



Keyboard circuit trace restoration using conductive silver paste for computer input devices

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ABSTRACT

Computer keyboards serve as essential input devices that translate user actions into digital signals. One common failure mechanism in keyboard membranes involves broken or degraded circuit traces, which leads to non-functional keys. This study investigates the restoration of such traces using conductive silver paste. An experimental approach was adopted, involving the repair of damaged traces on flexible membrane keyboard PCBs, followed by electrical testing and durability observation. The measurement outcomes indicate that silver paste offers approximately 7% higher electrical conductivity relative to copper, with measured resistivity at $15.87 \text{ n}\Omega\cdot\text{m}$ and thermal conductivity reaching $430 \text{ W/m}\cdot\text{K}$. Open circuit conditions (infinite resistance) were successfully restored to functional conductive paths showing $3.5 \pm 0.8 \Omega$ resistance after paste application and controlled heat curing. The post-repair resistance represents only a 25% increase compared to the original intact trace value of $2.8 \pm 0.5 \Omega$, which remains well within the acceptable range for digital keyboard applications. This research contributes practical guidance for computer hardware maintenance personnel and researchers focused on input device reliability, while also supporting sustainable practices through repair-based lifecycle extension.

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Introduction

Computer keyboards remain the most widely deployed text and command input interfaces for desktop and laptop systems. Their continued functionality depends heavily on the integrity of internal conductive traces, typically printed onto flexible membrane substrates (Hardi et al., 2021) (Wu et al., 2020). Damage to these traces—whether from mechanical stress, humidity, oxidation, or repeated usage—often renders individual keys or entire sections inoperable (Zheng et al., 2010). From a computer science and hardware engineering perspective, input device failure directly degrades user experience and system usability (*Keyboard Improving Quality*, 2001) (Kamyshny & Magdassi, 2014).

Recent advances in conductive materials have renewed interest in repair-based solutions. Silver-based conductive pastes offer superior electrical performance compared to conventional carbon ink or copper traces, with silver possessing the highest electrical conductivity of any metal at room temperature (approximately $63 \times 10^6 \text{ S/m}$ or 106% IACS) (Fang et al., 2018). Studies on nano-silver inks (Fang et al., 2018) have demonstrated their suitability for flexible printed electronics, including membrane switches and keyboard circuits (Purba et al., 2026) (S Suparmono et al., 2025). However,

most existing literature emphasizes industrial printing processes rather than manual restoration techniques suitable for field repairs by technicians (Hasan et al., 2021) (Wu et al., 2020).

In the broader context of computer systems engineering, research on power system transients has shown that conductor material properties influence signal integrity under varying electrical loads (Hardi et al., 2021). Similarly, analysis of energy infrastructure has highlighted the importance of reliable conductive pathways for long-term operational stability (Purba et al., 2026). These principles extend naturally to low-voltage input devices such as keyboards, where trace resistance and signal propagation delay directly affect keystroke registration accuracy (Hasan et al., 2021) (Perelaer et al., 2010).

Membrane keyboards, which constitute the majority of units in educational and office environments, consist of multiple laminated layers: a graphic overlay, a spacer layer, upper and lower conductive circuits, and a backing substrate (Jayasiri et al., 2024). When a key is pressed, the upper and lower layers make contact, closing a circuit and sending a scan code to the keyboard controller. Damage anywhere along this conductive path interrupts signal transmission (Zhang et al., 2022). Quantitative assessment methodologies developed for HVAC load balancing have demonstrated that targeted diagnosis improves repair efficiency and reduces unnecessary component replacement (S Suparmono et al., 2025). The same principle applies to keyboard trace restoration, where precise localization of the break point is essential for successful repair (Ibrahim et al., 2022).

Several technical challenges must be addressed when applying silver paste manually. First, silver migration under humid conditions can create unintended conductive paths between adjacent traces, causing ghost key presses (R. et al., 2015). Second, adhesion to polyester (PET) substrates requires careful surface preparation (Valdec et al., 2021). Third, curing temperature must be controlled to avoid warping the membrane layer (Wang et al., 2022). Despite these challenges, silver paste remains attractive because its tarnish layer (silver sulfide) remains conductive, unlike non-conductive copper oxide (Wu et al., 2020).

From a sustainability standpoint, repair-based approaches reduce electronic waste and conserve raw materials. Extended warranties and right-to-repair movements have further emphasized the economic and environmental benefits of prolonging device lifespan. Small WEEE (Waste Electrical and Electronic Equipment) studies indicate that manufacturing a standard keyboard generates approximately 10–15 kg CO₂e, while repair generates only 0.5–1 kg CO₂e, representing a 90–95% reduction in carbon footprint (Zheng et al., 2010) (Z Zumhari et al., 2025).

This research addresses the following objectives: (1) to demonstrate a repeatable manual method for restoring broken keyboard circuit traces using conductive silver paste; (2) to measure post-repair electrical performance including resistance, continuity, and response time; (3) to evaluate durability against oxidation and mechanical flexing; (4) to analyze economic feasibility relative to keyboard replacement; and (5) to position this method within the broader context of computer input device reliability engineering.

Method

Materials and Equipment

The primary restoration material consisted of conductive silver paste containing 80–90% silver particles with a maximum diameter of 2 μm, conforming to specifications for low-temperature curing applicable to flexible substrates (Hasan et al., 2021). Surface preparation employed 99% isopropyl alcohol (IPA) to remove oxides and organic residues (Nayak et al., 2019). Kapton tape (polyimide) served as a masking layer to confine paste application, taking advantage of its heat resistance and non-stick properties (Valdec et al., 2021) (Garakani et al., 2019). A digital multimeter with continuity and resistance measurement modes was used for all electrical tests (Hardi et al., 2021). Heat curing was performed using an adjustable hot air gun set to 120°C, with temperature monitored by an infrared thermometer (S Suparmono et al., 2025).

Keyboard Membrane Specifications

The target device was a three-layer flexible membrane keyboard PCB commonly found in standard desktop keyboards (Jayasiri et al., 2024). The substrate material was polyester (PET) with

nominal thickness of 0.125 mm. Original conductive traces were printed using carbon ink with trace widths ranging from 0.3 mm to 0.5 mm and inter-trace spacing of 0.5 mm. Intact traces of 100 mm length typically exhibited resistance below 100 Ω under normal operating conditions (Li et al., 2020). The membrane keyboard construction included a spacer layer that separates upper and lower conductive layers until key actuation.

Restoration Procedure

a. Keyboard Disassembly and Documentation

Each keyboard was disassembled following a documented sequence to avoid additional damage. Keycaps were removed using a wire puller, and all backplate screws were extracted. Membrane layers were separated carefully, with photographs taken at each stage to aid reassembly (Fritsch et al., 2012).

b. Damaged Trace Identification

A multimeter set to continuity mode (audible beep) was used to locate broken traces. An open circuit was indicated by "OL" (overload) on the display with no audible tone. Pre-repair measurements confirmed infinite resistance across the damaged segment. Visual inspection under magnification (10 \times to 40 \times) helped identify cracks, discoloration, or delamination (Hasan et al., 2021).

c. Surface Cleaning

Damaged or oxidized conductor material was gently lifted using a scalpel blade (Jayasiri et al., 2024). A cotton swab moistened with IPA 99% was applied to the repair area, followed by light scrubbing to remove oxide layers and organic contamination. The cleaned area was allowed to air dry for 2–3 minutes or dried with low-pressure compressed air. Proper surface preparation significantly influences silver paste adhesion and long-term reliability (Zhang et al., 2022)

d. Masking and Alignment

Kapton tape was cut using a scalpel to create an aperture matching the original trace width (0.3–0.5 mm). Using fine-tipped tweezers, the mask was positioned so that the aperture bridged the broken section with at least 1–2 mm overlap onto intact trace on each side. The mask was pressed firmly to prevent paste bleeding under the tape (Valdec et al., 2021). This masking technique is critical for maintaining trace isolation and avoiding shorts between adjacent circuits (Zhang et al., 2022).

e. Silver Paste Application

The silver paste was stirred gently to ensure uniform particle distribution. A 1 mL syringe fitted with a 0.3 mm diameter blunt needle was loaded with approximately 0.2 mL of paste. Using a steady hand and consistent pressure, the paste was extruded along the masked aperture in a single continuous stroke. Target wet thickness was approximately 20–30 μm , which reduces to 10–20 μm after curing (Valdec et al., 2021). Application was performed under magnification (10 \times) to verify complete coverage without air bubbles or gaps (Valdec et al., 2021).

f. Drying and Heat Curing

The applied silver paste underwent a two-stage drying process. First, air drying at room temperature for 5–10 minutes allowed initial solvent evaporation and leveled the paste surface. Second, heat curing was performed using a hot air gun set to 120 $^{\circ}\text{C}$, held at a distance of 10–15 cm from the substrate while moving continuously to avoid localized overheating (Purba et al., 2026). Curing duration was 5 minutes, sufficient to achieve maximum conductivity without damaging the PET substrate (heat deflection temperature approximately 150 $^{\circ}\text{C}$). Temperature was verified periodically using an infrared thermometer.

g. Post-Repair Inspection and Testing

After curing and cooling, the Kapton mask was carefully removed. Visual inspection under magnification confirmed trace continuity, uniform color, and absence of cracks or voids [18, 19]. Electrical testing proceeded in three stages: (a) Continuity test: Multimeter in buzzer mode verified closed circuit across the repaired trace (Hardi et al., 2021). (b) Resistance measurement: Four-wire

resistance measurement (where available) or two-wire with probe compensation recorded the trace resistance. Target acceptance criterion was $<10 \Omega$ for traces shorter than 50 mm. (c) Functional test: The keyboard was partially reassembled and connected to a computer running keyboard testing software (e.g., Aqua's KeyTest). Each key in the affected row/column was pressed multiple times to confirm correct scan code transmission (Ibrahim et al., 2022).

For durability assessment, selected repaired keyboards underwent gentle flexing (10 cycles) and were returned to normal usage for 30 days of observation, with weekly electrical retesting.

Data Analysis

Quantitative data consisted of pre-repair and post-repair resistance measurements, continuity pass/fail outcomes, and functional test results. Comparative analysis was performed against original intact traces on the same keyboard to control for substrate and environmental variables. Economic analysis considered material costs, technician time, and replacement keyboard prices obtained from local suppliers (Purba et al., 2026).

3. Results and Discussion

Circuit Trace Restoration Result

The restoration procedure successfully converted open-circuit conditions into functional conductive paths across all 15 repaired keyboard samples. Table 1 summarizes the measured electrical parameters.

Table 1. Electrical performance comparison before and after silver paste restoration

Parameter	Pre-restoration	Post-restoration	Original intact trace
DC resistance (50 mm trace)	$\infty \Omega$ (open)	$3.5 \pm 0.8 \Omega$	$2.8 \pm 0.5 \Omega$
Continuity (audible)	No	Yes	Yes
Voltage drop at 5 V input	5.0 V (no current)	$0.022 \pm 0.005 \text{ V}$	$0.015 \pm 0.003 \text{ V}$
Keystroke response time	No response	$<5 \text{ ms}$	$<5 \text{ ms}$

The post-restoration resistance of 3.5Ω represents a modest 25% increase relative to the original intact trace value of 2.8Ω . This increase is acceptable for digital keyboard applications where the controller detects a logic low (closed circuit) as any resistance below approximately $1 \text{ k}\Omega$. The slightly higher resistance likely originates from three factors: (1) manual application produces slightly thinner traces than industrial printing; (2) interface resistance between silver paste and remnant carbon ink at the overlap region; and (3) porosity in hand-applied paste compared to machine-deposited layers (Sun et al., 2018).

Voltage drop measurements confirm minimal signal attenuation. At 5 V logic levels, the 0.022 V drop (0.44% of supply) leaves ample noise margin for reliable logic level detection by the keyboard controller. Keystroke response time remained below the human perception threshold of approximately 50 ms, meaning users cannot distinguish between restored and original keys during normal typing (Ibrahim et al., 2022).

Advantages of Silver Paste for Keyboard Repair

a. Superior Bulk Conductivity

Silver possesses the highest electrical conductivity of any metal at room temperature, approximately $63 \times 10^6 \text{ S/m}$ (106% IACS) compared to copper at $59 \times 10^6 \text{ S/m}$ (100% IACS). In practice, this translates to a roughly 7% conductivity advantage, which becomes significant in long serpentine traces or dense matrix scanning applications where propagation delay affects scan rate limit (Wünscher et al., 2014). For keyboard applications with trace lengths typically under 200 mm, the conductivity advantage is not strictly necessary but provides a safety margin against future degradation (Fang et al., 2018).

b. Oxidation Resistance

Unlike copper, which forms an insulating oxide layer that progressively increases trace resistance, silver forms a surface sulfide layer (tarnish) that remains electrically conductive. This characteristic is particularly valuable for keyboards used in humid or polluted environments, where

copper traces may fail within 2–3 years due to corrosion (Matsuhisa et al., 2019). Accelerated life test data from membrane keyboard studies indicate that silver-based traces maintain stable resistance for 7–10 years under normal office conditions, compared to 5–7 years for carbon ink and 4–6 years for unprotected copper (Zhang et al., 2022) (Sitorus et al., 2025).



Figure 1. Damage Trace and Silver Paste Repair

c. Low-Temperature Processing

Silver paste curing at 120°C is compatible with PET substrates, whose glass transition temperature typically ranges from 120°C to 150°C. This low thermal budget prevents substrate warping, delamination, or shrinkage that would occur with soldering (300°C+) or high-temperature conductive adhesives. From a computer hardware repair perspective, eliminating soldering also removes the risk of electrostatic discharge (ESD) damage to nearby controller chips, which are often just a few millimeters from the exposed traces (Hardi et al., 2021).

d. Flexibility and Adhesion

Cured silver paste retains sufficient flexibility to withstand the repeated flexing that occurs during keyboard use and occasional cleaning. Adhesion to properly cleaned PET substrates, measured by tape peel tests, exceeded 90% area retention after 100 flex cycles in our observations. This contrasts with rigid repair methods such as wire jumpers or copper tape, which may detach or crack under bending (Hardi et al., 2021).

Challenges and Limitations

a. Silver Ion Migration

A well-documented failure mechanism in silver-based conductors is electrochemical migration under humid conditions and DC bias. When moisture bridges two adjacent traces at different potentials (e.g., row and column lines in a keyboard matrix), silver ions can migrate through the water film, eventually forming a dendritic short circuit (Zhang et al., 2022). This phenomenon manifests as ghost key presses (multiple keys triggering simultaneously) or stuck keys (continuous key press detection). Accelerated tests (85°C/85% RH with 5 V bias) have shown migration onset within 500–1000 hours for unprotected silver traces (Fang et al., 2018).

b. Mitigation strategies incorporated in this study:

(a) Maintaining minimum 0.5 mm trace spacing as per original design (Ramsey et al., n.d.) (b) Applying conformal coating (acrylic or silicone) over repaired traces for humid environments (c) Recommending repair only for keyboards used in climate-controlled indoor environments unless additional protection is applied.

c. Manual Application Skill Requirements

The quality of manual silver paste application varies significantly with technician skill. Inexperienced applicators may produce uneven trace width, gaps, excessive thickness, or accidental

bridging between adjacent traces. Our experience indicates that approximately 5–10 practice applications on scrap membrane material are sufficient to achieve consistent results. The use of stencils or masks (Section 2.3.4) substantially reduces skill requirements by confining paste to the intended region

d. Material Cost

Silver paste costs approximately Rp 80,000–150,000 per gram in the Indonesian market, compared to Rp 1,000–2,000 per gram for carbon ink. However, each keyboard repair consumes only 0.1–0.3 g of paste, making the material cost per repair Rp 8,000–45,000. When combined with consumables (IPA, tape, swabs) and technician time (30–60 minutes), total repair cost ranges from Rp 115,000 to Rp 215,000 (Purba et al., 2026)

Economic Viability and Comparison to Replacement

Table 2. Cost comparison: Silver paste repair versus keyboard replacement

Keyboard type	Replacement cost (Rp)	Repair cost (Rp)	Savings (Rp)	Break-even use duration
Basic membrane (office)	150,000 – 250,000	115,000 – 180,000	35,000 – 70,000	Immediate
Mid-range multimedia	300,000 – 500,000	130,000 – 200,000	170,000 – 300,000	Immediate
Gaming/mechanical	600,000 – 1,500,000	150,000 – 215,000	450,000 – 1,285,000	Immediate
Vintage/rare layout	>2,000,000	150,000 – 215,000	>1,800,000	Immediate

Repair becomes economically advantageous for any keyboard valued above approximately Rp 200,000, which includes the vast majority of keyboards beyond the most basic office models. For institutional settings (schools, universities, offices) with dozens to hundreds of keyboards, annual savings from repair over replacement can reach millions of rupiah.

Beyond direct cost savings, repair extends device lifespan and defers the environmental impact of manufacturing new units. Small WEEE studies indicate that manufacturing a standard keyboard generates approximately 10–15 kg CO₂e, while repair generates only 0.5–1 kg CO₂e, a 90–95% reduction. Extended warranty providers have begun recognizing repair-based models as both economically and environmentally preferable.

Comparison to Alternative Repair Methods

Table 3. Comparative assessment of keyboard trace repair methods

Method	Conductivity	Skill required	Substrate compatibility	ESD risk	Durability
Silver paste (this study)	Excellent	Medium	Excellent (low temp)	None	High
Wire jumper + solder	Excellent	High	Poor (heat damage)	High	Medium
Conductive carbon ink	Good	Low	Good	None	Low
Copper tape	Excellent	Low	Poor (thickness)	None	Medium
Conductive epoxy	Good	Medium	Good	None	Medium

Silver paste offers the best balance of electrical performance, substrate compatibility, and repair permanence for flexible membrane keyboards. Wire jumpers, while electrically excellent, risk melting the PET substrate during soldering and add thickness that may prevent proper keyboard reassembly. Conductive carbon ink is easier to apply but has higher resistivity (10–100× silver) and lower abrasion resistance. Copper tape adheres poorly to PET and creates localized stiff spots that may crack under repeated flexing

Implications for Computer Input Device Reliability

From a computer systems reliability perspective, keyboard trace restoration using silver paste addresses failure modes that are otherwise unrepairable with conventional tools. The ability to restore open traces without specialized equipment (no soldering station, no hot plate, no cleanroom) makes

this method accessible to university computer labs, IT support departments, and individual enthusiasts (S Suparmono et al., 2025). The method also aligns with emerging "right-to-repair" regulations in multiple jurisdictions, which increasingly require manufacturers to provide repair documentation and spare parts. While this study focused on post-failure repair, the same silver paste application technique could be adapted for preventive reinforcement of known weak points in keyboard trace layouts.

Conclusion

This research demonstrates that keyboard circuit trace restoration using conductive silver paste is an effective method for repairing damaged computer input devices (Zikulnig et al., 2023). Regarding electrical performance, silver paste restores conductivity from an open circuit ($\infty \Omega$) to approximately $3.5 \pm 0.8 \Omega$, approaching the original intact trace performance of $2.8 \pm 0.5 \Omega$ (only a 25% increase). In terms of durability, repaired traces exhibit good oxidation resistance, with an estimated operational lifespan of 7 to 10 years under normal office conditions. From an economic viability standpoint, the total repair cost ranging from Rp 115,000 to Rp 215,000 is significantly lower than replacing medium-to-high-value keyboards, which costs between Rp 150,000 and Rp 1,500,000. Finally, as a practical contribution, this research provides a detailed restoration protocol that can be readily adopted by computer hardware technicians and researchers focused on input device repair and reliability engineering.

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