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Voting System Anomaly Root Cause Analysis Template v2.0

Root Cause Analysis for:

VV40ECT-76: VxMark ESD failure at PAT & ATI
VxSuite, Version 4.0 and EAC Certification #VXS4

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Introduction

The purpose of this RCA document is to describe the failure of specific features of VxMark 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 2025. The failures were the 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 VxMark unit was power cycled. Efforts to reproduce the failures and isolate the cause are described, as well as mitigations in software. The findings and mitigations are important for having confidence in the resilience of VxMark 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.

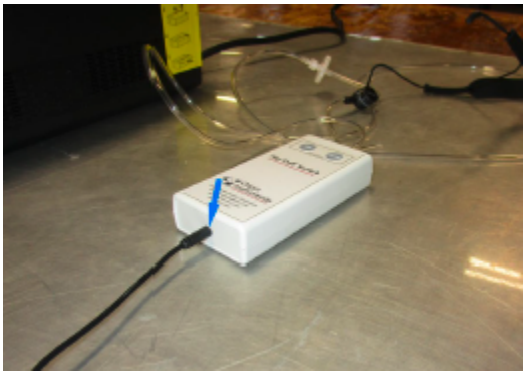
Date of Anomaly: March 13, 2025	Time of Anomaly: 8:09 AM (Mountain Time)
Place of Anomaly: Element, Longmont, CO	Person identifying Anomaly: Jessica Myers, VotingWorks
Expected Results of actions leading up to anomaly: VxMark should continue functioning normally when ESD is applied to any user-facing 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 VxMark is intentionally shut down or components are intentionally removed. This includes the Hardware Test Utility showing continued responses from the ATI and PAT device.	

Detailed description of the event / anomaly:

- After discharging ESD onto the sip/puff PAT device connected to the PAT port, the sip/puff device and accessible controller 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.

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

- Image VxMark with a hardware test utility software that continuously runs its major components. Connect all VxMark components, including the UPS into mains, the VxMark unit into the UPS, and the non-VotingWorks PAT accessory to be tested: a sip/puff device (AirVoter). Power on VxMark and run the test software utility. Insert a sheet of paper into the scanner to implement shoeshine mode.
- 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 VxMark. This location is indicated by the blue arrow in the photo below, as reported by SLI Compliance:

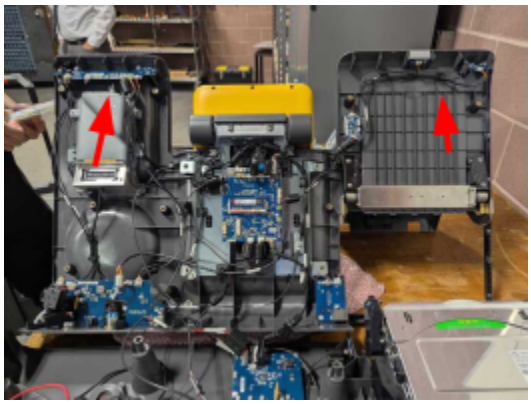


Chronology of Events / Timeline

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

EAC (Election Assistance Commission) Root Cause Analysis

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 VxMark 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	VxMark 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 VxMark unit MK-11-005 to plan mitigations. Mitigations were applied to VxMark 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 VxMark 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 VxMark is based on.
6	3/13/25, 9:20am	The modified VxMark 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 VxMark 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 VxMark 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 VxMark 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.

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

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. 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 test 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 mitigated the previous failures.

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 observable anomaly *"ATI & PAT stop responding after ESD on the sip/puff device."*
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 the PAT/ATI failure .

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 5 Whys ● 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	Pinpointed that the ATI and Sip/Puff 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

Findings and Root Cause

Key findings

- **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 of the anomaly described here is:

Root cause (single-point)

> *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 VxMark unit was power-cycled.*

This root cause fully explains:

- Why **all** failures cleared after a reboot (fresh daemon instantiation).
- Why **no** physical component damage was detected.
- 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.

Corrective Action(s)

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

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 this mitigation in place to verify continued expected functionality.

Software:

- The Hardware Test Utility used for certification testing should be upgraded in the next round of electrical tests for certification with SLI Compliance and Element.
- The same update will be applied to our customer-facing production software in our next release during the cert campaign (v4.0.2), so the production software, too, will be able to auto-recover without user intervention.