# Process-Integrated Monitoring of Flux Application

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The application of flux is a key requirement for defect-free wave or selective soldering. Flux removes oxide layers from the metal surfaces to be wetted and prevents them from re-oxidizing. Only then is sufficient wetting possible, laying the foundation for a metallurgically sound solder joint.

The quality of the solder joint depends not only on the chemical effectiveness of the flux, but above all on its precise dosage and precise location on the printed circuit board. Insufficient application can result in soldering defects such as incomplete penetration or cold solder joints. Conversely, over-application increases the risk of flux residues, which can affect the assembly's functionality and long-term reliability.

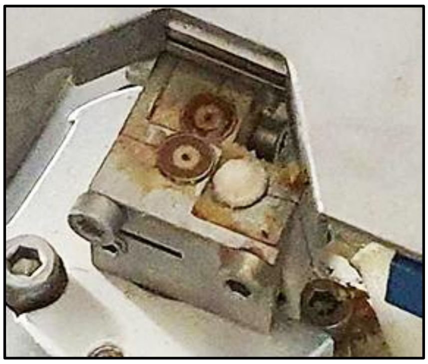
## 1 Introduction

During a SEHO-SIEMENS Technology Day, a meeting of experts identified the review of flux application as an area requiring urgent attention.

Current monitoring approaches are primarily based on random inspections – for example, using test assemblies – or on purely functional monitoring of the flux nozzle. However, these methods are not integrated into the production process and do not provide reliable data on the actual amount of flux applied to individual assemblies.

Common sources of error include dried-on flux residue on spray nozzles, air bubbles in the system, variations in flux composition, and deviations in spray nozzle positions from the defined target positions, particularly in multi-nozzle systems.

**Pic 1.** Fluxer with several heads.



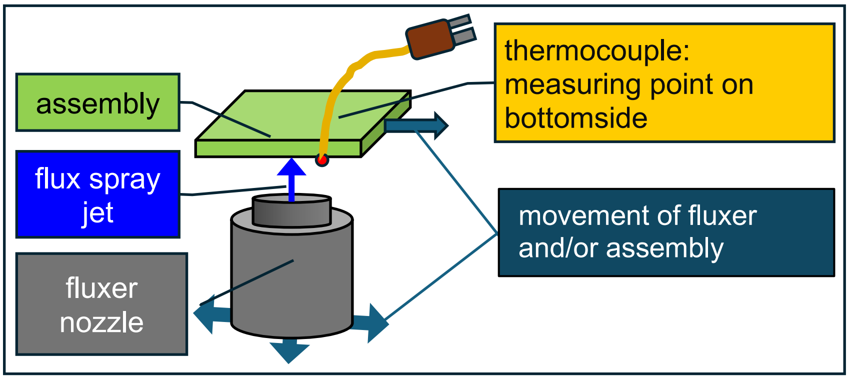
**Pic 2.** Flux residue at spray head; crystallization of solids due to a leak

Against this backdrop, as part of an internal SIEMENS collaborative project, the "Electronics Manufacturing" Research Group at SIEMENS AG, Foundational Technologies in Berlin, was tasked with systematically investigating potential solutions.

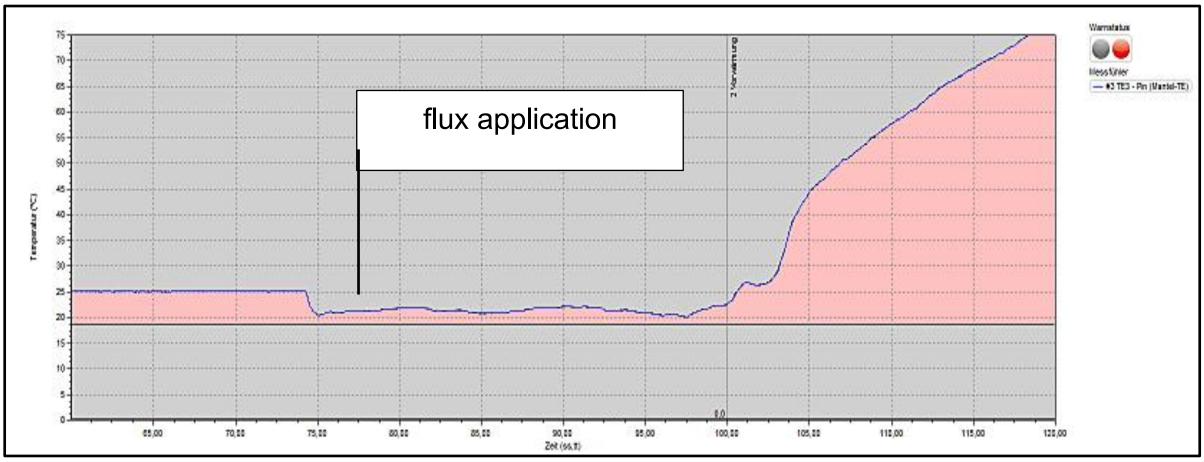
## 2 Search for Solutions

A key principle of SIEMENS Technology Berlin in process optimization is the measurement of quality-relevant process parameters as close to the product as possible.

Extensive experience of temperature profiling and optimization in the wave soldering process has shown that a measurable cooling effect can be detected at thermocouples positioned on the underside of assemblies during flux application.




**Pic 3.** Schematic diagram of temperature profiling using thermocouples.




**Pic 4.** Excerpt from a temperature profile recording using a thermocouple.

Based on these findings, the question arose as to whether this cooling effect could be measured not just at specific points using thermocouples, but across an entire surface using a thermal imaging camera. The expected advantage would be the ability to analyze larger areas, including entire product sections, even when multiple circuit boards are present within a single soldering frame.

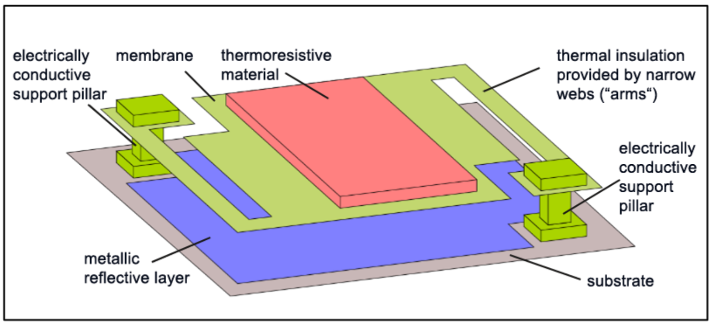
The cooling effect was assessed as potentially critical, especially in terms of the spatial separation between the flux application and the thermal imaging camera.
The aim was to ensure sufficient detectability while preventing the camera from becoming contaminated by flux.

Thermal imaging cameras consist of the following key components, among others:

a. The lens, which focuses the thermal radiation and directs it to the detector. The focal length determines the size of the object that can be imaged.

b. The infrared detector with a sensor array, which is used to detect thermal radiation – typically in the form of a microbolometer. Materials with a resistance that vary significantly with temperature, such as vanadium oxide, are used for this purpose. This material is fabricated into a wafer just a few micrometers thick and placed over a reflective metal layer. Thermal decoupling of the sensitive bolometer elements is achieved via two curved, thin connecting wires, thereby minimizing heat input into the structure.

c. A signal processor that provides electrical amplification, calibration, and further processing.

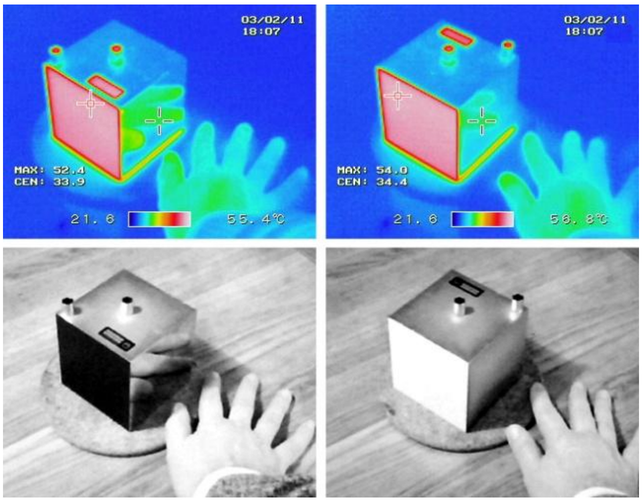



Simplified diagram of a microbolometer.
Source: Wikipedia/Michael Frey

Other fundamental aspects of the idea:

a. Enthalpy of vaporization
Even at temperatures below their boiling point, liquids will evaporate until a state of equilibrium with the surroundings is reached. The energy required for evaporation is drawn from the surroundings, including the surface on which the liquid is located. This energy removal leads to cooling of the surface. This effect is more pronounced with alcohol than with water, since alcohol has a higher tendency to evaporate.

b. Emission coefficient of surfaces
Emissivity depends on the material. It is defined as the ratio of the actual thermal radiation emitted by a surface to that emitted by an ideal black body at the same temperature. While the relevant materials have similar, yet not identical, emissivity coefficients, this enables different materials to be distinguished using a thermal imaging camera, even at the same temperature – similar to the principle of the Leslie cube.



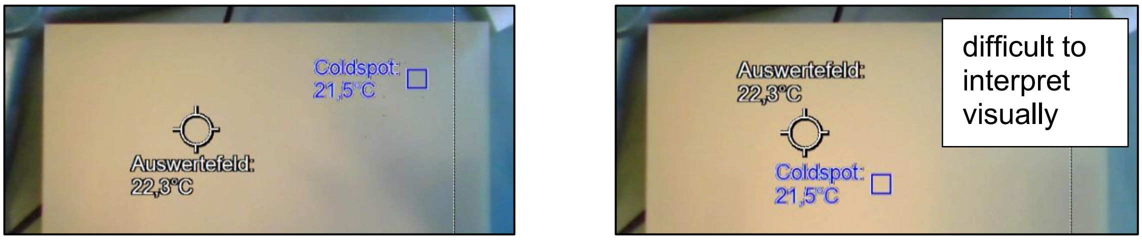
Two views of a Leslie cube captured with a thermal imaging camera, compared with black-and-white images in the visible spectrum. Source: Wikipedia/Pieter Kuiper

Application context:

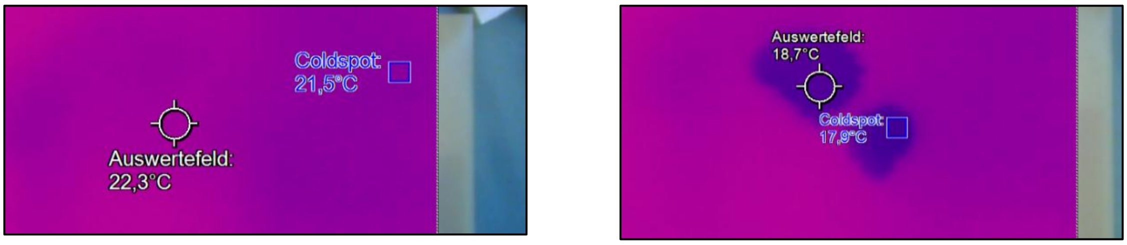
Both effects – the temperature reduction caused by evaporation and material-dependent differences in the emissivity coefficient – make it possible to detect the presence of flux on printed circuit boards using a thermal imaging camera.

## 3 Preliminary Tests

Initial preliminary tests involving manual flux application confirmed the fundamental potential of this approach and led to the idea being further developed, culminating in a patent application [1].



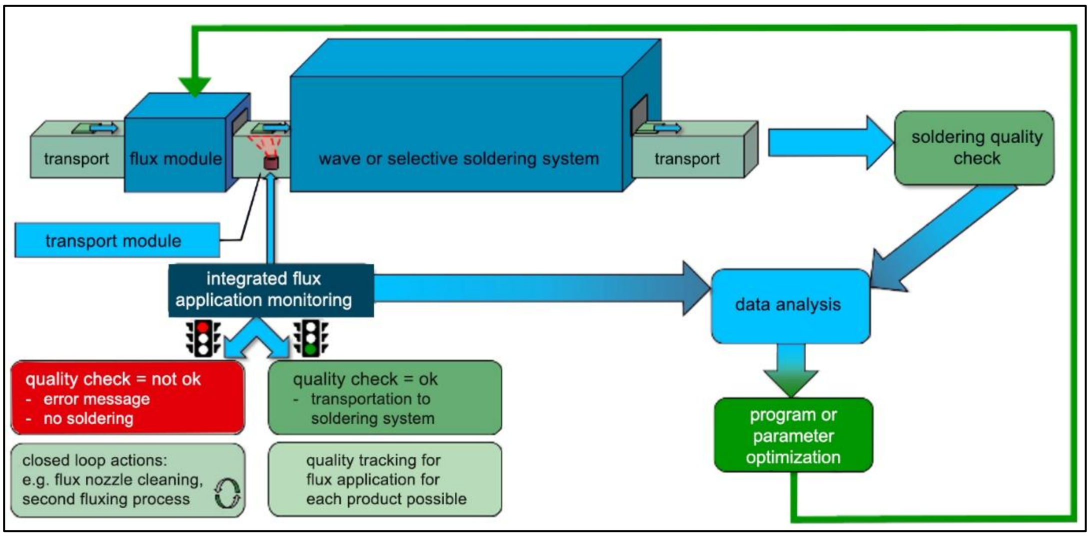

**Pic 5.** Visual comparison before (left) and after (right) applying the flux.




**Pic 6.** Thermal image before (left) and after (right) the application of flux.

Based on the positive results of the preliminary tests, specific application scenarios for industrial electronics manufacturing were identified. Particular emphasis was placed on developing an integrated system that can be easily incorporated into production lines.

Looking ahead, the use of modern evaluation algorithms, including AI-based ones, were also considered.




**Pic 7.** Possible use cases.

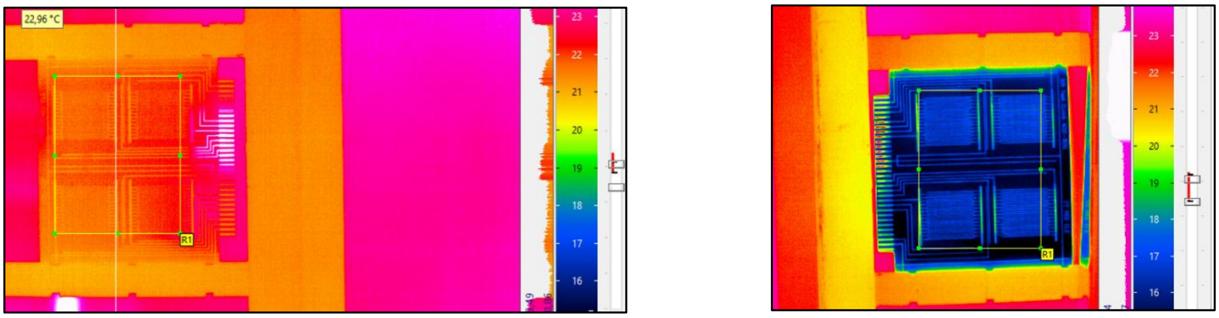
# 4 Testing

A. Wave Soldering Processes

As part of the testing process, thermal imaging was performed immediately after the application of flux in front of the wave soldering machine.

The results showed that areas with insufficient or uneven flux application could be clearly identified and that the cooling effect could be reliably detected by a thermal imaging camera, even over a period of several minutes.

However, the distance between the camera and the assembly must be considered. Capturing larger areas of the assembly requires a correspondingly large field of view, necessitating the selection of suitable lenses. Additionally, there must be no sources of interference between the camera and the assembly that could restrict the field of view or cause shadows.

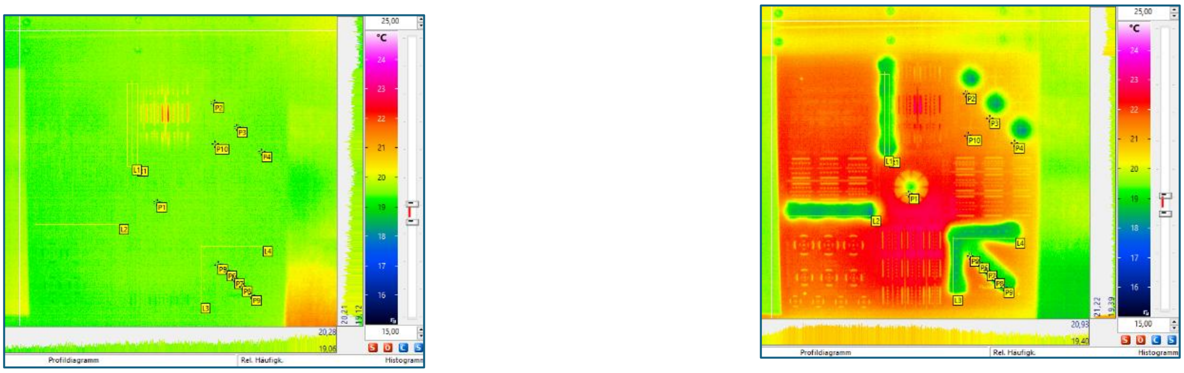


**Pic 8.** Thermal image before flux application (left) and after (right).

B. Selective Soldering Processes

In selective soldering processes, flux is usually only applied locally to the areas that will be soldered later. For these experiments, the „Quick and Easy“ test structure for selective soldering, which is widely used at SIEMENS, was employed. The flux was applied in line and dot patterns to this test PCB.

A thermal imaging camera with sufficient pixel resolution is required for a meaningful evaluation of selective flux applications. Systems with a resolution of 640 x 480 pixels were used in the tests. The experiments confirmed that this resolution is sufficient to reliably detect even small wetted areas in the selective soldering process.



**Pic 9.** Thermal image before flux application (left) and after flux application (right).

# 5 Collaboration

As SIEMENS AG wanted to apply the process to its own electronics manufacturing operations, but does not manufacture soldering equipment itself, a partnership was established with SEHO Systems GmbH. A corresponding license agreement was signed by SIEMENS and SEHO.

Together, the partners entered the productronica Innovation Award at the world's leading electronics manufacturing trade fair in Munich in 2025, taking second place in the 'Future Markets' category.

In addition, a joint pilot test was planned and conducted at the SIEMENS DI MC production facility in Erlangen. Close collaboration with a manufacturer of thermal imaging cameras was also involved in this project.

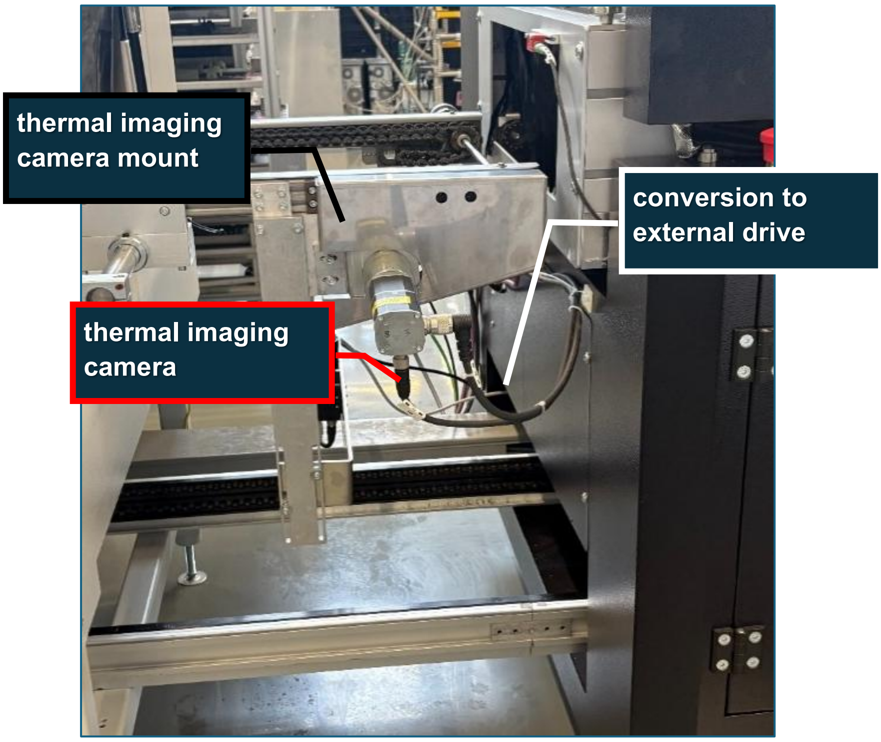
This partnership is a prime example of successful, technology-driven collaboration between a user and a system supplier. The jointly developed solution enables automated, inline control of flux application for each individual printed circuit board for the first time, directly within the ongoing manufacturing process.

How the system works:

Thermographic imaging of the flux application takes place within a defined time frame immediately after fluxing. The subsequent image-based evaluation is then carried out using a defined reference image. This can be either a thermographic image of an untreated printed circuit board, or a digital twin from the CAD system.

The wetted areas are analyzed in terms of their location and extent based on the measured temperature differences. The system then makes an automated decision to approve the subsequent soldering process.
The soldering process only continues automatically if there is a clear match with the predefined target values. If there are any deviations, the system generates an error message and blocks access to the soldering system.

Additional measures, such as the automatic cleaning of the fluxer nozzle or the reapplication of flux, can also be triggered.




**Pic 10.** System test setup during the pilot phase

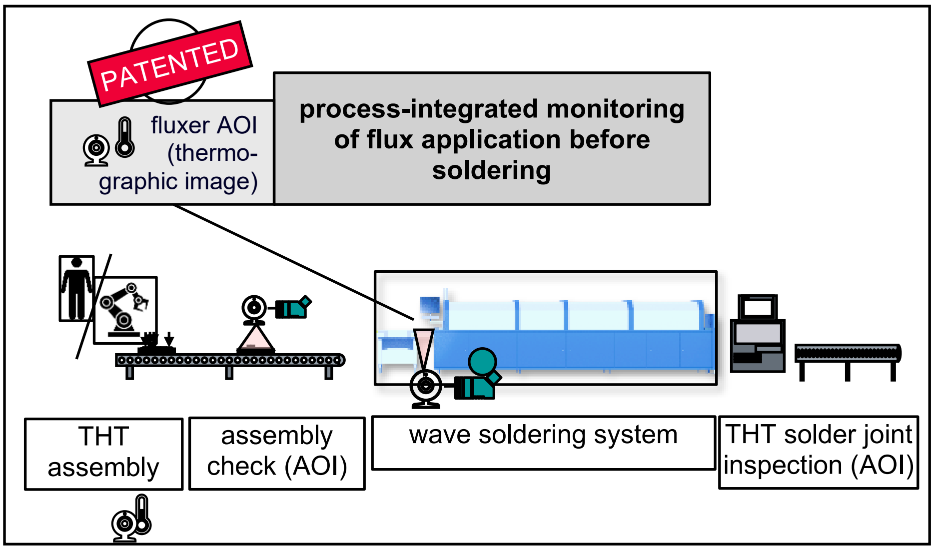
# 6 Results

Inline thermographic monitoring of flux application bridges a gap in process monitoring that previously existed. It detects incorrect or incomplete flux applications even before the soldering process begins, allowing them to be corrected specifically.

This leads to demonstrable improvements in manufacturing quality, significant reductions in scrap and rework, and higher overall equipment effectiveness. At the same time, the system establishes the necessary data foundation for future AI-based process control, where parameters adjust automatically.

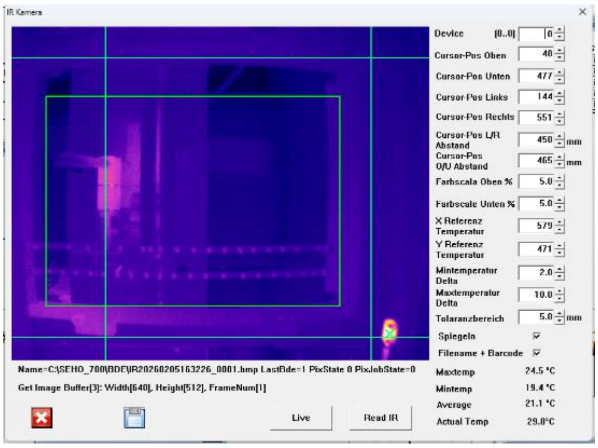
# 7 Implementation in Series Production and Outlook

Particular emphasis was placed on a robust, reproducible and low-maintenance system design for series production. Integration into production line concepts is performed inline without affecting cycle time. The mechanical interfaces, camera positioning and protection against contamination are all designed for continuous industrial operation.



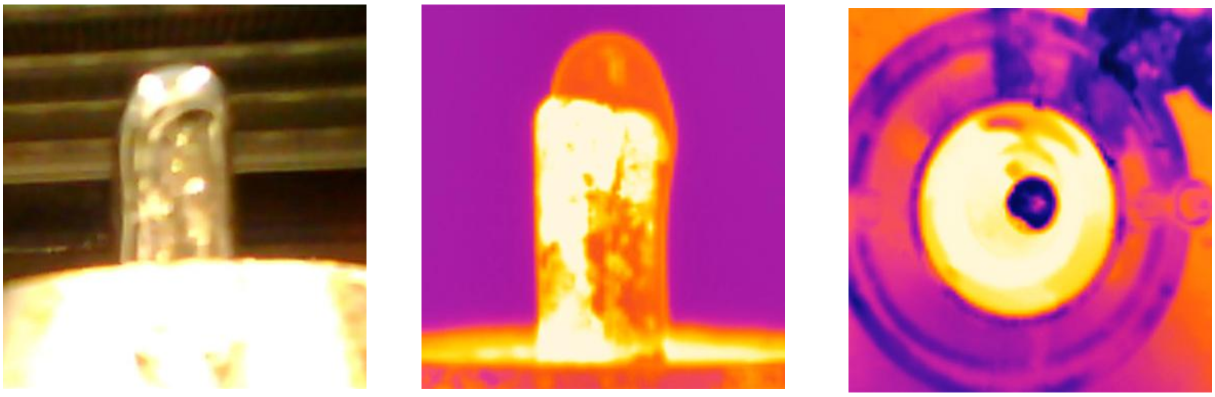

**Pic 11.** Integration of the system into automated manufacturing lines.

The modular system architecture allows for adaptation to different PCB formats and process variations. This makes the solution suitable for both new installations and the retrofitting of existing production lines.




**Pic 12.** Settings window ‚process-integrated monitoring of flux application‘.

Additional applications for thermographic monitoring are currently being tested. These include process-integrated monitoring of mini- and multi-waves in selective soldering processes, for example.



**Pic 13.** Example of thermographic monitoring of a miniwave soldering nozzle: poor solder flow.

Thermographic flux monitoring is ready to be integrated into the SIEMENS Industrial Edge ecosystem.

At the same time, the system generates the necessary data foundation for future AI-based analysis with the aim of automatically and continuously optimizing process parameters in real time.

This paves the way for adaptive, autonomous manufacturing, where process stability, quality and efficiency are systematically enhanced using data.

[1] European patent application by SIEMENS AG, published in Patent Bulletin 2025/08 on 19 February 2025.