OMB Control # 3265-0024.
Expires: 9/30/2025

Voting System Anomaly Root Cause Analysis Template v2.0

Root Cause Analysis for:

VV40ECT-76: VxMarkScan ESD failure at PAT & ATI and Card Reader - Rev. 2
VxSuite, Version 4.0 and EAC Certification #VXS4

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Contents

Introduction

The purpose of this RCA document is to describe the failure of specific features of VxMarkScan (formerly “VxMark” before September 2025) during standard electrostatic discharge (ESD) testing according to IEC 61000-4-2 (2008) Ed.2.0, in the hardware certification process at SLI Compliance in March and July 2025. The failures were:

- Temporary loss of normal function of the personal assistive technology (PAT) port and accessible tactile interface (ATI) controller following ESD on a plugged-in PAT accessory, until the VxMarkScan unit was power cycled.
- Persistent loss of normal function of the card reader following ESD on the top of the card reader external housing.
- Persistent loss of normal function of the PAT and ATI following ESD on the lower left side seam of the touchscreen display housing.

Efforts to reproduce the failures and isolate the causes are described, as well as mitigations in software and hardware. The findings and mitigations are important for having confidence in the resilience of VxMarkScan to static shocks.

Anomaly Description

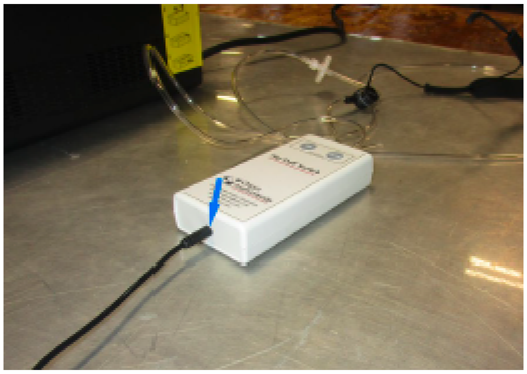
Complete all sections. Descriptions must be as detailed as possible, while being clear and concise since the anomaly is the source of the entire RCA. This detail should include a complete list and/or description of the “symptoms” of the anomaly and the conditions present which the symptoms occurred.

<table>
<tr><td>Date of Anomaly:
March 13, 2025</td><td>Time of Anomaly:
8:09 AM (Mountain Time)</td></tr>
<tr><td>Place of Anomaly:
Element, Longmont, CO</td><td>Person identifying Anomaly:
Jessica Myers, VotingWorks</td></tr>
<tr><td colspan="2">Expected Results of actions leading up to anomaly:
VxMarkScan should continue functioning normally when ESD is applied to any user-facing part, with the installed Hardware Test Utility software continuing to communicate regularly with the scanner, printer, touchscreen, audio output port, card reader, USB reader, ATI, and PAT port, unless VxMarkScan is intentionally shut down or components are intentionally removed. This includes the Hardware Test Utility showing continued responses from the ATI, PAT device, and card reader.</td></tr>
</table>

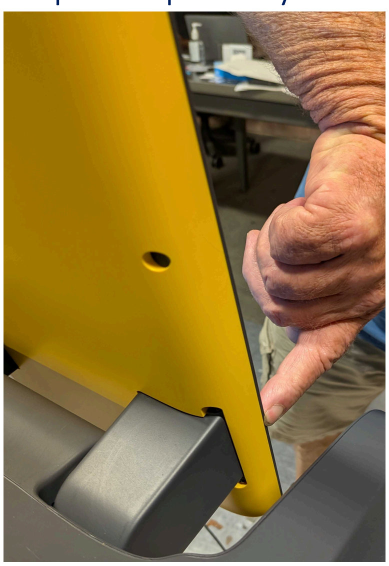
<u>Detailed description of the event / anomaly:</u>
The original anomaly related to temporary sip/puff malfunction of the PAT and ATI. After discharging ESD onto the sip/puff PAT device connected to the PAT port, the sip/puff device and accessible tactile interface (ATI) stopped responding. All other functions were normal. The scanner would run in a regularly scanning “shoeshine” mode, the printer would regularly print lines, the touchscreen would remain responsive and show updated logs.

After addressing this first ESD issue and continuing standard ESD testing in July 2025, two other issues arose. First, discharging ESD on the card reader led to malfunction of the card reader in two VxMarkScanScan units, which was persistent after reboot in one of the units and temporary in another. Second, discharging ESD on the lower left part of the touchscreen display housing led to persistent malfunction of the PAT and ATI even after reboot.

If the anomaly is repeatable, provide step by step instructions to recreate it:

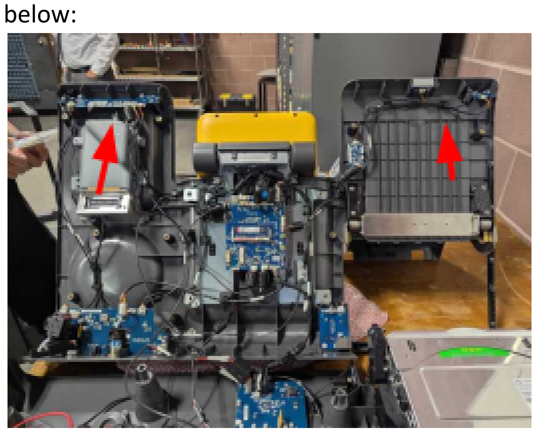
1. Prepare the system. Image VxMarkScan with a hardware test utility software that continuously runs its major components. Connect all VxMarkScan components, including the UPS into mains, the VxMarkScan unit into the UPS, and the non-VotingWorks PAT accessory to be tested: a sip/puff device (AirVoter). Power on VxMarkScan and run the test software utility. Insert a sheet of paper into the scanner to implement shoeshine mode.
2. To reproduce the temporary PAT and ATI issue: Apply ESD (15kV air discharge, 10 pulses, 1 per 2 sec) according to IEC 61000-4-2 to the PAT accessory where it starts to connect to its phone jack cable, which in turn is plugged into the PAT port on VxMarkScan. This location is indicated by the blue arrow in the photo below, as reported by SLI Compliance:

3. To reproduce the persistent card reader issue: Apply ESD to the card reader plastic housing, especially around the seam between the card reader housing and the surrounding plastic, shown in this photo:

4. To reproduce the persistent display ESD issue affecting the PAT and ATI: Apply ESD to the lower left part of the touchscreen display, at the seam in the plastic housing, shown in this photo reported by SLI:



Chronology of Events / Timeline

Provide a detailed chronology of the events leading up to, and following, the anomaly. Add additional events if necessary.

ID	Date/Time	Description	Entity Org/person	Result / Notes
1	3/12/25, 1pm MT	ESD testing begins with SLI Compliance at Element in Longmont, CO.	Jessica Myers, VotingWorks, with SLI	Testing proceeds as expected on VxMarkScan unit MK-11-004. No failures detected in response to ESD at multiple locations, including unit legs, touchscreen, PAT port, power input port, power button, and headphones input port.
2	3/12/25, 3:21pm	Reported that the ATI and sip/puff device stopped responding following 8kV contact ESD applied to the right rear leg. Touchscreen, shoeshine, and sound are still functional.	Jessica Myers, Don Chu, VotingWorks	Lab time ran out to investigate, so plans were made to confirm function next morning and plan mitigations or swapping units according to findings.
3	3/13/25, 7:35am	VxMarkScan was powered up again and completely operational. ESD testing was continued.	Jessica Myers, VotingWorks	No issues found with ATI or PAT and sip/puff, so testing resumed as normal.
4	3/13/25, 8:09am	Reported that ESD testing was proceeding without issues, then failed when applying 8kV ESD to the sip/puff device itself.	Jessica Myers, Don Chu, VotingWorks	Don Chu opened up the alternate VxMarkScan unit MK-11-005 to plan mitigations. Mitigations were applied to VxMarkScan unit MK-11-005 involving an internal cable running between the PAT and the ATI along the front edge of the system. Ferrites were added on either side of the cable, denoted with arrows in the photo below:  The original unit MK-11-004 was planned to be used for power dip testing.

5	3/13/25, 8:58am	The modified VxMarkScan unit MK-11-005 was put into ESD testing. ESD on the sip/puff device was tested again, leading to the same behavior as before with a nonresponsive ATI and sip/puff device. The components were functional after reboot.	Jessica Myers, Don Chu, Jesse DeWald, VotingWorks	Ground continuity was measured and confirmed to be good (<0.1 ohms) from the grounding strap on both sip/puff PCB and ATI PCB. A ground strap was added on the other side of the ATI PCB to offer a more direct path to discharge. Additional research was done on potential causes. It was noted that one pulse could cause the observed failures, so no plans were made to alter the pulse signal. The public test documents on VSAP hardware were also searched for more information on ESD behavior; VSAP is the hardware that VxMarkScan is based on.
6	3/13/25, 9:20am	The modified VxMarkScan unit was tested again with the same ESD that caused issues previously. The unit failed in the same way at the ATI and PAT or sip/puff device. The components were functional after reboot.	Jessica Myers, Don Chu, VotingWorks	Logs were collected from the VxMarkScan unit. The data suggested that if more hardware changes were to be applied for mitigations, it would be needed at the PCB electronics level, which would not be feasible during the test. Plans were made to investigate mitigation options more deeply and retest with SLI in June 2025.
7	3/17/25, 10am	VotingWorks planned more internal ESD testing to reproduce and investigate the issue. Equipment and settings were set up to match failing conditions as closely as possible.	Jesse DeWald, Chris Pedersen, Don Chu, VotingWorks	Plans centered on investigating two general mitigation hypotheses: 1. The PCB that the PAT device connects to needs to be redesigned. 2. It's possible for software to identify that the device stops and simply restart the daemon in the Hardware Test Utility as needed. These plans were based on hardware and software root causes of the observed failures. A software approach was reasonable, noting that there was no actual damage to hardware following ESD. VotingWorks staff in Bellingham, WA, set up two VxMarkScan units for testing and associated sip/puff devices, separate from the original test units with SLI. The software approach would be tested first, and if that failed the hardware approach would follow.
8	3/24/25, 11pm PT	Testing reproduced the ESD failure seen at SLI, and it confirmed that restarting the Hardware Test Utility daemon was all that was needed to continue normal function.	Jesse DeWald, Kevin Shen, VotingWorks	The commands needed to restart the daemon were logged in the open-source software here: https://github.com/votingworks/vxsuite-complete-system/blob/main/run.sh#L71

				Plans were made to patch the software to increase its robustness to momentary hardware disconnections. Logic was put in place to restart the daemon when the daemon exited upon an ESD.
9	4/2/25, 7:30am PT	A new software image of the Hardware Test Utility was created that could restart the daemon in response to errors in device reading.	Arsalan Sufi, Kevin Shen, Jesse DeWald, VotingWorks	Plans were made to test this software solution on the test units in Bellingham.
10	4/2/25, 12:35pm PT	The updated Hardware Test Utility did not successfully recover the ATI or sip/puff from ESD.	Jesse DeWald, Kevin Shen, Arsalan Sufi, VotingWorks	After monitoring logs and investigating the code, a software bug was identified in the patch related to outputting the wrong error code when the daemon exits. This was fixed, recorded in the open source pull request here: https://github.com/votingworks/vxsuite/pull/6213 A new image was prepared for further testing.
11	4/4/25, 12:20pm PT	The test VxMarkScan units were updated again with new software. The updated Hardware Test Utility successfully recovered from the previously failing ESD.	Jesse DeWald, VotingWorks	The software-only fix confirmed the hypothesis of a software root cause in the original Hardware Test Utility. Plans were made to review the code in the customer-facing production software, to ensure similar measures are taken to restart processes if ever they are stopped due to minor hardware disconnections, including from ESD applied to a sip/puff device.
12	7/22/25, 11:00am MT	Continued ESD testing of MK-11-005 at Element in Longmont, CO, reveals a passing test of ESD applied on the PAT device.	Jessica Myers, Jesse DeWald, VotingWorks	The first ESD issue from March was addressed with the software update described above. Also the ESD interval was adjusted to 30 seconds apart.
13	7/22/25, 1:58pm	VxMarkScan card reader fails on ESD applied to card reader housing.	Jessica Myers, Jesse DeWald, VotingWorks	Failure occurred at 15keV. The card reader did not function properly after restart. Logs were collected for analysis, and plans were made to retest on a second backup unit the next day.
14	7/23/25, 7:06am	In another VxMarkScan unit MK-11-003, the card reader fails on ESD applied to card reader housing.	Jessica Myers, Jesse DeWald, VotingWorks	Failure occurred at 8keV. The card reader did not function properly after restart. It was noted that ESD appeared to spark through the seam between the card reader plastic housing and the main unit plastic housing.

15	7/23/25, 7:06am	ESD applied on the lower left side of the VxMarkScan touchscreen display at the seam in the plastic housing cause the PAT and ATI to stop functioning.	Jessica Myers, VotingWorks	Did not recover upon reboot. The screen appeared to be unaffected and was still responding to touch. Log files were saved for analysis. Plans were made to partner with an EMC engineering firm to analyze the new ESD issues seen with VxMarkScan in July testing.
16	9/30/25, 2pm	EMI Test Lab in Longmont, CO, begins ESD investigations of VxMarkScan, on a unit different from the one that underwent ESD testing at Element. EMI Test Lab reports initial findings.	Dennis King, Uriah Higgins, EMI Test Lab; Pius Wong, VotingWorks	Some potential mitigations were found to help but not completely resolve the issue, including applying additional grounding between the card reader support bracket and the main chassis, and applying more electrical insulation around the card reader itself.
17	9/8/25, 2pm	EMI Test Lab confirms moving the card reader further back resolves ESD issues in lab testing.	Dennis King, Uriah Higgins, EMI Test Lab	The root cause for ESD vulnerability in the card reader was too close a distance between the card reader board and the outer plastic shell seam. At higher level of ESD sparks jumped to the board electronics.
	9/15/25, 2pm	EMI Test Lab reports reproduction and mitigation of a similar display failure when ESD is applied near the edge of the display.	Dennis King, Uriah Higgins, EMI Test Lab	The display of the VxMarkScan unit at EMI Test Lab was opened up and confirmed to have thin or compromised gasket material between the glass display and its plastic bezel, where ESD would cause a failure in the system. When an insulative silicone was applied around the bezel to reseal all gaps around the display, ESD no longer was triggered around the display seam, even at 15keV. Analysis of the internal grounding of the display components was evaluated to be good and not needing changes.

Investigative Team and Method

This section shall describe how the investigative team is assembled by the voting system manufacturer, who it consists of, and how it gathers the data to be used in the analysis. Include the RCA method employed by the manufacturer in conducting the analysis and why this method was used.

Names and Positions of members of the investigation team:
Jessica Myers - Head of Compliance
Don Chu - Lead Design Engineer
Jesse DeWald - Head of Hardware
Chris Pedersen - Operations and Prototyping Support Technician
Kevin Shen - Software Engineer
Arsalan Sufi - Head of Software
Pius Wong - Quality Assurance Lead
Dennis King, Uriah Higgins - Engineers at EMI Test Lab

Describe the data gathering process:

Jessica Myers and Don Chu started the investigation, being in-person at Element with SLI Compliance during the original ESD tests in March. They directly received the data from SLI, handled the devices under test when needed, and coordinated the response with other VotingWorks staff. Don made the initial observations and electrical measurements of the internals of the tested units, looking for potential hardware defects that would lead to the combined failures of the ATI and PAT input. He tested possibilities that ESD-induced emissions and insufficient grounding caused the errors when applying ferrites and additional grounding connections to the unit, and eliminated them as causes. Don and Jessica also obtained software logs to share with the wider VotingWorks team to analyze. After initial hardware mitigations proved unsuccessful, the investigation was handed off to more VotingWorks staff.

Jesse Dewald joined the investigation to reproduce the errors seen at Element/SLI separately in VotingWorks labs in Bellingham, Washington. He worked with Chris Pedersen to prepare systems for ESD testing close to conditions at Element. Both hardware and software root causes were discussed. After reproducing the failures, plans were made to investigate the software solution first, noting that the failed components would always prove to be functional after power cycling.

Kevin Shen and Arsalan Sufi joined the investigation to analyze logs, investigate existing code, and develop potential software patches to the Hardware Test Utility. They prepared a new version of the utility that attempts to restart the connections to any components that are disconnected, rather than not attempting it at all as in the original utility. Working with Jesse, VotingWorks then repeated ESD tests with the new software, confirming the software upgrade would mitigate the previous failures. They further supported testing when it continued at Element in July 2025, advising on the proper ESD intervals needed for testing.

Pius Wong coordinated working with outside engineers from EMI Test Lab in Longmont, CO, to analyze ESD in VxMarkScan in August-September 2025. Dennis King and Uriah Higgins analyzed an extra VxMarkScan provided by SLI, reproducing ESD issues with the card reader and the display and determining root causes in hardware.

Describe which methodology(s) is used to conduct the root cause analysis:

The investigative team adopted **a two-step analytical framework**:

1. **Fault-Tree Analysis (FTA)** – a top-down diagrammatic breakdown of every plausible fault path beginning with the first part of the anomaly: *"ATI & PAT stop responding after ESD on the sip/puff device."* This then branched into the second and third parts of the anomaly relating to the card reader and display.
2. **"5 Whys" iterative questioning** within each branch to push the analysis to first-principle causes rather than symptoms.

This hybrid approach was chosen because it:

- Provides a visual map that the entire multidisciplinary team can interrogate in real time (mirroring the workflow proven effective in other incidents) .
- Works equally well for **software-centric** and **hardware-centric** hypotheses, both of which needed to be assessed for each component failure.

For example, key steps in the investigation of the failure when applying ESD to the PAT device are listed here:

Step	Action	Outcome/Decision Gate
1	Construct high-level **FTA** with two primary limbs - hardware-induced fault vs. software-induced fault.	Enabled parallel workstreams
2	Collect empirical **evidence** (lab ESD re-tests, continuity checks, ferrite/grounding trials, detailed daemon logs).	Hardware branch progressively disproved: no permanent damage, cable ferrites + added grounds did not avert failure
3	Drill down the software branch with	Pinpointed that the ATI and Sip/Puff

	the **5 Why's**:
	● Why are button presses not recognized?
	    ○ daemon is unresponsive
	● Why is daemon unresponsive?
	    ○ Thinks the controller is disconnected but is not listening for a reconnect
	● Why is it not listening?
	    ○ needs to be restarted by systemd
	● Why was it not restarted by systemd?
	    ○ daemon did not exit with an error code
		devices drop connection momentarily; daemon records error but does not exit, so systemd never restarts it

4	**Implement** and test counter-factuals (patched daemon exit-on-error, auto-restart)	Patched units survived identical ±15 kV ESD with no loss of functionality, closing the software branch root-cause loop

Similar steps were taken to analyze the card reader and display ESD issues. Those investigations led to more hardware-centric investigations, because the persistent nature of the failures indicated more hardware-related causes. Within those branches of the FTA, common potential root causes were systematically investigated, including the need for additional grounding, insulation, and separation of components.

Findings and Root Cause

The root causes of the ESD anomaly described here is threefold, associated with the PAT/ATI, card reader, and display:

1. Software not attempting to reconnect or restart the PAT and ATI connections after ESD. The PAT/ATI subsystem lost normal function because the Hardware Test Utility's daemon was not configured to exit (and thus would not auto-restart) when the PAT or ATI devices momentarily disconnected after an ESD event. The absence of an automatic restart left the ATI and PAT accessory in an unrecoverable state until the entire VxMarkScan unit was power-cycled.
2. Too close a path between the card reader electronics and the external ESD source at the surface. At higher keV ESD levels, the generated air discharge spark could travel through openings around the plastic card reader holder to the card reader board. This could directly damage electronics.
3. Compromised insulative material at the bezel around the display. Similarly to the point above, at higher keV ESD levels, the spark could travel through gaps at the seams around the touchscreen display plastic housing, and through thin or broken parts of the insulation around the screen. The ESD could transfer to other parts of the system from there, depending on the location of the discharge. At Element, the previously observed failure was likely through ESD conducting through the lower display support brackets to the PAT and ATI.

More details about the root causes are given below.

Key Findings:

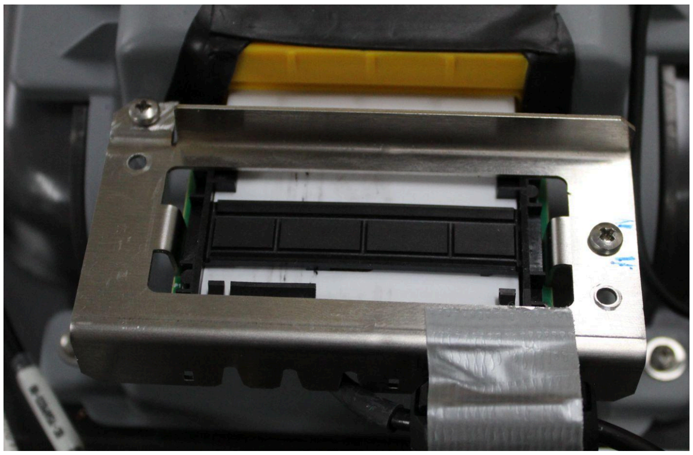
For the PAT & ATI temporary failures:

- **Transient disconnect only** – ESD to the connected sip/puff accessory causes the PAT and ATI interfaces to disconnect from the daemon for <1 s; no permanent hardware effect was ever observed.
- **Hardware path eliminated** – Additional ferrites, alternative ground paths and PCB inspection produced **no change**; therefore shielding/grounding inadequacy is *not* the triggering mechanism.
- **Software recovery gap** – The Hardware Test Utility's daemon logs the read-error but **continues running**, preventing systemd from triggering its built-in restart policy.
- **Reproducibility & fix verification** – In-house re-tests faithfully reproduced Element/SLI failures and subsequently demonstrated full immunity after the daemon-restart patch. The root cause in software fully explains why **all** failures cleared after a reboot (fresh daemon instantiation), why **no** physical component damage was detected, and why

ferrite or grounding experiments alone gave no benefit. The updated daemon (exit-on-error → systemd restart) restores functionality within 10 s after each discharge and has now passed ESD campaigns during internal testing.

For the card reader failures:

- **ESD conducted to the card reader board** – This led to damage to the card reader leading to persistent errors. This stemmed from too short a distance that an ESD arc had to travel between the card reader housing and the card reader board electronics.
- **Optimal mitigation by only moving card reader** – Altering the card reader position by moving it further back into the system by 0.5-0.75” led to no ESD sparks, even at 15keV air discharge. This resolved card reader ESD issues in lab testing. See photo below of prototype positioning tested, where the bracket fastener holes were adjusted to shift the card reader deeper into the main module.



- **Partial benefits from other optional mitigations** – Other hardware changes helped increase resistance to ESD without moving the card reader, but they did not eliminate damage from ESD up to 15keV. These include better grounding between the card reader bracket and the main chassis near the motherboard, applying insulative tape around the card reader bezel, and grounding the card reader board. However, none of these actions could fully mitigate ESD even when combined together, if the card reader was not also moved deeper into the system.

For the display-related PAT & ATI failure:

- **Existing gasket material around display compromised –** The tested unit at EMI Test Lab showed ESD sparking around the display edge in the upper left corner, and upon opening and analyzing the internals, the gasket material between the display glass and its bezel in this area was found to be thinned. This allowed ESD to penetrate into the display at this area and not in other areas around the display.
- **Reapplying electrical insulation around the screen prevented ESD sparking** – High-voltage RTV silicone with 30keV breakdown dielectric strength applied to the

outer touchscreen bezel to seal the seams prevented ESD sparking and associated damage.

Corrective Action(s)

1. Software Update

The Hardware Test Utility software that previously failed ESD tests with Element/SLI was patched to be more robust to momentary disconnection of components.

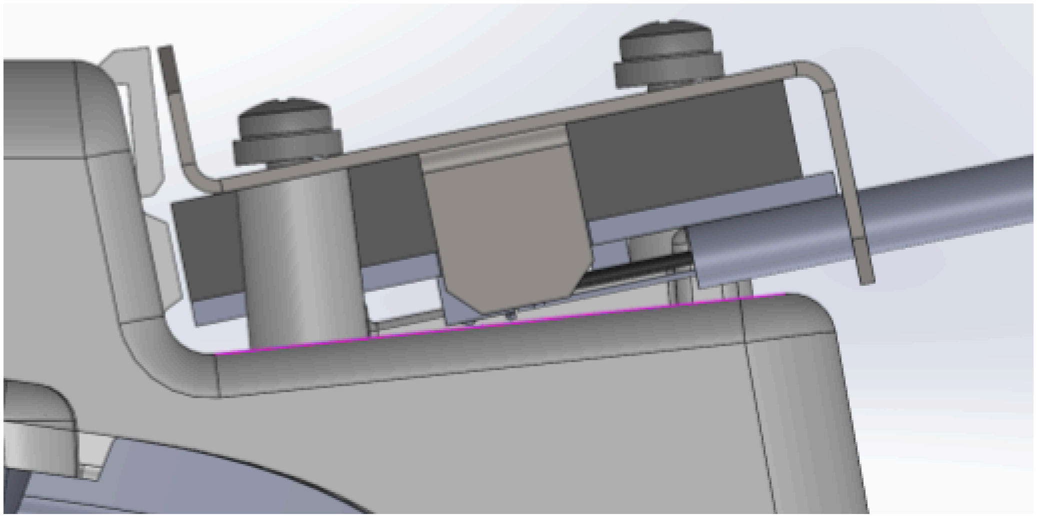
Both ATI controller status and PAT input status are addressable by software through a single serial USB device, the FAI-100, which physically sits near the PAT input. Previously, the FAI-100 could become momentarily unavailable after ESD through the sip/puff device connected to the PAT. This breaks existing connections to the device. In this state, attempts to read status from the FAI-100 device report an error.

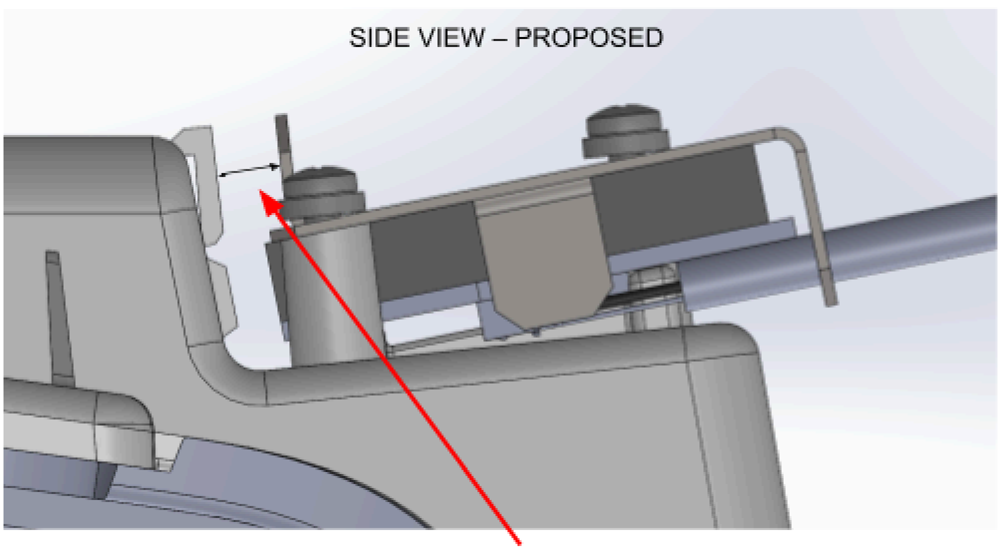
The software daemon responsible for continuously reading the FAI-100 USB device status was previously configured to log the error and continue running. The software was updated to exit with code 1 when a read error, including error due to disconnection, is encountered. This triggers the existing systemd service configuration for the daemon to restart on exit code 1. Daemon restart forces reconnection to the FAI-100 USB device and subsequently allows successful querying of device status. These code changes are visible in the open source pull request here: https://github.com/votingworks/vxsuite/pull/6213

2. Reposition and Insulate Card Reader

The bracket holding the card reader was modified to move the card reader deeper into VxMarkScan by approximately a half inch, determined by testing to be sufficient for ESD resistance. See the diagram below for a comparison of the original card reader bracket positioning versus the new positioning, that allows a greater offset between the card reader and the plastic housing:

SIDE VIEW – CURRENT





Increased offset

This modification did not change any mating surfaces or electrical connections. It would not detract from election worker's user experience, only making the depth of the card reader more closely match up with that of the VxScan precinct scanner.

As an extra precaution, insulating polyimide tape (3M 1205) will also be applied around the card reader housing internally to help prevent ESD travel into the system at its seam, even though this was not found to be necessary in testing. The tape would not harm any normal function and could only help in more extreme ESD scenarios.

3. Reapply Insulation Material Around Display

The original compromised gasket material that lies between the display glass and the plastic display bezel would be inspected and replaced with insulative RTV silicone with 30keV dielectric breakdown strength. The silicone would also seal the gap between the two halves of the plastic housing for the display.

Solution Management

The purpose of this section is to manage the corrective action(s) moving forward. This should detail all process changes to manage those corrective actions, and steps taken to ensure the actions eliminate the anomaly over time.

Plans to manage the solution following this RCA are as follows:

Testing and Verification:

- Continue electrical certification testing with SLI Compliance with these mitigations in place to verify continued expected functionality.

Software:

- The Hardware Test Utility used for certification testing was upgraded for electrical tests for certification with SLI Compliance and Element in July 2025.
- The same update is applied to the production software, so that it will also be able to auto-recover the PAT and ATI without user intervention.

Hardware & Production:

- Assembly and quality control processes will be updated to include the updated bracket and display insulation steps.