

# Actel RTAX-S Series FPGAs

The Actel RTAX-S is a new series of antifuse-based FPGAs now being shipped. A qualification package was submitted to DSCC in October 2005. The related AX series FPGAs (commercial, industrial, military) have been in production since 2003.

### Problems:

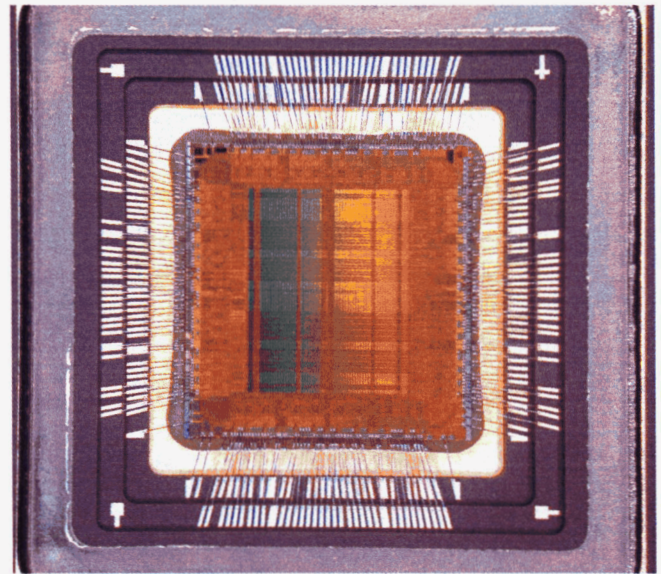
While initial radiation testing showed expected supply current levels, subsequent Actel radiation testing with updated silicon and design software detected anomalous currents.

The onset of the problem is thought to be a result of the change in the RTAX-S design software. Regression tests suggest that this problem is not a result of any silicon issues. This class of problem, early in the product cycle, is consistent with that seen on the previous two generations of FPGAs, and was solved by an update to the design software.

### Issues/Concerns:

The Actel RTAX-S is a new series of antifuse-based FPGAs.

The previous generation of parts (RT54SX-S) had reliability issues with the programmed antifuse.



*RTAX2000S FPGA*

**Parts:** RTAX250S, RTAX1000S, RTAX2000S

**Manufacturer:** Actel Corporation

**Foundry:** UMC, 0.15 μm

## MISSION IMPACT

Continued Mission Critical Usage	GSFC Project	Project Usage	Contingency Plan
✓	LRO	C&DH system, S-Comm, Ka-Comm, HK/IO, and mass storage boards	ASIC (aggressive schedule and significant budget impact)
✓	LOLA	Analog and DU boards	Actel Act 3, Xilinx Virtex, and one ASIC
✓	JWST	ISIM/C&DH, IRSU, NIRCAM, and NIRSPEC	ASIC (Honeywell, BAE, and Aeroflex to be assessed)
✓	HST Express Pallet Mission	Sensor Interface Module and Mass Storage Module	Xilinx

In addition to GSFC projects, these parts are also being used for various other NASA, JPL, and DoD missions.



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## KEY TESTING AND RESULTS

- 1. Qualification Reliability Testing:** In addition to the Actel “standard” qualification burn-in, Actel has added a second test vehicle, based upon NASA Office of Logic Design work, dedicated to testing the stability of the programmed antifuse. 700+ parts were tested with 1 significant failure (random defect).
- 2. Lot Specific Reliability Testing:** Using the same programmed antifuse test pattern used for device qualification, samples from each production lot will be tested by Actel.
- 3. Radiation Testing:** Actel radiation testing for total dose and single event effects shows adequate performance for the listed missions, with the one outstanding item being the anomalous currents described on sheet 1 of this document. This issue must be resolved and is being actively worked by Actel. NEPP sponsored testing shows results consistent with Actel’s.
- 4. DPA Testing:** NASA Office of Logic Design and Code 562 have sent 6 devices, two of each of the three models, to Hi-Rel Laboratories for a destructive physical analysis (DPA). The RTAX250S and RTAX2000S device sets both passed. An issue with the bond wires of the RTAX1000S was detected. The devices were from an early test lot, and Actel and NASA are investigating this issue. Additional samples will be tested and corrective actions will be implemented, as needed, as this class of packaging/assembly problem is routinely fixable. No residual risk is expected.

## RECOMMENDATIONS

- 1. Perform Additional Reliability Testing:** NASA testing can complement vendor data and can accelerate understanding the reliability of parts. The NASA Office of Logic Design and the GSFC Parts Branch have developed such a test plan with inputs from JPL and other industry partners.
- 2. Perform Additional Radiation Testing:** Actel, Code 561, and the NASA Office of Logic Design plan to continue radiation evaluations of these devices, for both single event effects and total ionizing dose.
- 3. Lot Specific Reliability Testing and Procurement:** RTAX-S parts shall be procured to Mil-Std-883 Class B Flow, which is the traditional GSFC approach. Risk is mitigated in two ways. First, read and record data for each flight device will be obtained and reviewed, screening outliers from the flight part population. Secondly, a NASA Office of Logic Design/Parts Branch designed “Mini Lot Qualification” will be performed on each procurement lot, subjecting a sample of devices to accelerated tests.
- 4. Lot Specific DPA:** Actel will cross section two dice from each wafer to assess antifuse construction. NASA GSFC Parts Branch will have DPA performed on two samples of each procurement lot, per standard practice. NASA Office of Logic Design will collect DPA and failure reports from all participating users.
- 5. Design Guidelines:** Designs shall meet the requirements of 500-PG-8700.2.7, “Design of Space Flight Field Programmable Gate Arrays.”
- 6. Flight Part Programming:** Flight parts will be programmed at Actel, permitting trending of high volume, well-maintained equipment, operated by experienced technicians.
- 7. Operating Hours:** All FPGAs will have a minimum of 1000 hours of operation prior to launch.

## **Project Parts Engineer Guidance: Actel Field Programmable Gate Array (FPGA)**

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10/29/2004

### **Purpose**

The purpose of this paper is to provide an overview of the Actel field programmable gate array (FPGA) issues and investigations to date, provide information to GSFC parts engineers on the risks associated with the use of these parts in flight, provide procurement options for their respective projects, and provide general guidance for use of these devices if no other acceptable options exist.

### **Background**

Actel Corporation FPGA devices are used in nearly all flight programs today. Most of the currently used devices have been produced at MEC (Japan), while newer versions are being produced at UMC (Taiwan). Several programs have experienced assembly-level failures of MEC programmed devices, causing concern with the use of these devices in high-reliability space flight applications. Some of these failures have been attributed to exceeding the electrical specifications of these devices, while others have been attributed to flaws in the programming algorithms applicable at that time. There is a good chance that lack of calibration or bad programming equipment also contributed to the observed failures. An industry-wide tiger team (ITT) has been formed to investigate these failures and determine the suitability of these parts for flight. The analysis and experimentation continue and will continue into the near future.

The ongoing GSFC affected missions include the GLAST, JWST, NPP, Themis, AIM, SWIFT/BAT, and Aquarius missions. The affected missions must decide whether to stay with the MEC components they have, use newly designed UMC FPGAs that have not accumulated flight data, use another FPGA family from Actel, Aeroflex, Xilinx etc, redesign with other technologies (i.e., ASICs), or work a hybrid of the various options.

To date, the Swift project has decided to launch with MEC parts after extensive analysis of test data, 1500 hours of successful ground operation and redundancy. SDO and GLAST, who are in the procurement phase, have decided to switch from MEC to UMC parts and issued purchase orders. AIM is planning to make their decision to procure UMC parts. Also, based on the failures of MEC parts seen in ITT testing, Aerospace has recommended to U.S. Air Force not to use MEC parts.

### **Discussion**

The Actel FPGA issue is very serious, and there is no risk free solution at this time. MEC parts cannot be considered as high-reliability parts because of their demonstrated failure rates; more details concerning the risks can be found in enclosure (1). UMC parts cannot be considered as high-reliability parts because of their unverified reliability by independent authority (ITT, Aerospace, and Office of Logic Design at GSFC etc.) and lack of flight heritage as detailed in enclosures (2 and 3).

Rather than mandate an across-the-board solution, GSFC has decided to allow each affected project to decide how to proceed with consultation from the GSFC parts engineering organization, resident parts specialists, and the Office of Logic Design (OLD). Details of the ongoing experimentation can be found on the OLD Web site (enclosure 4).

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### Recommendations

The following recommendations are provided to aid each project in making a decision towards ensuring the appropriate application of these parts.

1. Project engineers shall ensure that their designs comply with parts specification limits, application notes and guidelines provided by Actel, as well as follow the design rules at OLD website @ <http://www.klabs.org/> (enclosure 4).
2. Latest programming algorithm shall be used for either the MEC or UMC devices.
3. Actel FPGAs shall accumulate 1,000+ cumulative hours of device (whether MEC or UMC) operation after programming and assembly before launch to identify and remove **most** parts that have defective antifuses. However, this requirement is not sufficient to provide reliability for parts used in violation of Actel's specification limits and application guidelines.
4. Projects shall perform destructive physical analysis (DPA) on all flight lots focusing on the device construction, registration, and antifuses.
5. Projects should consider other companies' FPGAs (e.g., Aeroflex) as part of their decision analysis.
6. For projects that have not yet procured flight FPGAs from Actel, FPGAs are recommended from the UMC foundry, and independent verification on UMC parts shall be performed. Caution: Projects shall consider alternative designs (e.g., ASICs) as a backup to mitigate schedule and technical risk, should ongoing/future tests identify reliability issues with UMC parts.
7. New projects that are in the design phase should accommodate MEC parts and their power-sequencing requirements, as the MEC parts can be replaced with UMC parts or ASICs. UMC designs can only be replaced with ASICs; again, other FPGAs are available, but they must be qualified.
8. For the long term, GSFC needs the ability to fully inspect these devices for future missions. It is important to extend the collaborative relationship with Actel to gain more insight into the construction, physics, and reliability of the newer FPGAs. More stringent controls are needed until Actel demonstrates that they are providing a high-reliability device that meet projects application needs and reliability requirements.

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### Enclosure1: MEC RT54SX-S family

The MEC 0.25  $\mu\text{m}$  foundry in Japan provides the majority of the RT54SX-S family of devices. MEC devices have demonstrated antifuse failures during actual use, as well as in independent industry evaluation and test. Key details for MEC die are as follows.

- The MEC process for RT54SX-S devices is 0.25  $\mu\text{m}$ , five-level metal. This is a radiation-tolerant process; radiation-hardened parts are not available. Actel does not maintain wafer-level lot-specific traceability for these parts.
- MEC parts have been found to be sensitive to noise on the core voltage lines or temporary undershoot on the I/O due to large number of simultaneous switching. Both can cause electrical overstress on programmed fuses, and shall be avoided as per application guidelines from Actel and OLD.
- Programming MEC FPGAs with old algorithms resulted in possible damage to antifuse from overheating during the programming operation. Actel is incorporating new antifuse design in newer version parts made at UMC.
- Evaluation of ITT parts has found registration/alignment issues in one lot of parts supplied for test. Actel indicates that an internal screen was not performed in order to expedite delivery. The internal screen would have been performed to an LTPD of 30. It is not clear whether this small sample size (8[0]) would have been sufficient to identify the problem. Actel indicates that it has now increased the internal sampling, as well as QML qualification (life) sample sizes.
- ITT tests of the MEC die FPGA included 600 parts. Results of the test were 25 early failures, 4 failures before 600 hours, and 1 final at 2,100 hours, which suggests that infant mortality of the MEC device continues to decrease with increasing operating hours.
- GSFC has performed analysis on the specific set of data provided by the ITT on MEC parts. Failure data appears to show two populations of parts, with two different failure modes, and two different failure rates. One population has an approximate 4% to 6% failure rate. The other population has shown no failures out to more than 3,500 hours.
- The most notable project affected by MEC parts usage at GSFC is SWIFT/BAT. The project decided to fly SWIFT as is due to extensive analysis of test data, the instruments design, and 1,500 hours of successful operation and redundancy. SWIFT/BAT uses a primary and secondary box requiring the use of 10 Actel parts. Based on aerospace probability analysis as applied by Dr. Henning Leidecker of Code 562, the reliability for a 2-year mission is 92%.
- Evaluation of a device removed from a SWIFT project flight assembly has identified carbon (and other) contamination and intermetallic formation between the wire bond and die pad, beyond that expected for a QML device. Further investigation on additional devices continues.
- Another GSFC project, STEREO, had a 1 out of 80 failure at 700 hours. This failure is still being evaluated.
- MEC parts having demonstrated a failure rate of ~4% to 6% in ITT testing, as well as various contamination and alignment issues in several parts, should not be considered as high-reliability devices. This failure rate may negatively impact instrument/spacecraft reliability.
- **New procurements for the RT54SX-S (MEC) family of devices are not recommended. New procurements should be changed to the RT54SX-SU (UMC) family whenever possible as the preferred device due to specified (but unverified) performance improvements. See the UMC details in enclosure 2.**

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### Enclosure 2: UMC (0.25 $\mu\text{m}$ Design) - RT54SX-SU family

The UMC 0.25  $\mu\text{m}$  foundry in Taiwan supplies the newly released RT54SX-SU family of devices, as well as the majority of the commercial-grade devices. UMC devices have not demonstrated any antifuse failures during the normal QML qualification process. Reliability data are provided by Actel Corporation only, and have not been independently verified to date.

Key details for UMC die are as follows.

- UMC process for SX-SU devices is 0.25  $\mu\text{m}$ , seven-layer metal. This is a radiation tolerant process; radiation-hardened parts are not available. The lot identification number on the package bottom side begins with a D. Actel does not maintain wafer-level lot-specific traceability for these parts. Actel indicates that, in the future, it will be implementing a new tracking system that will make this traceability information available.
- QML status was received in September 2004 for 54SX-SU families of devices. These parts are available to DSCC SMD 5962-01508 and 5962-01515, dash numbers 05-08.
- The UMC process implements a purported improved antifuse structure (per Actel) when compared with the MEC process.
- The RT54SX-SU family has been redesigned to eliminate the inrush current issues and power sequencing requirements of the RT54SX-S family. This simplifies power supply circuitry necessary to support these devices. This is a major performance improvement (unverified).
- Only the latest software revision of Silicon Sculptor II (v4.46.0 for Win) is compatible with the RT54SX-SU family of devices.
- The current lead-time estimate for QML-Q devices is 18 weeks.
- ITT independent evaluation of devices with the same antifuse structure, from the same foundry (though not the RT54SX-SU device), is underway. Results are expected within 6 weeks.
- **This is a new device family, redesigned from the RT54SX-S family. As such, there is no existing flight heritage or independent reliability verification data. Because of this inherent risk, projects may want to design for MEC die (known failure rate, power sequencing, inrush current circuitry), in the event that ITT evaluation results are negative, or explore other options such as ASICs or other vendor's FPGA.**

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### Enclosure 3: UMC (0.15 $\mu\text{m}$ Design)- AX family

The UMC foundry in Taiwan will also supply the newest 0.15  $\mu\text{m}$  RTAX families of devices, due to be introduced as QML products in 2Q05. Prototype devices from this family are available now, but QML qualification has not been completed.

Key details for the RTAX die are as follows.

- The UMC process for RTAX devices is 0.15  $\mu\text{m}$ , seven-layer metal.
- This family does not support 5 V I/O; 3.3 V is the maximum, and 1.5 V, 1.8 V, and 2.5 V I/O are also available selections.
- Pre-production units are available now; QML devices are expected in 2Q05. The SMD specification has not been released. QML qualification testing has not been completed by Actel. Product delivery schedule may be delayed due to QML qualification test issues, impacting program schedule.
- First part deliveries are being offered in ceramic quad flat packs (CQFP), with limited I/O availability – thereby restricting the design and gate usage number.
- The largest devices are available as ceramic column grid array (CCGA) packages, which may present previously unseen assembly issues.
- FIFO controller and SRAM circuitry on the RTAX die are not radiation hardened. EDAC and other mitigation strategies may be required to meet project radiation requirements.
- At this time, there is no ITT testing planned for this device family.
- This series of devices needs independent qualification to assure their reliability for space applications.
- Radiation characterization data on flight parts is needed to determine the suitability of parts to each mission requirements.
- **This is a new device family. As such, there is no existing flight heritage or independent reliability verification data. Programs using these devices incur risk to cost and schedule associated with the introduction of any new, untested product.**



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### Enclosure 4 : Application Guidelines for All Actel FPGA Devices

Users shall diligently follow the published Actel design guidelines and application notes. Concrete evidence of the negative effects of improper design and application of Actel FPGAs is available, and continues to accumulate; hence, the need for more attention is emphasized here. Below are **key** design and application criteria that **affect all Actel FPGA products, regardless of the die foundry**. These are repeated here for emphasis; all are described within the Actel application notes and design guidelines documents, as well as on the GSFC Office of Logic Design (OLD) Web site (<http://www.klabs.org/>).

1. Recommended operating conditions should be observed in the flight use of these devices. Use of the parts beyond the published Actel data sheet (and/or DSCC SMD 5962-01508 or 5962-01515 as applicable) absolute maximum ratings is prohibited, and may be deleterious to part reliability. No voltage/current/timing margins, beyond that explicitly specified, should be assumed by the user.
2. Use of programmed parts not in compliance with published Actel application notes and usage guidelines is prohibited. Some examples include, but are not limited to:
  - a. Simultaneous switching noise and signal integrity.
  - b. Power cycling and sequencing (RT54SX-S only).
  - c. Cold sparing.
  - d. TRST\* and IEEE JTAG configuration.
  - e. Clock skew and short paths.
  - f. High/low slew rate output driver use.
  - g. Board-level considerations (including capacitor selection).
  - h. Quadrant clocks.
3. Designs must be properly analyzed to assure that signal integrity parameters are met. Clocks and logic levels must be clean and glitch-free. Phase relations with other signal lines must be taken into account. Worst-case analyses should take into account factors such as pulse width, propagation delays, and jitter. Environmental and aging effects need to be assessed for their impact on propagation delays.
4. Programming software should be verified to be the latest version available, prior to device programming. Silicon Sculptor II (Win) is currently at v 4.46.0 (as of October 14, 2004). This latest programming algorithm does not eliminate the low-current antifuse damage caused during programming, but claims to eliminate all high-current antifuse damage. Independent analysis continues; results are expected before then end of CY2004. A newer software version, claiming to eliminate both high-current and low-current antifuse failures, is expected by the end of October 2004.
5. Programming hardware should be maintained in accordance with the Actel instructions and Code 562 calibration procedure (to be developed). Recommendation for calibration of hardware used to program flight devices is attached (Appendix A), and should be implemented immediately.
6. Designers should consider use of JTAG (IEEE 1149.1) circuitry in new designs. Information on module, device, and PWB operation, without the need for special probes or device removal, would enhance troubleshooting capability.



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7. The URLs below provide link to specific topics regarding guidance in the use of Actel RTSX FPGAs:

"OLD News #1: Terminators for Silicon Explorer"

[http://www.klabs.org/richcontent/old\\_news/old\\_news\\_1.htm](http://www.klabs.org/richcontent/old_news/old_news_1.htm)

"OLD News #3: Input Transition Times for SX-S FPGAs"

[http://www.klabs.org/richcontent/old\\_news/old\\_news\\_3.htm](http://www.klabs.org/richcontent/old_news/old_news_3.htm)

"OLD News #9: Heat Sinks In Integrated Circuit Packages Can Cause Shorts"

[http://www.klabs.org/richcontent/old\\_news/old\\_news\\_9/](http://www.klabs.org/richcontent/old_news/old_news_9/)

"OLD News #10: RT54SX32S High ICCI Inrush Current"

[http://www.klabs.org/richcontent/old\\_news/old\\_news\\_10/old\\_news\\_10.htm](http://www.klabs.org/richcontent/old_news/old_news_10/old_news_10.htm)

"OLD News #13: Minimum Delays and Clock Skew in SX-A and SX-S FPGAs"

[http://www.klabs.org/richcontent/old\\_news/old\\_news\\_13/](http://www.klabs.org/richcontent/old_news/old_news_13/)

6a. Refer to the following URL for general guidelines and Criteria for Space Flight Digital Electronics"

[http://www.klabs.org/DEI/References/design\\_guidelines/nasa\\_guidelines/](http://www.klabs.org/DEI/References/design_guidelines/nasa_guidelines/)

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### Enclosure 5: Alternates To Using Actel FPGA Devices

There are other options available to the system designer, to replace Actel FPGA devices. Many of these options have their own specific set of risk factors. A small, representative list is provided here. Additional details on these options may be provided, as required. Please contact Code 562 for additional assistance.

1. Custom ASIC Device. QML radiation-hardened devices are available. There is no specific flight heritage, since each design is unique; 22+ weeks must be allowed for flight devices. Each new "spin" (design) requires additional schedule (8+ weeks) and additional NRE. Mature design is required for cost efficiency.
2. Aeroflex FPGA. QML qualification is in process and expected in December 2004. This is a radiation-hardened FPGA with no existing flight heritage. It uses antifuse technology, but the logic structure within the cells is very different from the Actel parts. There is no clear formula for Actel gate count to Aeroflex gate count. Design and simulation tools are commercially available (e.g., Quicklogic). The part is similar in price to the Actel RT54SX72S.
3. Xilinx FPGA. This is available as a TID radiation-hardened device, but it has no SEE specification. SRAM-based logic allows reprogramming. Radiation effects evaluation is in process by Code 561. The largest devices are available only as CCGAs.
4. FPGA to ASIC Migration. This is a hybrid approach using FPGA for breadboard, brassboard, and engineering models to finalize design. Finalized design is then converted to ASIC for flight assemblies. This option allows less expensive, commercial FPGAs for development. Costs rise if the design requires modification after the ASIC run begins.

**Appendix A. Silicon Sculptor Programmer Calibration Verification Procedure 1/**

In order to maintain the Silicon Sculptor Programmer and reliably program flight devices, two separate verification processes are required, as described below. The procedural information is current as of October 21, 2004; refer to the Actel Corporation Web site to verify the latest procedures. The verification intervals, as specified below, are highly recommended for maximum programming reliability, and to minimum unnecessary damage to flight devices.

Calibration verification is required to be performed prior to the start of programming for a batch of flight devices, at a minimum. Self-diagnostic test is required to be performed prior to the start of programming for each flight device.

**A. Calibration Verification.** It is necessary to verify the accuracy of the programmer's self-diagnostic test to ensure that the test will provide accurate results. The programmer uses an internal digital volt meter (DVM) to measure the voltage and/or current of 13 internal nodes and 48 analog pin drivers, allowing verification. The internal DVM accuracy may be verified with a bench DVM. An option in the self-diagnostic test may be executed to allow testing of the accuracy of the internal DVM and time base using a bench DVM and oscilloscope or period counter. **The following DVM and AC calibration procedures shall be performed prior to the start of each flight programming batch operation.** If the unit fails the accuracy or self-test, it must be returned to the factory (Actel) for repair and failure analysis.

Procedure for verifying accuracy of internal DVM:

1. Secure the SM48DB (48-pin DIP socket module) in place on the programmer.
2. Press the ALT D keys.
3. Press the T key when prompted.
4. Connect the BLACK lead of your DVM to pin 3 of the DIP socket.
5. Measure the voltage at pins 1 and 2 of the DIP socket and check that they fall within the minimum and maximum levels displayed on the screen.
6. Press any key to continue.

Procedure for verifying AC calibration: At this point in the test, the programmer will produce a 900  $\mu$ s pulse width on pin 1 of the DIP socket. Use an oscilloscope or period counter to verify that the positive pulse on pin 1 is between 890  $\mu$ s and 910  $\mu$ s.

This completes the traceability test. The programmer will continue with normal self-test. It must pass the self-test.

**B. Self Diagnostic Test.** During the FPGA programming operation, each pin driver is continuously monitored and calibrated by a special supervisory circuit. The programmer's self-diagnostic test will verify correct operation of the pin drivers, power supply, CPU, memory, and communications. **This self-diagnostic test should be successfully completed performed prior to the start of programming for each flight device.**

1/ (Reference Actel SiliSculptProgCali.pdf file)