National Aeronautics and Space Administration

Ceramic Capacitor Delamination Problem

Safety and Mission Assurance

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December, 2017

SAFETY and MISSION ASSURANCE DIRECTORATE Code 300

SAFETY and MISSION ASSURANCE NASA Goddard

Outline

- TIRS SSM anomaly description
- DoD failure
- SDO EVE capacitor failures
- Other vendor failures
- Testing taking place
- Experience summary
- Summary

Note on Timeline

- This presentation is told from the GSFC SMA viewpoint as we saw the story come together.
- ***It is not told in chronological order.***

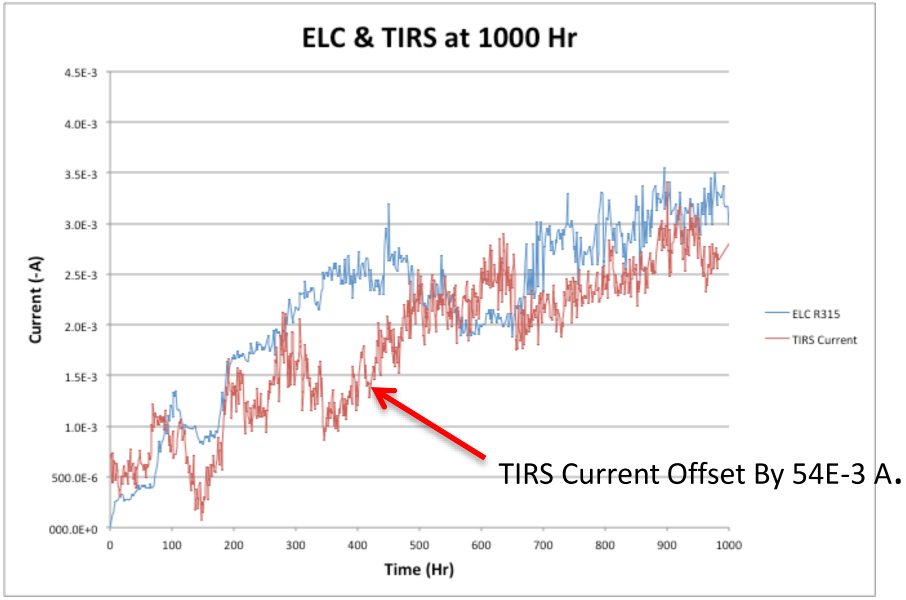
TIRS on-orbit SSM anomaly

About 10 months after launch of LandSat-8 an anomalous current trend was noted on the Mechanism Control Electronics (MCE) on TIRS A side electronics. Over time the 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) was creating a shorting path within the A side electronics. To prepare for possible loss of MCE, tests were conducted to understand a mirror's drift without positive feedback control.

Approximately 5 months after resuming nominal operations on the TIRS B side, indications of an anomalous current were observed.

TIRS on-orbit anomaly cont'd

- In preparation for TIRS-2, Code 300 was reviewing anomaly history of TIRS, noting the behavior and open items on the fishbone
- Code 300 was concurrently performing reverse bias capacitor testing to support projects using the Express Logistics Carrier (ELC) on ISS.
- Behavior of the on-orbit leakage currents on TIRS bore a striking resemblance to the reverse bias capacitor performance in our ground testing

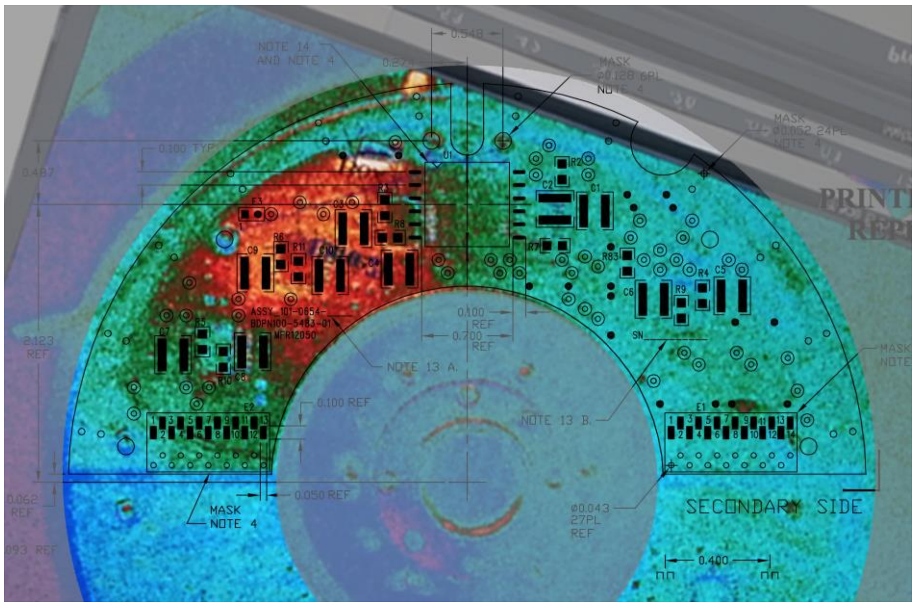


TIRS on-orbit anomaly cont'd

- Suspecting a polarity problem, polarized capacitors on TIRS were thoroughly examined. The polarity was correct for all capacitors in the affected area.
- GSFC SMA requested that spare boards be brought out of storage to be powered up
- A thermal camera was placed over the board to watch for hot spots.
- Not long after power-up, the board started to exhibit an increase in (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 temporary results

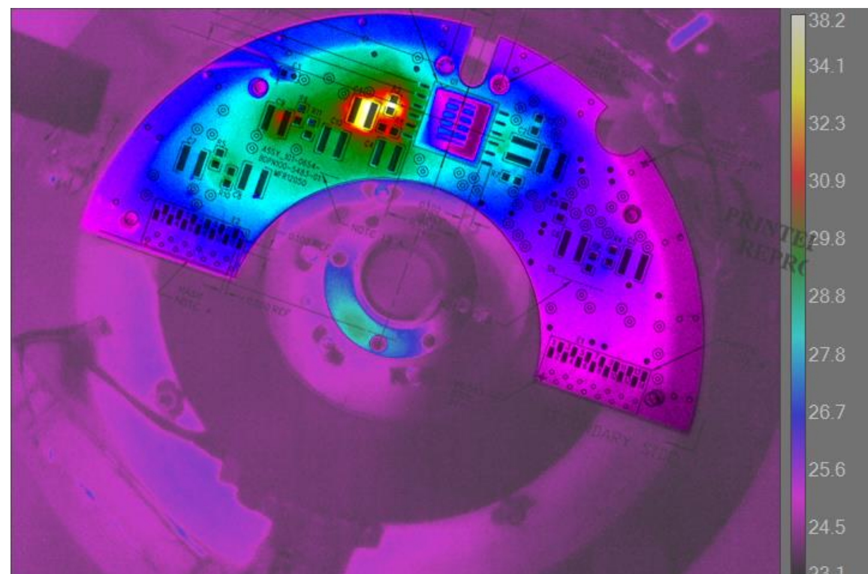
TIRS on-orbit anomaly cont'd

- 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



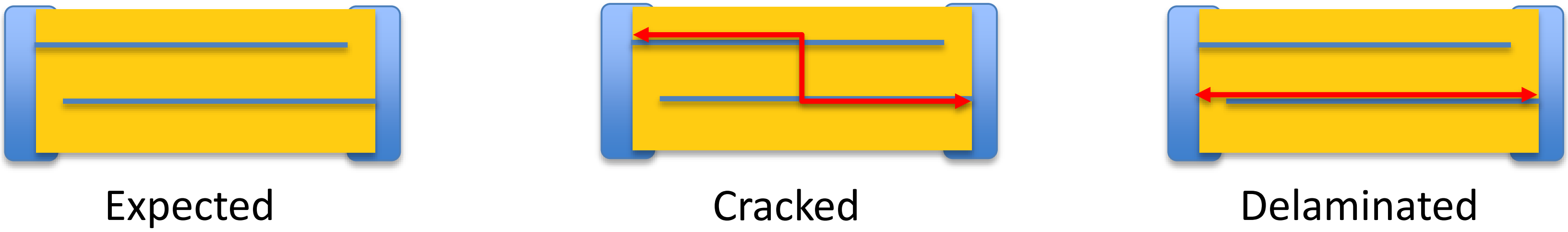
Differential Temperatures
from Front of PWA

Actual Temperatures
Once the PWA was Inverted



TIRS on-orbit anomaly cont'd

- Localized heating gave a strong indication that the caps were cracked.
- The manufactures do not recommend hand-soldering of ceramic capacitors, and the "failing parts" were hand soldered.
- This is the first instance we have seen of cracked capacitors making it through I&T undetected and becoming anomalous on-orbit.
- In all cases the cracks on TIRS did not propagate to the surface of the part.



TIRS on-orbit anomaly cont'd

- Once removed from the PWA C-mode Scanning Acoustic Microscopy (C-SAM) was performed on the anomalous parts, which subsequently showed delaminations that aligned with cracks internal to the parts that subsequently lined up with the hot spots on the parts.

- Fortunately, we had hundreds of spares from the LDC (1011-BY) that enabled some lot-based views.

- A large-scale effort to perform C-SAM was undertaken, resulting in discovery that about 50% of the LDC 1011-BY parts had delaminations internal to the pristine parts, in many cases similar to that present in the anomalous parts.

- While the hot spots line up with the delamination features, we have not fully established the delamination features as failure or degradation mechanisms

Outside Investigation

- Investigation revealed that this specific problem was discovered in at least one classified mission years ago, but proper warnings did not make their way into the NASA community.
  - Through significant dialog with others affected by this problem, we were able to gather an abundance of information to help bound the problem and define paths forward.
  - Events occurred on at least one classified system, but the failure and resolution details are unclassified.

Internal Testing Prompted by Outside Investigation

- Due to the “Outside” information we began performing C-SAMs on other spare parts that we had on hand, first to determine whether there was lot dependence, and next to start exonerating applications on GSFC projects
  - Lot dependence was established
  - Many more lots are clear of the problem than those that exhibit the problem
  - Some lots, however, do exhibit the problem, but none to the extent of 1011BY.

SDO capacitor failures

- While talking to some of our Parts Engineers it was found that SDO had had a problem that could be attributed to the present problem
  - In 2007, LASP and MIT engineers found a leaky capacitor on the EVE instrument's MEGS-A board.
  - While on the board, the part was inspected and photo-documented, no visible anomalies were noted.
  - In preparing for sectioning, the part was removed from the board and leads were attached using a soldering iron. The capacitor was potted for cross sectioning. Then during a standard check test it was found that the capacitor was no longer shorted, and the short had been lost.

SDO capacitor failures

- Sectioning at the 5-percent cross section level found a delamination spanning between capacitor terminations.
- Cross sectioning continued to approximately the 10-percent level, at which the delamination was fully revealed and seen to extend from termination to termination of the capacitor.

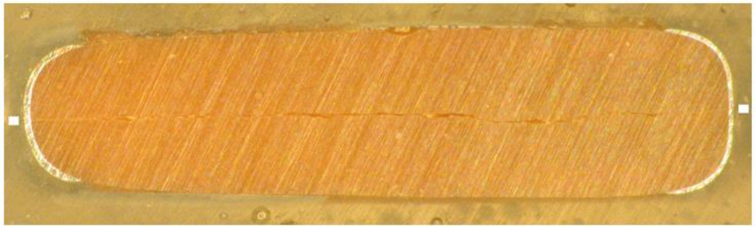


Figure 1. A delamination spanning between terminations was found at the 10-percent level. Square dots in the image above mark the ends of the crack. Note that the cross section plane is near the end of the part and does not reveal the electrodes.

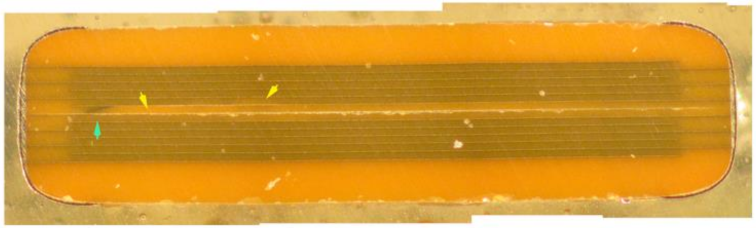


Figure 2. The 21-percent level with polish first reveals the electrode structure and simultaneously revealed a diagonal crack, marked by a green arrow, bridging between the center, and an adjacent electrode. This location is considered a likely candidate for the failure site. Yellow arrows mark a difference in layer color later shown to be caused by internal light reflection from a discontinuity in the dielectric. EDS found no material difference between the layers.

- Ultimately, the part was replaced and the rest of the lot remained in place

SDO capacitor failures (cont'd)

- In May of 2014, the MEGS-A board in the EVE instrument experienced a voltage drop, prompting ops to move it into safe mode
- Problem was ultimately traced to a capacitor from the same LDC (0509) as the part mentioned above.
- Many attempts were made to clear the short, as had been done for other capacitor-related shorts
- Ultimately, MEGS-A was shut down after several unsuccessful attempts
- Recently a parts engineer recalled a discussion with one of the LASP engineers concerning a capacitor failure, which prompted us to open some records associated with SDO/EVE.
- Review of the original FA from 2007 and the details of recovery efforts for EVE, indicated that the problem appears to be related to our current ceramic capacitor problem
- The part number and lot date code were then found in one of the recent C-SAM batches we had tested and declared to be an implicated lot.
- The parts in the MEGS instrument were all handsoldered
  - MEGS-B had parts from the same LDC, but they were handsoldered by a different organization
  - MEGS-B exhibited no anomalies or failures

Recent testing completed

- The process to C-SAM parts that are spares from lots that are installed on spacecraft and instruments has been completed to the extent that spares exist on all projects except for one.
- The manufacturer has performed 85% RH/85 deg C accelerated life testing on 25 parts from the 1011-BY lot installed using their preferred method of reflow soldering, then 50 parts on two boards handsoldered by GSFC contractors. A very high percentage of the handsoldered parts visibly cracked. For the manufacturer-installed parts, three parts severely degraded in IR (< 50 kohms), and the others degraded by 2-4 orders of magnitude. Therefore, at least with a “bad” lot, handsoldering is not necessary to degrade the parts.
- In some cases, very few parts were available, so we performed combinations of 85/85 testing, solder dip tests, and other thermal stress tests to try to exonerate them or establish them as very low risk.

We think we know

- Most, if not all, parts in a “bad” lot are likely to have the same defect, and probably the same potential for anomalous behavior, subject to the thermal stresses they encounter (even if they have no delaminations)
- If we perform “blind” statistical assessments, they should be based on likelihood of encountering a bad lot, rather than overall percentage of delamination defects
- Bad lots may be more prone to external cracking (based on 1011BY LDC assessment)
  - Could be a sign of weak integrity of the ceramic
- Parts affected by this problem are generally in-specification but none of the specifications at the time were sufficient to address the degradation of the part that occurs in the installation process

We definitely know

- Even bad parts from bad lots may be just fine over a long period of time
- Handsoldering and manual touchups are a very important risk factor
- There are cases where handsoldering processes are well controlled such that bad lots are used successfully
- In the DoD program, there were four bad lots over multiple subsystems and the only parts replaced were those that had had manual touchups, and no related anomalies have been reported

Advisory status

- NASA advisory has been released: NA-GSFC-2017-002

Summary

- A part issue has been identified that is intrinsic to a number of pre-2011 ceramic capacitors
- Over a dozen failures were encountered on one DoD program in I&T
- Multiple major on-orbit anomalies occurred on LandSat-8/TIRS due to capacitor degradation
  - Repeated on the ground using spare hardware
- The EVE MEGS-A instrument failed due to a capacitor short, with a second one emerging with a similar problem
- All incidents involved intrinsically flawed, but in-specification, ceramic capacitors (leadless), and had either manual soldering installation or hand touchups
- Intrinsic flaws are LDC-dependent, but more LDCs are free from the problem than those that have the problem
- Testing has indicated that with the worst lot, problem may exist in parts that are reflow soldered, but also that even parts from the worst lot may be installed manually in a very benign way, and may not exhibit problems
  - First indications are that they elevate risk significantly, but are not necessary