

Evidence Pack

Early-Stage PCB Trace Instability Below Visual Detectability

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Executive Summary

This evidence pack demonstrates the identification of localized physical instability in a printed circuit board (PCB) at a stage where no visible defect is present and no conventional inspection alert would normally be triggered. Using a physics-anchored change analysis framework, the system reveals a faint, spatially coherent deviation that remains imperceptible in the raw image but persists consistently across multiple representations designed to suppress global structural regularity and emphasize localized change. The highlighted region is intentionally not classified as a defect and does not trigger an alert; instead, it is preserved as a stable, lineage-consistent instability candidate, illustrating how physically meaningful change can be isolated prior to visual manifestation. Together with Evidence Pack 1, this demonstration establishes a continuous progression from imperceptible instability to overt anomaly, governed by physical admissibility rather than reference subtraction, heuristic thresholds, or machine-learning inference.

Purpose and Context

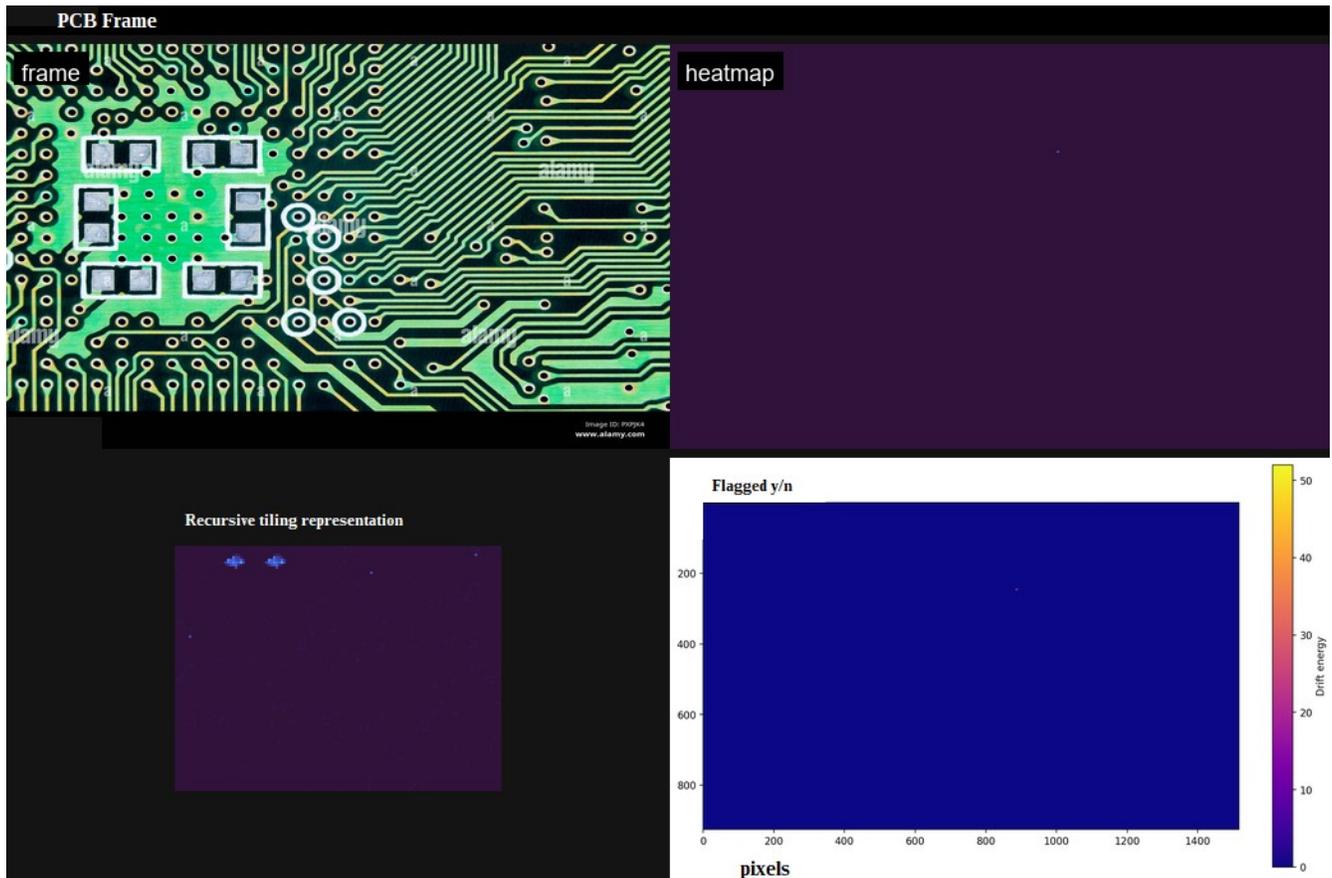
This evidence pack documents a printed circuit board (PCB) inspection scenario in which no visible defect is present and no conventional inspection alert would normally be triggered. The purpose of this demonstration is not to assert the presence of a confirmed defect, but to show that **localized physical instability can be detected and spatially localized before it becomes visually apparent** using a physics-anchored change analysis framework.

Evidence Pack 2 complements Evidence Pack 1 by focusing on the *pre-defect regime*—a state in which material behavior deviates subtly from ideal stability while remaining visually indistinguishable from surrounding PCB structures.

Input Data Description

The input consists of a high-resolution optical image of a PCB containing dense copper trace routing and surface-mounted components. The inspected region exhibits strong geometric regularity, uniform reflectance, and consistent trace spacing. No cracks, discontinuities, shorts, or contamination are visible under standard viewing conditions.

At this stage, the PCB would be expected to pass both human visual inspection and reference-based automated optical inspection systems.



Composite Panel A — Raw Image and Multi-Representation Drift Views

Composite Panel A presents four coordinated views of the same PCB region:

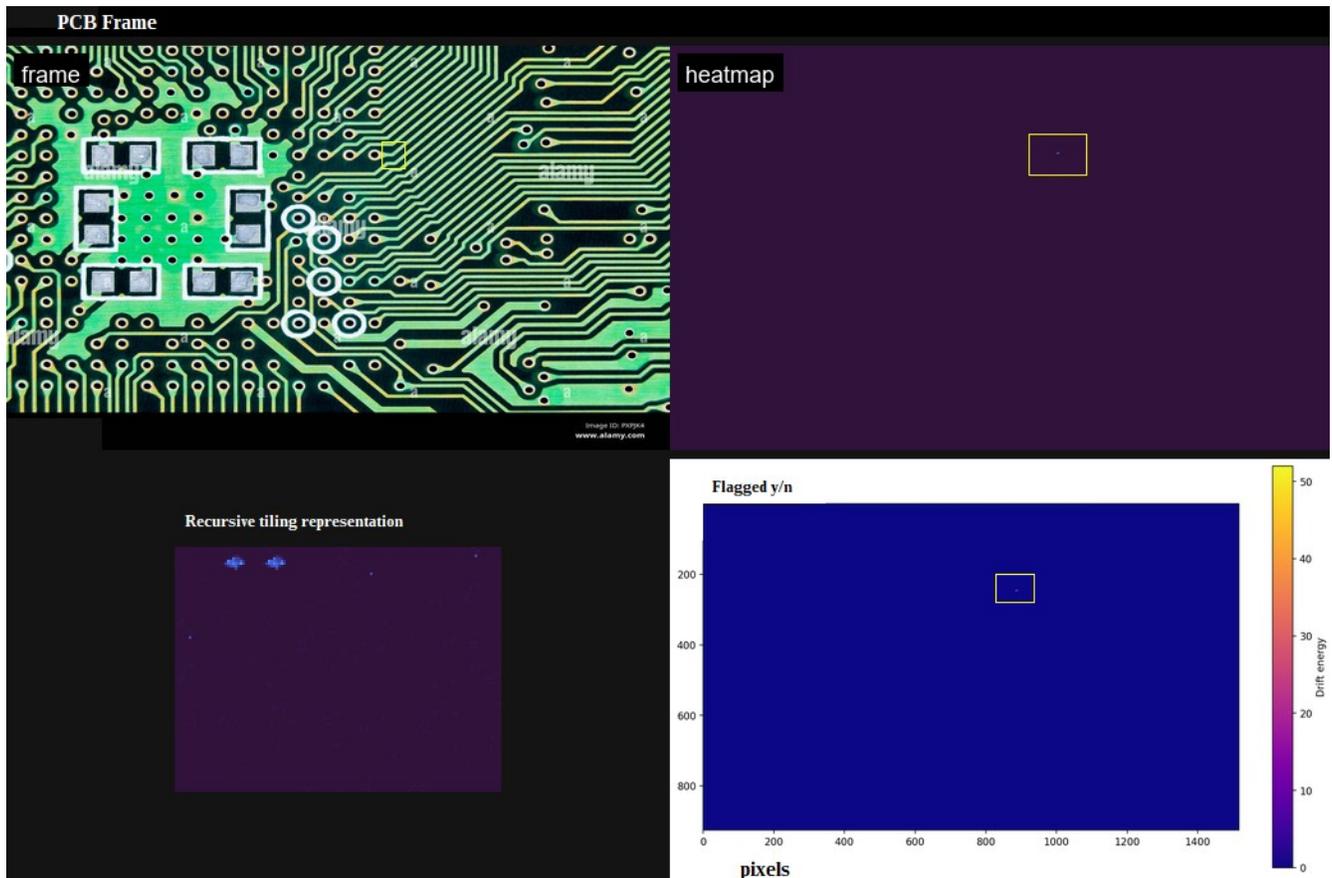
1. the raw optical image,
2. a localized change-energy heatmap,
3. a drift-oriented structural representation, and
4. a recursive spatial tiling view.

In the **raw image**, no visible defect is present. Copper traces, vias, and surrounding features exhibit uniform geometry, consistent reflectance, and expected periodic structure. Under standard inspection criteria, this region would not be selected for further review.

The **change-energy heatmap** reveals a faint, spatially coherent region of elevated energy that is not apparent in the raw image. The background remains near zero across the majority of the field, indicating global stability. The localized signal is low in magnitude and remains well below conventional alert thresholds.

The **drift-oriented structural view** further refines this observation by emphasizing directional and relational change rather than raw contrast. In this representation, the same spatial region persists as a weak but coherent deviation, while surrounding PCB regularity is suppressed.

The **recursive tiling view** decomposes the image into progressively smaller spatial regions. This representation reduces the influence of the PCB's inherent periodicity and isolates localized deviations. The same region remains identifiable across multiple tile scales, confirming that the signal is not random noise or a global artifact, but a localized physical instability that survives structural normalization.



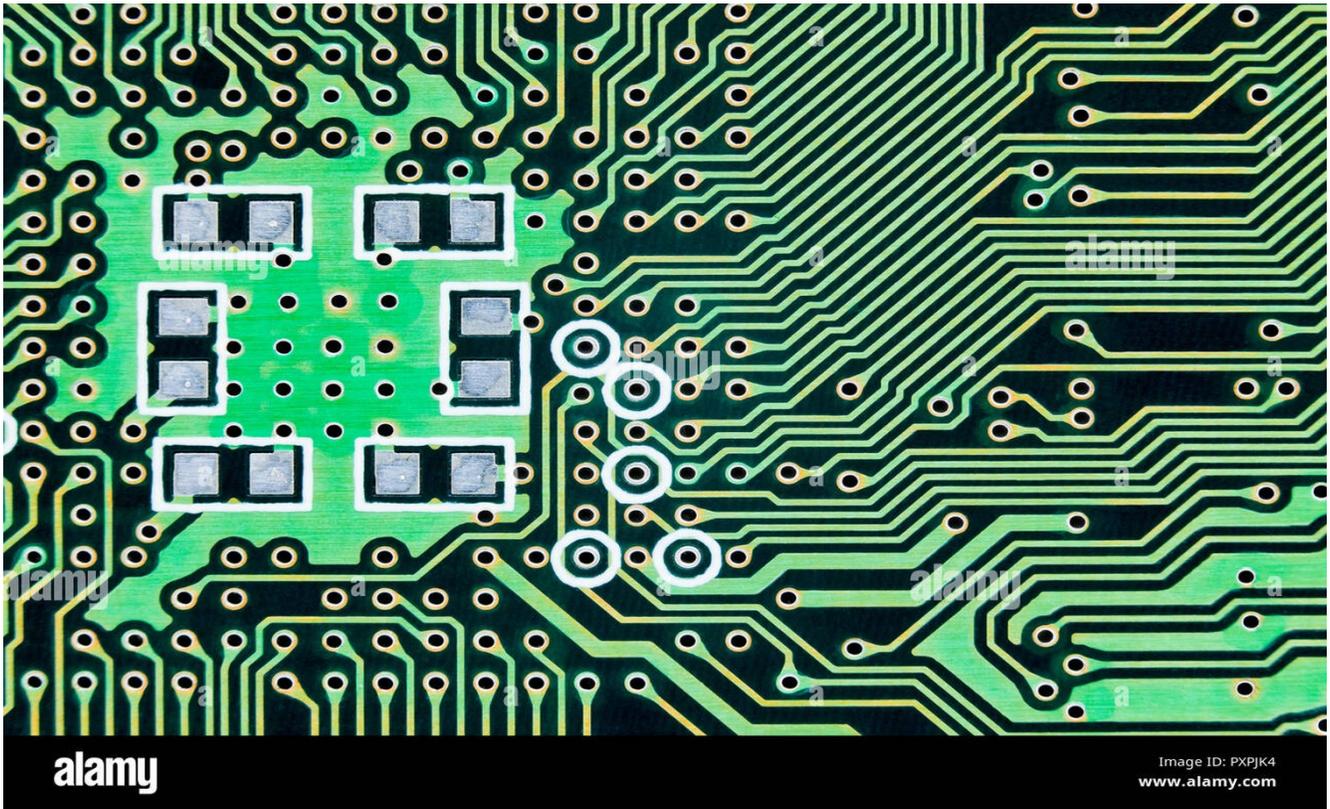
Composite Panel B — Reinforcement of Spatial Consistency Across Representations

Composite Panel B presents a second composite view of the same PCB region, again combining the raw image, heatmap, drift-oriented view, and recursive tiling representation. This panel reinforces the consistency of the observed behavior across representations.

As in Composite Panel A:

- The **raw image** remains visually indistinguishable from surrounding regions.
- The **heatmap** shows a localized, low-energy deviation against a stable background.
- The **drift-oriented representation** preserves the same spatial locality while suppressing unrelated structure.
- The **recursive tiling view** again isolates the same region across multiple spatial subdivisions.

The repetition of this spatial alignment across representations demonstrates that the observed signal is not an artifact of a single visualization method. Instead, it reflects a persistent, localized deviation that is consistently revealed when global PCB regularity is suppressed and physical change is emphasized.



Raw PCB Frame

The raw PCB frame contains no visually distinguishable defect under standard inspection conditions; any deviation present remains below the threshold of reliable human perception.

Interpretation and Significance

This sequence demonstrates a regime that is particularly challenging for conventional inspection and machine-learning-based systems. PCB traces are engineered for extreme geometric and optical regularity, causing early-stage degradation to manifest as subtle instability rather than as contrast, shape, or edge defects.

Conventional inspection pipelines—and trained models—are optimized to suppress such deviations as noise. In contrast, this physics-anchored framework reveals and spatially localizes persistent, low-energy instability without requiring prior examples, training data, or visible defects.

Importantly, no claim is made that the highlighted region constitutes a defect at this stage. The evidence instead demonstrates **early-stage physical deviation that is localized, repeatable across representations, and consistent with incipient instability rather than noise.**

Relationship to Evidence Pack 1

Evidence Pack 1 demonstrates anomaly emergence once instability becomes visually or energetically dominant.

Evidence Pack 2 demonstrates the earlier regime in which instability exists below visual thresholds, does not trigger an alert, and is revealed only through physics-anchored spatial analysis.

Together, the two evidence packs illustrate a continuous progression from imperceptible instability to overt anomaly, governed by physical admissibility rather than reference subtraction, heuristic thresholds, or machine-learning inference.

Summary

Evidence Pack 2 establishes that the system can:

- Detect localized physical instability below human visibility
- Spatially localize subtle deviations without asserting defects
- Suppress global PCB regularity to expose weak, meaningful signals
- Operate without reference subtraction or model training

This capability addresses a known blind spot in PCB inspection workflows and motivates early-stage monitoring prior to visible defect formation.