating temperature: -40°C to 85°C
- Radiation characteristics
  - 50krads (Si) high dose rate (MIL-STD-883, TM1019 Cond A.)
  - Heavy ion characterization testing complete
- Protoyping 16-Gb die stack for use in same package outline
Radiation Tolerant Solid State Drives

- TCS is working with NASA to characterize its rugged COTS SSDs for use in space.
- COTS SSDs are already in use on the ISS and other non deep-space missions.
- COTS SSDs:
  - Pros: low cost, high capacity and performance
  - Cons: nonhermetic parts, may require system-level mitigation for SEU
- TCS is exploring SSDs with higher levels of tolerance and prototyping a custom FPGA-based controller for a radiation-tolerant SSD utilizing our hermetic NAND product.
Phase-change RAM (PRAM, chalcogenide RAM)

- Chalcogenide glasses contain one or more chalcogens: sulfur, selenium, or tellurium
- Chalcogenide glasses exist in either amorphous or crystalline states
- Heating and quenching a chalcogenide glass results in an amorphous state, representing a binary 1
- Holding a chalcogenide glass in its crystallization temperature range for some time allows the material to solidify in a crystalline state, representing a binary 0
- The crystalline and amorphous states are distinguished by their very different electrical resistivities
- **Advantages**: switching speed, size, durability, radiation resistance
- **Disadvantage**: temperature sensitivity
- QML-qualified rad-hard 2-Mb, 4-Mb, and 20-Mb C-RAMs are available
Ferroelectric RAM (FRAM or FeRAM)

- Similar construction to DRAM: each cell is one storage capacitor and its signaling transistor
- Achieves nonvolatility by use of a ferroelectric layer instead of a dielectric layer, usually lead zirconate titanate, Pb(Zr\textsubscript{x}Ti\textsubscript{1-x})O\textsubscript{3} (or “PZT”) or strontium bismuth tantalate, SrBi\textsubscript{2}Ta\textsubscript{2}O\textsubscript{9} (“SBT”)
- When built with rad-hard CMOS, have shown resistance to proton, high-energy particle, and total dose radiation, but applications of FRAM are still primarily commercial

- **Advantages over flash**: lower power consumption, faster write speed, much higher number of write-erase cycles (>\textsuperscript{10^{16}}), radiation tolerance (total dose, single-event upset, and latchup)
- **Disadvantages over flash**: much lower storage densities, storage capacity limitations, higher cost, data retention degrades at higher temperatures
Magnetoresistive RAM (MRAM)

- **Conventional**: data are stored by magnetic storage elements rather than as electric charge or current. Each element is made up of a permanent magnet and another ferromagnetic plate separated by an insulator. When current is passed through a pair of write lines, a magnetic field is induced between them in the storage element. Fast, small, durable, rad-resistant.

- **Spin-transfer torque (STT-MRAM)**: data are stored by spin-aligned electrons. When electrons entering a layer have to change their spin, this creates a torque that is transferred to the nearby layer. This lowers the amount of current needed to write the cells, thereby allowing for faster access times and smaller cells.

- **Thermal-assisted switching (TAS-MRAM)**: uses a heating element to briefly heat the storage layer (ferromagnetic and antiferromagnetic layers) to reduce the field needed for switching (writing), thus consuming less power.

- **Vertical transport (VMRAM)**: uses current through vertical columns to write, allowing for smaller cells.

All must be kept away from strong magnets, which can alter the bit states.

*Standard designs of these devices are subject to latchup caused by ionizing radiation*
Honeywell Radiation Hardened MRAM

- Conventional MRAM built as 150-nm silicon on insulator (SOI) CMOS makes latchup impossible
- Data retention >15 years
- Nearly unlimited read-and-write cycles (>10\(^{15}\) cycles)
- Full operating temperature range of -55°C to +125°C
- QML V qualification in progress

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>CONFIGURATION</th>
<th>VOLTAGE(V)</th>
<th>PERFORMANCE</th>
<th>TOTAL DOSE/SEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M-bit</td>
<td>64K X 16</td>
<td>1.8V, 3.3V</td>
<td>Read: &lt;80ns Write: &lt;140ns</td>
<td>1M (rad[Si]) &lt;1E-10 upsets/bit-day</td>
</tr>
<tr>
<td>HXNV0100</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16 M-bit</td>
<td>2M x 8 or 1M x 16</td>
<td>3.3V</td>
<td>Read: &lt;90ns Write: &lt;140ns</td>
<td>1M (rad[Si]) &lt;1E-10 upsets/bit-day</td>
</tr>
<tr>
<td>HXNV01600</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64 M-bit*</td>
<td>8M x 8 or 4M x 16</td>
<td>3.3V</td>
<td>Read: &lt;100ns Write: &lt;150ns</td>
<td>1M (rad[Si]) &lt;1E-10 upsets/bit-day</td>
</tr>
<tr>
<td>HXNV06400</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*64 M-bit MRAM in development

Source: Honeywell
## Technology Comparison

<table>
<thead>
<tr>
<th>Function</th>
<th>MRAM</th>
<th>EE Prom</th>
<th>Flash</th>
<th>C-RAM/PRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read Speed</td>
<td>Fast</td>
<td>Fast</td>
<td>Moderate-fast</td>
<td>Fast</td>
</tr>
<tr>
<td>Write Speed</td>
<td>Fast</td>
<td>Slow</td>
<td>Moderate-Fast</td>
<td>Moderate</td>
</tr>
<tr>
<td>Read/Write Endurance</td>
<td>Very High</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
</tr>
<tr>
<td>Data Retention</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low at High Temperatures</td>
</tr>
<tr>
<td>Capacity/Density</td>
<td>Med/High</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Temperature Range</td>
<td>Full Military</td>
<td>Full Military</td>
<td>Limited</td>
<td>Limited</td>
</tr>
</tbody>
</table>

*Source: Honeywell*
Conclusion

- The move to NAND has allowed satellites and probes to store more, at a lower cost.
- Emerging memory technologies show promise and are currently being used in space to store code and replace EEPROMs.
- As density increases, it is likely that these newer memory technologies will be seen in radiation-hardened solid-state drives.
- Several new technologies are being studied and currently MRAM seems to be most promising for space.
Questions
Contact Information

TCS Space & Component Technology
19951 Mariner Avenue, Bldg. 157
Torrance, California 90503
(888) 264-0793
www.tcsspace.com
TSYS (NASDAQ)

Keith Watanabe
Program Manager
kwatanabe@telecomsys.com

Alex Takagi
Engineering Manager
atakagi@telecomsys.com

Japanese Representation
www.marubun.co.jp
Appendix
Working with TCS

**Cost Advantages**
- Combined procurement and testing
- Inventory opportunities
- Redeploy your component engineering assets
- Reduce minimum order quantity with combined buys

**Export / ITAR Advantages**
- US company working with ITAR suppliers, acting as technical liaison on behalf of European customers

**Technical Advantages**
- Customer's engineering resources available to perform tasks other than component engineering
- TCS Engineering knowledge and experience
- Extensive NASA, Government and International customer experience

**Schedule Advantages**
- Network of valuable testing resources to reduce cycle time
- Oracle parts management system to keep track of parts, providing web-based status portal
- Dedicated procurement staff for constant supplier management
Program Manager works with full range of staff to meet any needs required

Our Goal: To Exceed Expectations

A Single Point of Contact

Customer

Program Management Team

- Engineering
- Purchasing
- Quality Assurance
- Production Control
- Oracle/CPMS
- Document Control
- Finance
- Marketing

Our Goal: To Exceed Expectations

Customer
Senior-Level Component Engineering, Quality Assurance and Procurement Staff

- Specializing in difficult part procurements, qualification and testing
- Technical expertise in most all part technologies
- Development of all drawing types: custom procurement specs, upscreen documents and special procedures to meet specific customer quality and reliability requirements
- Significant experience working with most high-rel manufacturers
- Expertise to solve manufacturing, test and quality problems
- Space and MIL parts knowledge
- Significant experience with PEMs selection, screening and test
- Library of over 1000 SCDs and more than 1700 upscreen documents to meet high reliability requirements
- Parts also procured to customer SCDs, US MIL specs, ESCC specs and customer drawings
- Independent qualification testing
- Performance of DPA by independent laboratories, with reports reviewed and approved by TCS Component Engineering
What Problems Can We Solve For You?

**We Solve Parts Management Problems**

**Supply Chain Challenge**

- **Timely PO Execution**
- **Supplier Management**
- **Technical Resources**
- **Quality Assurance**

**The TCS Solution**

- Agile, responsive, scalable program team focused on your requirements
- Single point of contact for all suppliers, periodic status reporting
- Senior experienced engineers that can augment your existing staff
- Parts and documentation, delivered compliant to your requirements
<table>
<thead>
<tr>
<th>Challenge</th>
<th>The TCS Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>License application</td>
<td>Direct communication with MFR to assure order proceeds while we apply</td>
</tr>
<tr>
<td>Supplier Management</td>
<td>During manufacturing and testing our US engineers handle all technical issues</td>
</tr>
<tr>
<td>Technical Resources</td>
<td>Senior engineers that can perform source inspection and data review</td>
</tr>
<tr>
<td>US oversight</td>
<td>Parts and documentation can be reviewed at any time without a license</td>
</tr>
<tr>
<td>Export Compliance</td>
<td>Complete internal contracts and export compliance office with an attorney</td>
</tr>
</tbody>
</table>
What Problems Can We Solve For You?

We Solve Parts Obsolescence Problems

Challenge

- EOL or Obsolete
- Counterfeit Parts
- Technical Resources
- Obsolescence Management

The TCS Solution

- TCS parts obsolescence database and numerous sources for obsolete parts
- Counterfeit detection services including XRF, SEM, DPA and inspection
- Parts and designs can be reviewed and we provide alternate solutions
- Long term storage, wafer & die banking, custom builds
TCS performs all types of electrical and environmental testing

- Testing for space and MIL level qualification
- Manufacture and test of obsolete / heritage devices
- Upscreening, special testing, Quality Conformance Inspection (QCI)
- Complete die lot qualification - including radiation testing as needed
- Integrated circuits, ASICs, memory, hybrids, diodes, transistors, connectors, capacitors, resistors, RF/microwave devices, relays, switches, fuses, filters, thermal control devices, magnetics, oscillators, converters, wire, cable, cable assemblies, and many other device types

- Our network agreements make us uniquely able to apply competent, timely, cost effective and efficient test resources

*From basic characterization to full qualification*
Destructive Physical Analysis (DPA)

Utilized on high-reliability parts programs

- To discover workmanship or process defects
- Find lot-related problems
- Prevention of latent failures

TCS works with numerous laboratories - selection based on specific device characteristic or special study requirements…TCS manages the analysis

DPA methods used:

- MIL-STD-1580
- SSQ 25000
- GSFC S-311-M-70
- MIL-STD-883 Method 5009
- Customer specific requirements
Failure Analysis Services

Failure analysis capabilities are critical

Need to determine exactly what happened…root cause
- Bad part?
- Overstress or ESD?
- Design / application issue?
- Process issue?

Need to eliminate or minimize risk
- Must understand why part failed
- Must have experience and history with all high-reliability part types
- Must understand appropriate techniques and when to use them…preserve evidence

Good failure analysis skills are critical
- Failure in-orbit can cost millions of dollars in losses
- Mission-critical failures can endanger human lives
- Understanding the failure mechanisms drives corrective measures

_TCS engineers have decades of space component engineering experience utilizing a vast network of resources_
Our engineers have decades of space component engineering experience utilizing a vast network of internal and external laboratory capabilities:

- Electrical testing (bench and automated), die probing
- Hermeticity testing: fine leak, gross leak, open face
- Particle-impact noise detection (PIND) testing,
- Particle capture and analysis
- Radiography (real-time or wet-film), n-ray
- Computed tomography (3D imaging)
- Residual gas analysis (RGA)
- C-mode scanning acoustic microscopy (C-SAM)
- Scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS)
- Voltage contrast, electron beam induced current (EBIC) imaging
- Photoemission microscopy and externally induced voltage alteration (XIVA)
- Infrared thermal imaging
- Cross-sectional analysis, metallurgical and junction etching
- Focused ion beam (FIB) microsectioning
- Fractography
- Fourier transform infrared (FTIR) spectrometry and other organic analysis
- Auger electron spectroscopy and other surface and contaminant analysis
Multiple radiation test facilities utilized based on our customers needs…TCS manages the testing

TCS’s test data base contains over 1000 radiation test reports

Data also obtained from JPL, GSFC, NASA, NGST, ERRIC, Aerospace Corp, Sandia and many manufacturer data bases

**Radiation testing performed:**

- Total Ionizing Dose (TID)
- Enhanced Low Dose Rate (ELDRS)
- Displacement Damage
- Flash X-Ray
- EMP
- SEE-Single Event Effects
  - Heavy Ion testing
  - Proton testing
  - Neutron testing
  - Gamma testing
Prohibited Materials Analysis

• TCS performs Prohibited Materials testing with in-house XRF

  – Since 2006, the EU’s Restriction of Hazardous Substances (RoHS) directive has restricted lead in metal finishes and solder coatings

  ▪ “Lead-free” designation can mean “pure tin”
  ▪ “Pure-tin” can translate to tin whiskers
  ▪ Counterfeiters re-mark new RoHS parts with older, leaded part numbers
  ▪ Cadmium and zinc can sublimate in a hard vacuum
  • The sublimation products are conductive and can redeposit causing short circuits and whisker growth
Counterfeit Parts – An Industry-Wide Problem

• **Why is the risk increasing?** Component counterfeiters are driven by profit potential. They are able to exploit current market conditions such as:
  - Shrinking high-reliability product life cycles and long lead times
  - Obsolete high-reliability components command high market prices
  - Buyers under increasing pressure to reduce costs
  - The steady flow of recycled electronic components
  - 22% of counterfeit parts are sold by manufacturers or authorized distributors  

• **How do they do it?** They employ both simple and sophisticated methods:
  - Recycled components sold as new parts
  - Falsified certificates of compliance
  - Commercial components re-marked as high-reliability components
  - New components re-marked as obsolete components
  - Re-marked components matching form but not function or reliability
  - Buy genuine parts from manufacturers and authorized distributors, then “return” counterfeits to get them into the legitimate market
Counterfeit Screening Services

Basic Screening Package
- Database Review / Comparison
- External Visual Inspection (100%)
  - Physical Dimensions
  - Marking
  - Package / Lead Conditions
  - Irregularities
- Solvent Testing
- Real-Time X-ray Inspection (100%)

Optional Screening Steps
- Electrical Characterization (100% or sample)
- De-lid and Die Visual Inspection
  - Cross section – Passives
  - Decapsulation – Plastic Devices
- SEM
- Solderability
- Materials Analysis via XRF
- CSAM
Export Compliance

- Historically, less than 5% of all contract parts shipped to customers require an export license.

- TCS is highly experienced and knowledgeable of U.S. Export Regulations and the export licensing process for parts regardless of country of manufacturer or destination.

- TCS places significant emphasis on proper export compliance to minimize contract risk and to ensure on-time delivery.
A Sampling of our Domestic and International Customers

Domestic

BAE SYSTEMS
Honeywell
LOCKHEED MARTIN
Raytheon
NORTHROP GRUMMAN
HARRIS
L3 communications
DRS
Hamilton Sundstrand
Pratt & Whitney
A United Technologies Company
JPL
CURTISS WRIGHT
TECHNOLOGIES
Goodrich
BOEING

International

Mitsubishi Corporation
ENERTEC
ZODIAC
JAXA
Japan Aerospace Exploration Agency
MITSUBISHI ELECTRIC
NEC/TOSHIBA
EMBRAER
RAFAEL
MITSUBISHI HEAVY INDUSTRIES, LTD.
FUJI HEAVY INDUSTRIES LTD.
INPE
FANUC
KARI
KAI
S.P.Korolev Rocket and Space Corporation
JAE
NEC
ENERGIA
Quality Certifications

- MIL-Q-9858A, MIL-I-45208 and NHB5300.4(1C) compliant
- ISO27001 certified
- DO-254 certification in process
- Fully Documented
  - Policy / Procedures
  - Work Instructions
- Records maintenance