

A Tale of three capacitor problems



GSFC Safety and Mission Assurance

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SAFETY and MISSION ASSURANCE
DIRECTORATE Code 300



Outline

- Reverse-bias capacitors in the ExPRESS Logistics Carrier on ISS
- The LandSat-8 TIRS on-orbit anomaly
- Historical problems in ground testing with ceramic capacitors
- The circle is closed on capacitors

ELC LVPS reverse cap problem

Background

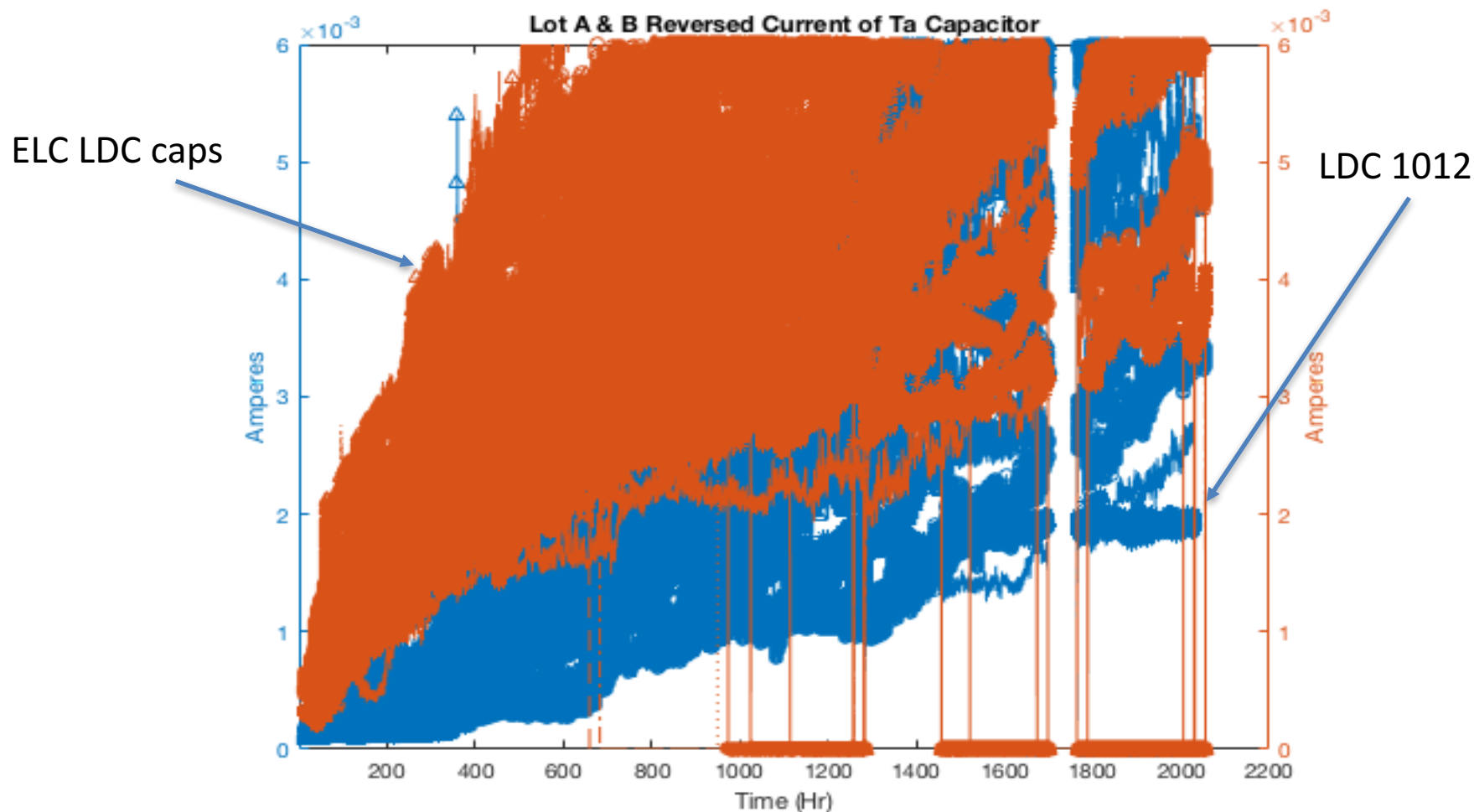
- On the ExPRESS Logistics Carrier on the International Space Station, the Tantalum Capacitor for both main/aux feeds of the low voltage power supply was installed in reverse polarity, in all four locations
- This has resulted in 2 failures on the ground - one in initial ground testing of the ELC simulator (at KSC in 2011, resulting in replacement of parts without solving problem*), and another in 2012 in operation of the ELC simulator to support a customer, each after a few hundred hours of operation
- The primary sides of each ELC pallet have been operating continuously without any observed anomalies for many years; secondary sides have not been exercised on-orbit (with the possible exception of initial checkout).
- **The assertion from NESC testing has been that temperature is the critical factor and that 25 deg C is the threshold above which there is a real threat to the capacitors and associated circuits**
 - This drives ISS to restrict Payloads' operations loading in the 120 to 28V converter above a particular beta angle
 - There have been no failures, leakage current excursions, or circuit issues to date in any operation in vacuum
 - No failures have occurred on-orbit in 4+ years of operation, albeit at temperatures mostly around 15 deg C with infrequent excursions up to about 30 deg C

*Since there was no resolution of the problem failure record, there is not broad agreement that this failure is due to the reverse-bias capacitor

Testing, Phase 1

- Our initial hypothesis based on previous testing
 - Based on manufacturing variability, capacitors will roughly bin into two groups, one of which will head off to failure within about the first several hundred hours and the other will either recover after some time or stabilize
 - Groups may vary by temperature or by voltage across the cap
- Result: At room temperature (23 deg C), all caps either reached max allowable leakage current (surpassed 6 mA) or were on path to failure even below 5 V. Given results, no further temperatures were tested.
- Observation: data viewed at high resolution showed a weak weekly periodicity, perhaps due to weekend reduction in HVAC
- **We were a bit baffled because our ground testing is not representing what we are seeing on-orbit.**

Phase 1 – all caps go to failure in ambient temperature/pressure



Phase 2: Proof of concept – drying out caps

All 23C, Ambient Pressure

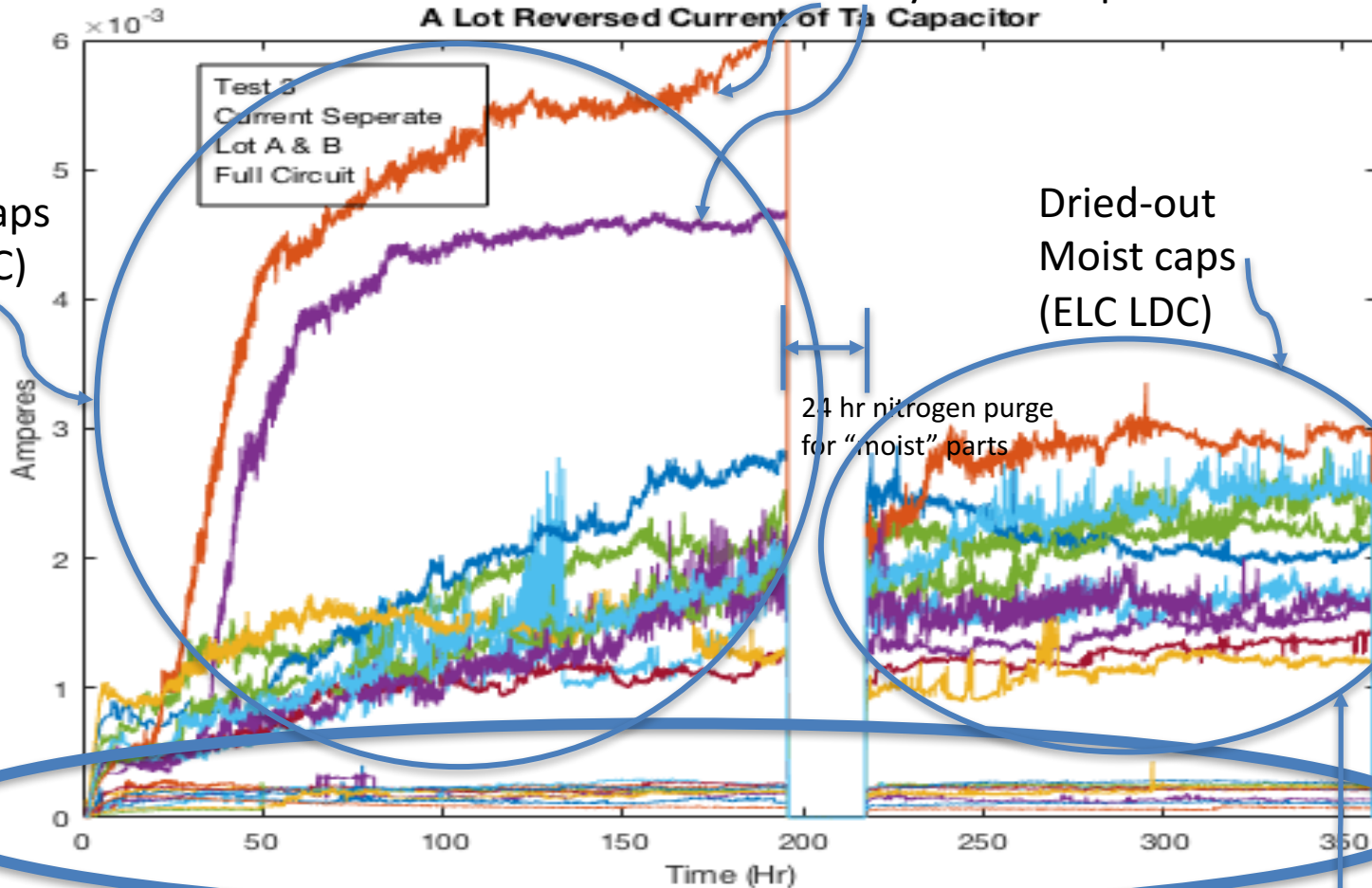
Severely stressed parts

A Lot Reversed Current of Ta Capacitor

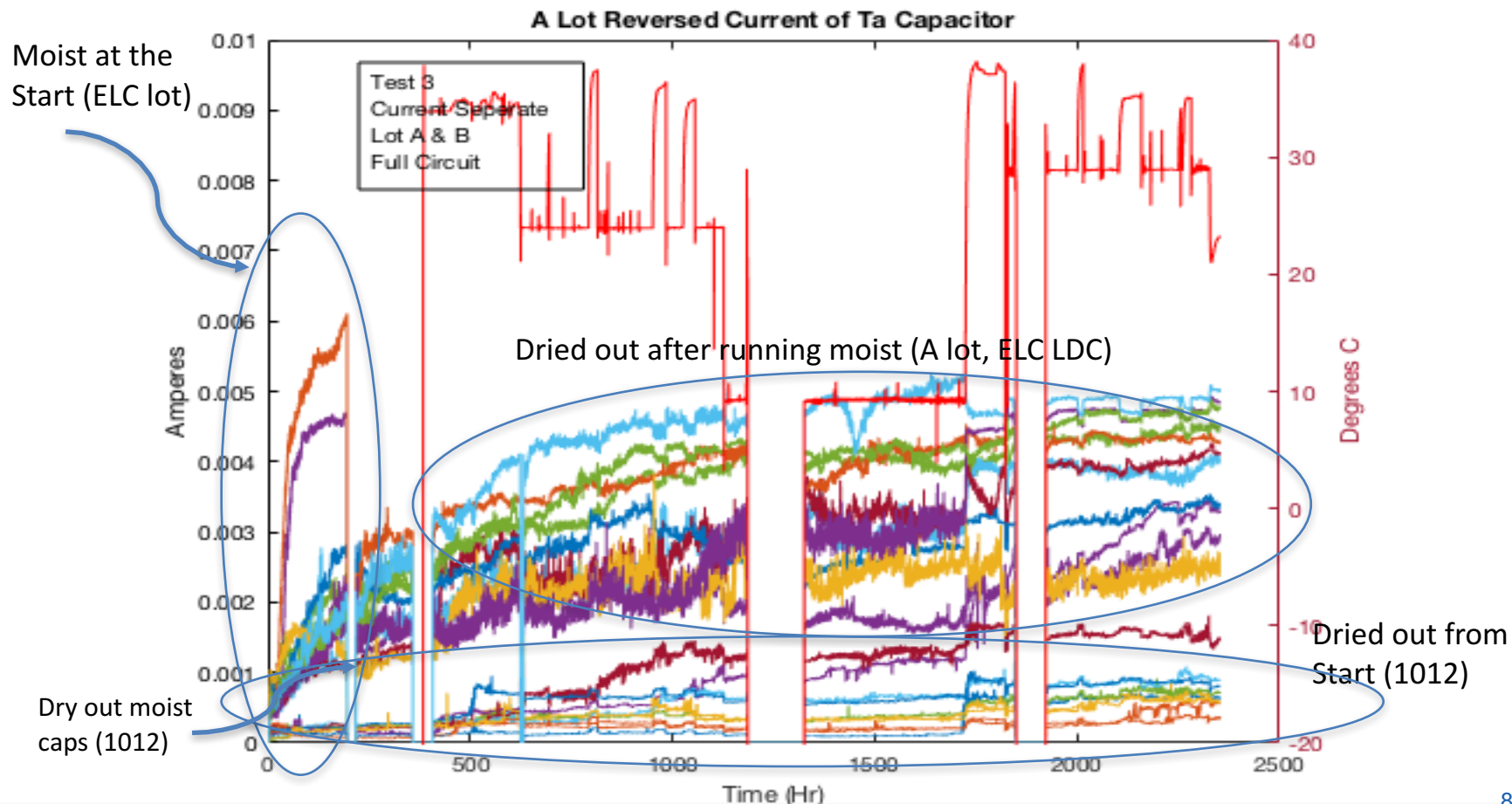
Moist caps
(ELC LDC)

Dried-out
Moist caps
(ELC LDC)

24 hr nitrogen purge
for "moist" parts

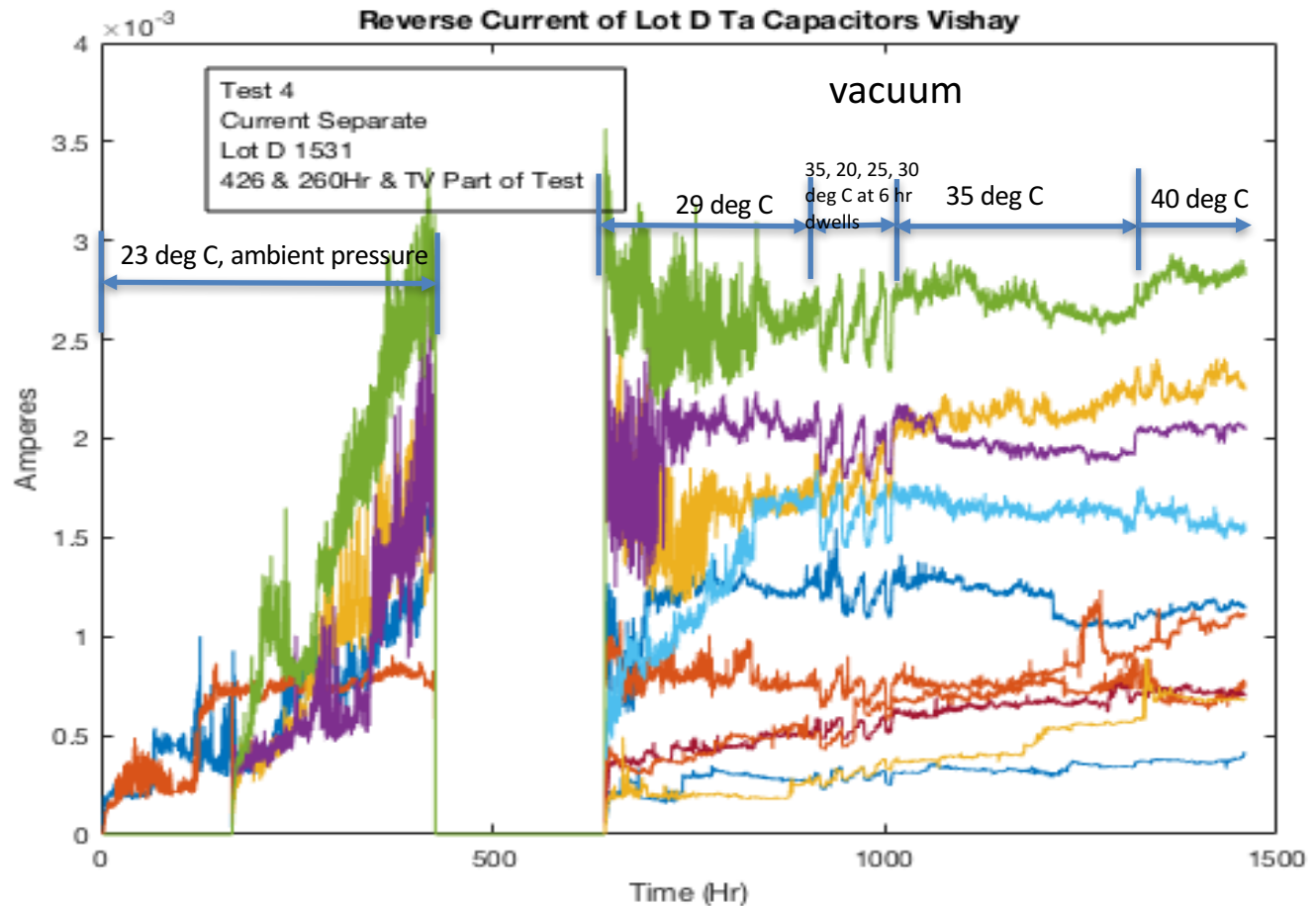


Phase 3 (ambient pressure)



Behavior of wet/dry caps is comparable to Aerospace vacuum testing at 22 deg C

Phase 4 TVAC results (ambient, then vacuum), LDC 1531



Findings

- Vacuum operation and drying through purge induces recovery in failing caps
- There is temperature dependence in vacuum but it is mild, at least below 35 deg C
- Only one or two caps even appear to indicate a slight climb at the end in early results
 - First and second derivatives indicate that there is no long-term climb in the GN2 purge results, the vacuum results, or in the original Aerospace vacuum results.
- No failures have occurred in any application in a fully-dry environment at any temperature due to the reverse caps
 - Aerospace testing – 4000 hrs
 - On-orbit – 4+ years
 - Our testing – 1500+ hours

LandSat-8 Thermal Infrared Sensor (TIRS) on-orbit Scene-Select Module (SSM) anomaly

TIRS on-orbit SSM anomaly

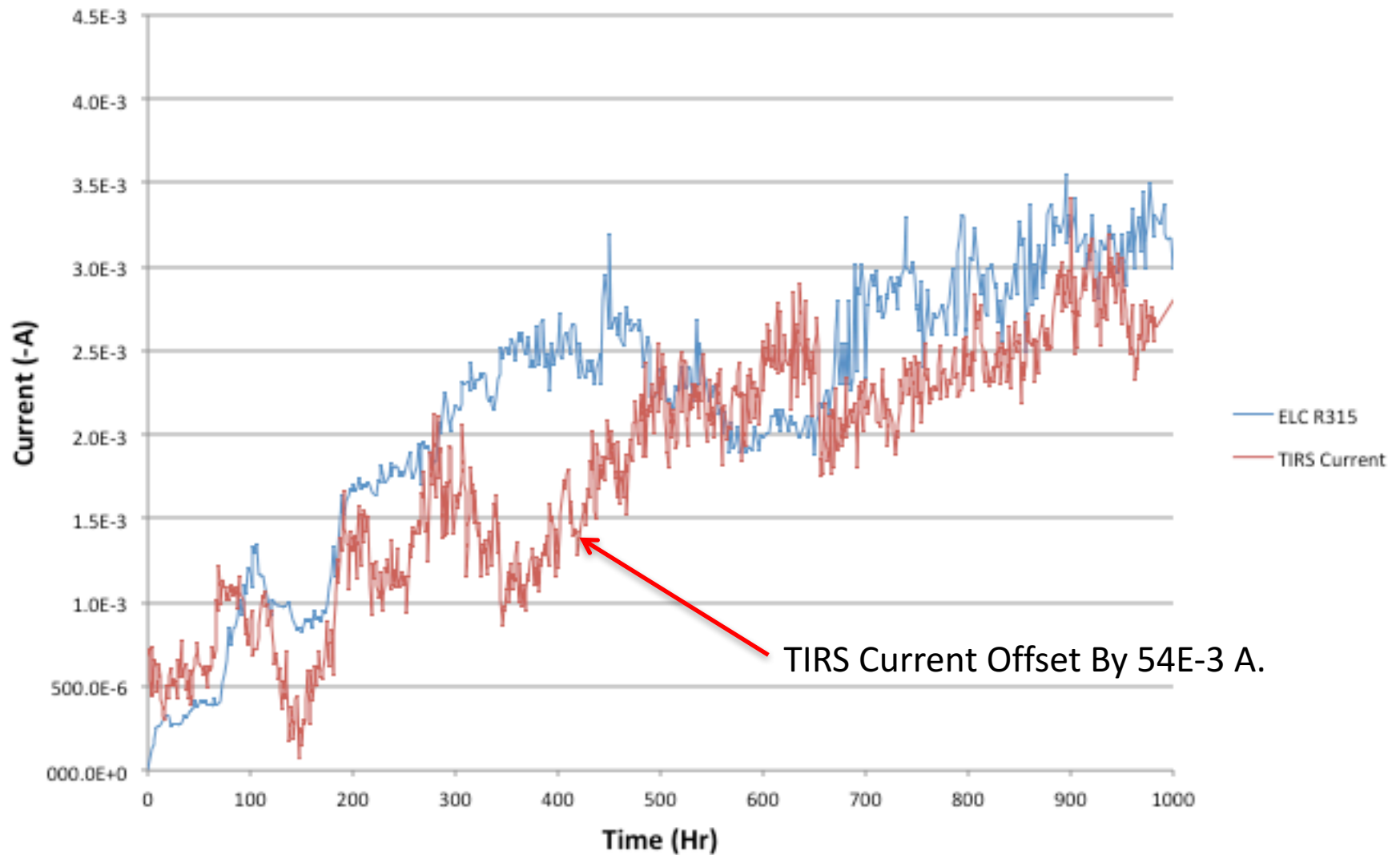
Starting approximately 10 months after launch of LandSat-8 an anomalous trend was noted in the –EV MCE current on the TIRS A side electronics. Over time the –EV MCE current began to grow at an exponential rate and an anomaly investigation commenced. A lengthy investigation could not confirm root cause, however it was suspected at the time that a conductive anodic filament (CAF) created a short path within the A side electronics. To prepare for possible loss of MCE, tests were conducted to understand SSM drift without positive feedback control.

Following the recommendations from the A side ARB investigation, TIRS was swapped to the B side electronics to collect optimal science for the 2015 growing season. Approximately 5 months after resuming nominal operations on the TIRS B side, indications of an anomalous current have been observed in the +EV MCE current.

TIRS on-orbit anomaly cont'd

- In preparation for TIRS-2 (LandSat-9), GSFC S&MA (Code 300) was reviewing anomaly history of TIRS, noting the behavior and open items on the fishbone
- Behavior of the on-orbit leakage currents on TIRS bore a striking resemblance to the reverse bias capacitor performance in our ELC ground testing
- A thorough examination was performed of the capacitor polarities in all related components on TIRS
 - Polarity was correct at all levels
- Code 300 requested that spare boards be brought out of storage to be powered up
- Not long after power-up, the board started to exhibit the leakage current reflective of the on-orbit behavior
 - Many attempts were made to power cycle the boards, induce recovery, or otherwise affect the profile, with mixed results
- We placed a thermal camera over the board to watch for hot spots

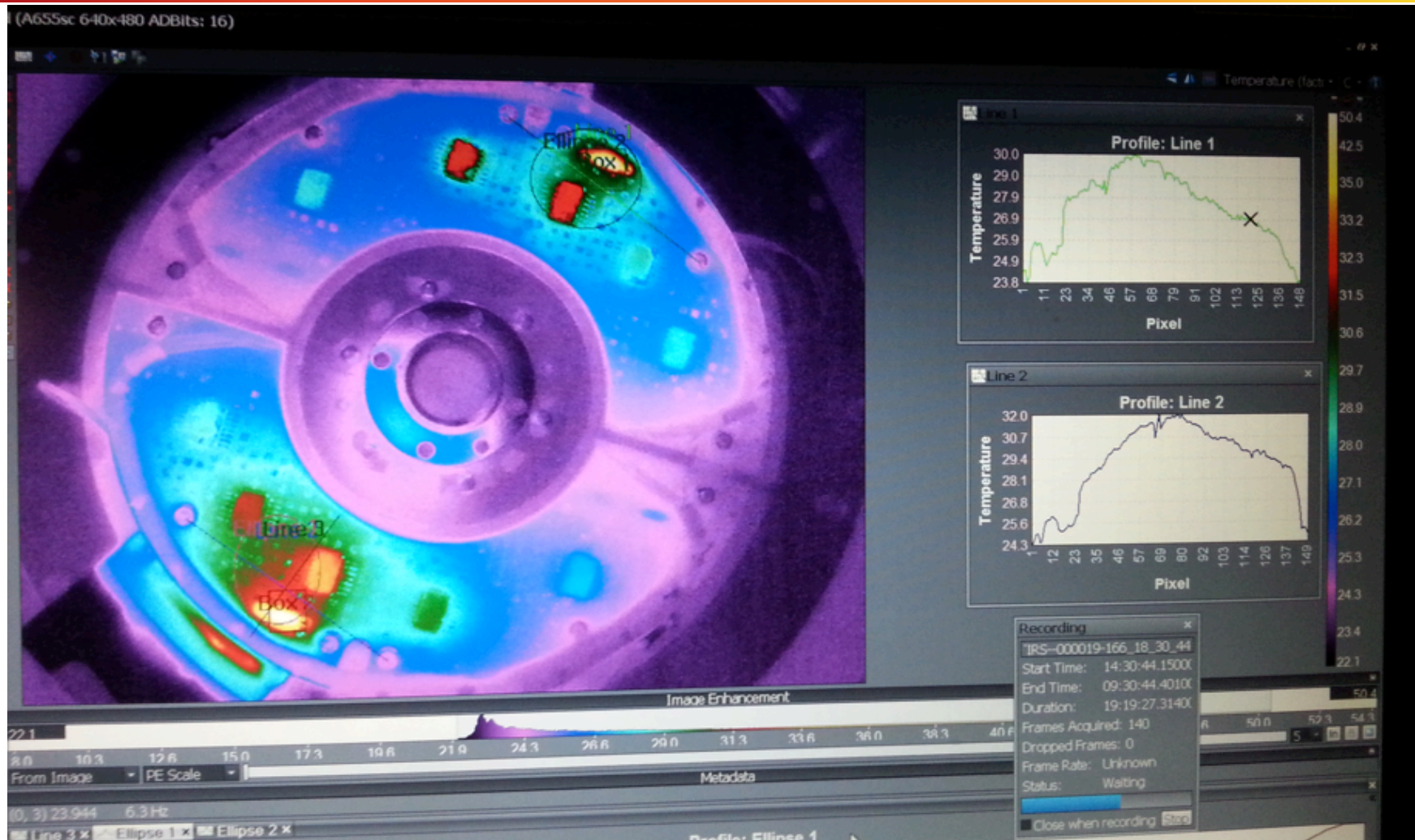
ELC & TIRS at 1000 Hr



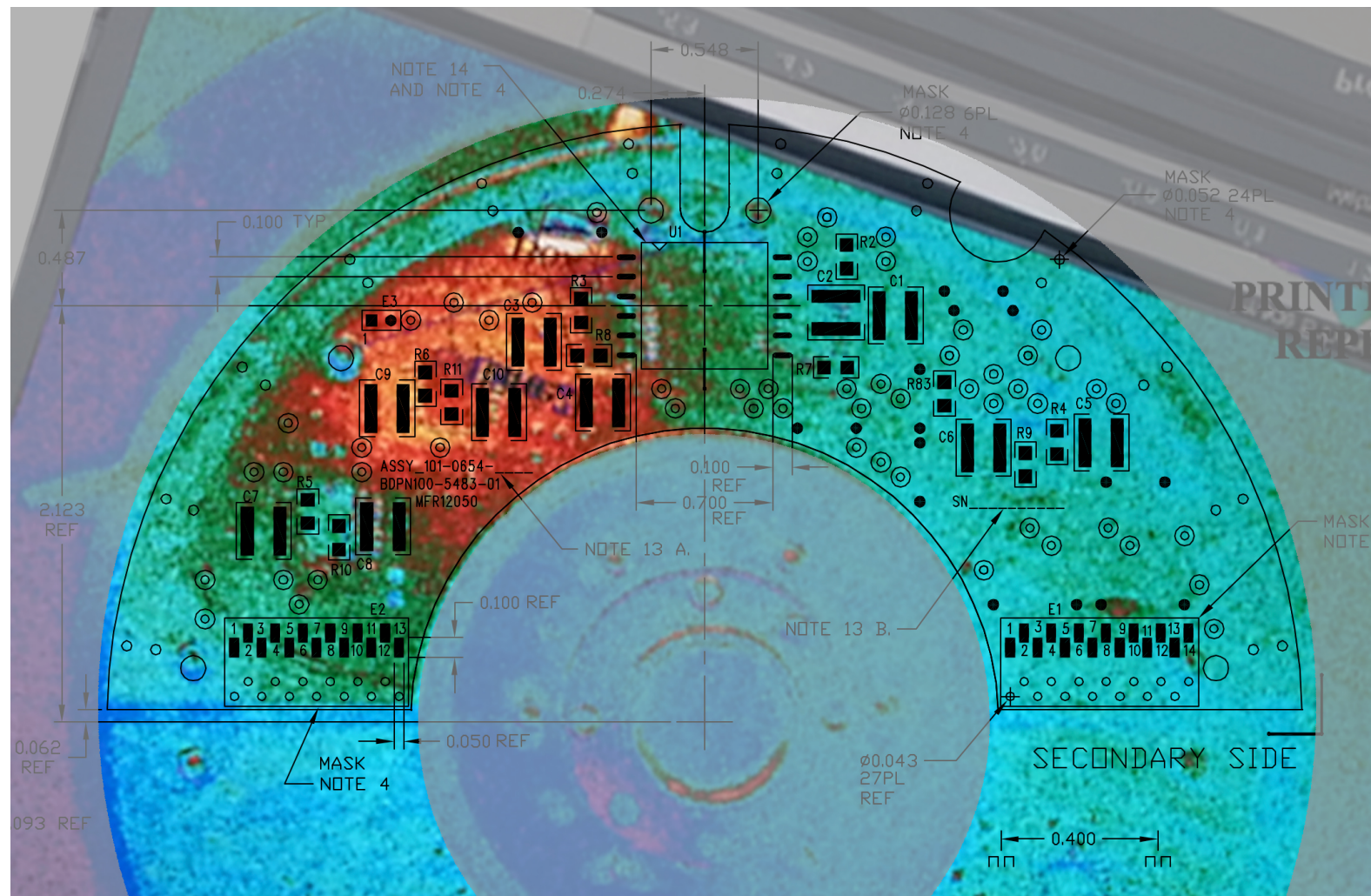
TIRS on-orbit anomaly cont'd

- After weeks of operation, noticeable locations of excessive temperature rise were seen on the board
- These were located in the vicinity of some RC filters feeding into amplifiers on the board
- Probe measurements were taken at points on the bank of filters that indicated reduced voltage (and hence current leakage) at at least two of the caps.
- GSFC parts branch brought in a thermal camera with high spatial resolution that identified that the hot spots were unequivocally located on two of the capacitors themselves.
- The focused heating combined with the fact that the capacitors are hand-soldered ceramic caps (not recommended for handsoldering) give a strong indication that they are cracked.
- Inspections of the board and x-rays performed did not show signs of cracking
- The process then began to remove the suspect parts from the board for failure analysis and replacement.

Initial IR image showing mirror in Lower LHS



Initial IR image



TIRS on-orbit anomaly cont'd

- This is the first instance we have seen of cracked capacitors making it through I&T undetected and becoming anomalous on-orbit
- However it is possible that the problem was present on the ground and the particular telemetry was not noticed.

Proximate and deeper causes

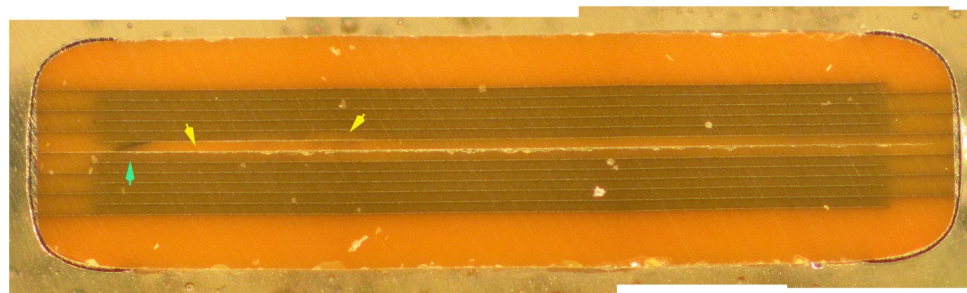
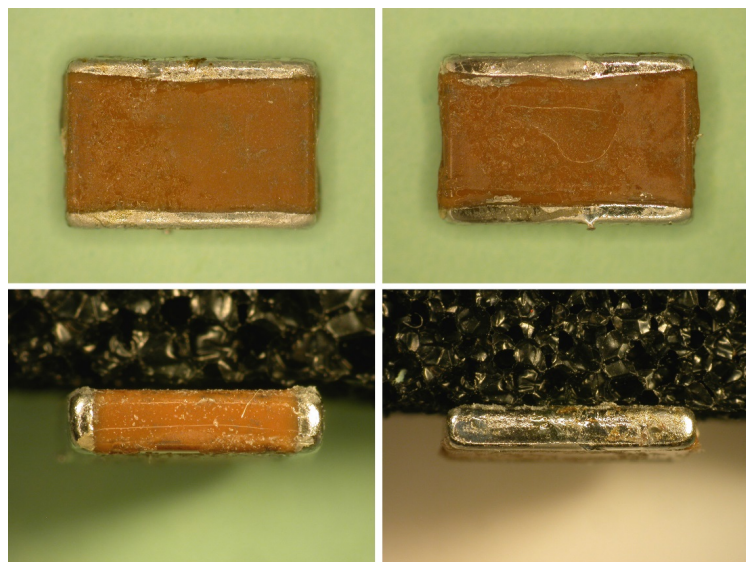
- Proximate cause: leakage current is caused by cracks in one or more ceramic capacitors
 - Part was carefully removed from the board (no damage, fortunately)
 - Board powered up without suspect capacitor – functioned flawlessly for two weeks
 - CSAM showed significant crack
 - DPA identified two internal cracks, not apparent from the surface of the part
- Intermediate cause possibilities
 - Handsoldering without proper preconditioning caused thermal cracking condition
 - Mechanical properties of the board and associated assembly and handling led to cracks in caps
 - Sensitive lot of parts susceptible to cracking under proper handling and installation
 - Excessive moisture in the parts led to popcorn effect while soldering
 - Other internal flaws in the part
- Activities to determine intermediate cause:
 - Complete DPA on part
 - Testing of spare parts from lot

Cracked ceramic capacitors

History of cracked ceramic caps at GSFC

- LRO – Kemet SM20– cracks in dielectric – unknown cause
- SDO – AVX 0.1 μ F CDR35 – crack near end of electrode
- RRM – Kemet 0.1 μ F CDR33 – corner crack in ceramic due to installation – either mechanical or thermal
- TIRS MEB – AVX 0.1 μ F CDR35 (8) - corner crack in ceramic due to installation – either mechanical or thermal
- GPM – AVX 33 μ F SM01 – cracks due to installation, mechanical or thermal
- GPM – AVX SMPS – cracks due to installation, mechanical or thermal
- GPM- AVX SM01 – cracks due to soldering of nearby component lead
- JWST – Presidio SR1206 0.1 mF – suspected handsoldering thermal cracking or of nearby components
- MMS- Presidio G311 (5+) 1 nF, machine installed, caused by aesthetic touch-ups of solder joints
- GOES-R - AVX M123 many variants, hand-soldered
 - May have been process problem or lot problem, not clear
- NICER – Presidio – likely failure on installation

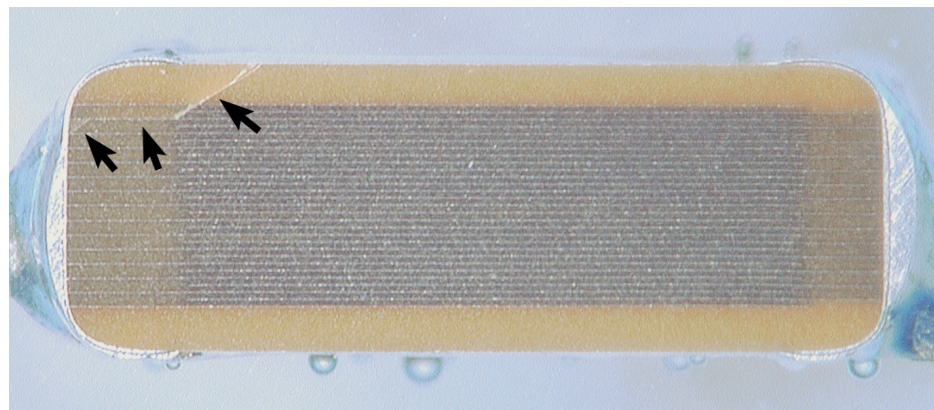
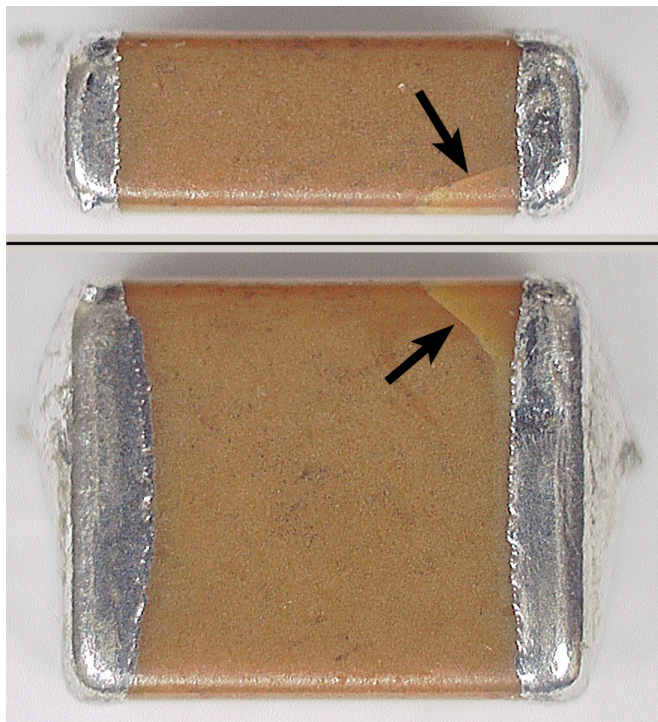
Project:	SDO	Part Type:	Capacitor
System:	EVE Instr – CEB/MIT	Part Number:	CDR35BX104BKUS
Requester:	A. Reyes 286-0879	Generic Number:	CDR35BX104BKUS
Report Date:	10 October 2007	Description:	0.1uF, 10%, 100V
Investigator:	F. Felt 286-9634	Manufacturer:	AVX
Serial Number:	None	Lot Date Code:	0509
Job	Q70430FA	Package Type:	Ceramic



Conclusion

Electrical testing confirmed that the capacitor exhibited a 1500-ohm short. Cross sectioning found a delamination along one side of the center electrode, extending across the entire part from termination to termination. This defect was probably due to a problem during fabrication. A smaller, crack-like defect located near the floating end of the center electrode was found, apparently a secondary effect of the delamination. This diagonal crack appeared to connect opposing electrodes and is a likely candidate for the location of failure.

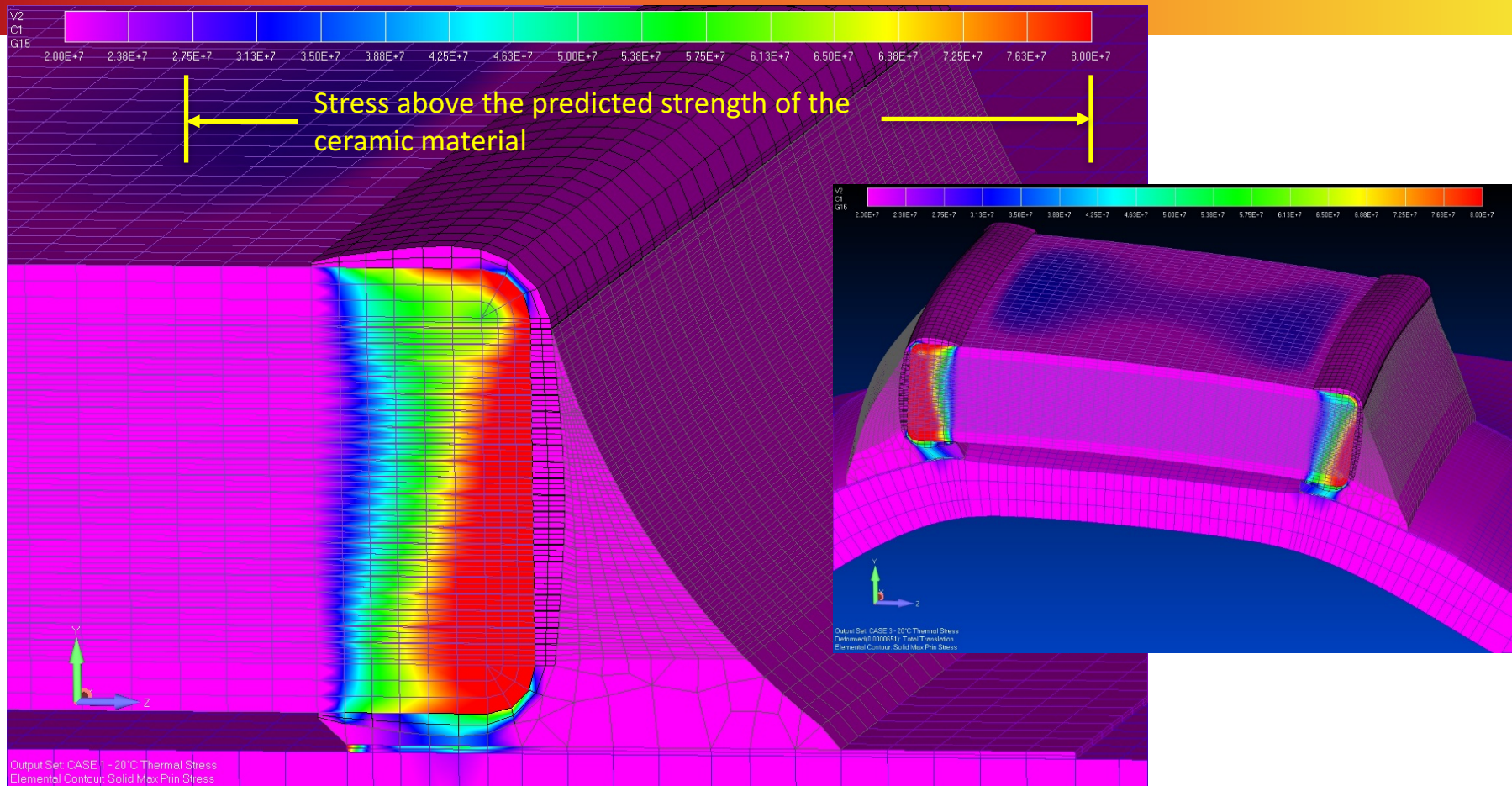
Project:	Space Services Capabilities Project	Part Type:	Capacitor
System:	FHST - DPP	Part Number:	2000467-041
Requester:	T. Miccolis	Generic Number:	CDR33BX104AKUS
Report Date:	04/28/2011	Description:	0.1uF $\pm 10\%$, 50V, MLCC
Investigator:	C. Greenwell	Manufacturer:	Kemet Corp.
Job	J10748FA	Lot Date Code:	Lot # 09MLH11277-1-1



Conclusion

The capacitor was most likely damaged during or as a result of the attachment process. No extrinsic defects were observed in this capacitor nor the three DPA samples (see report J10748DPA).

Stress Model of MLCC Capacitor



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What to do in common situations (ceramic caps in general)

- Parts not installed
 - Avoid handsoldering, but if necessary, carefully follow and monitor process
 - If machine soldered, avoid solder joint touch-ups and rework in vicinity
- Installed parts, machine-soldered
 - Review leakage currents or nearby voltages where feasible
 - If possible, identify critical and/or non-FT applications
 - Avoid any risky interrogations, do not pull parts without risk comparison
 - Avoid rework in vicinity, and take note of any that has occurred
 - Take note of any solder touch-ups that have occurred (ask techs)
- Installed parts, hand-soldered
 - Carefully review process used (thermal conditioning, timing) and prior experience
 - If possible, identify critical and/or non-FT applications
 - Perform inspections from separate package. where not risky

Do not start reworking or risky handling of boards without comparison of risks

Summary

- Three capacitor anomaly conditions have been presented
 - Ceramic caps cracking upon installation or touch-up/rework
 - Designed-in reverse-bias tantalum
 - Cracked ceramic caps that have made their way on-orbit, leading to an elusive failure cause
- Interesting linkages among problems and coincidental investigations aided our path to proper conclusions
- We have found a circular relationship among several anomalous capacitor conditions
 - Reverse bias
 - Moisture effects
 - Cracking