

# Practical experience manufacturing PCBs with embedded active and passive devices

Thomas Hofmann

President & Owner

Hofmann Leiterplatten GmbH

D-93057 Regensburg Germany, Auerbacher Straße 4

Phone: +49-941604900

Email: [thomas.hofmann@hofmannlp.de](mailto:thomas.hofmann@hofmannlp.de)

Paper code: EU173; Session: S11-Embedded & Stacking

## Introduction

Printed Circuit Boards with embedded devices have been used in the European PCB industry under development contracts for a number of years. Recently the embedding technology has gained momentum due to the availability of new smaller components, design software and PCB fabricators that are willing to step into this advanced technology. In addition, the sensor-, industrial-, medical- and automotive industry have seen the features that embedding devices in PCB will offer improved miniaturization and reliability of electronic equipment. Companies that are forward and backward integrated have already seen these as clear benefits to manufacture chip packages. In other sections, design engineers are trying to use the embedding for the next generation of electronic equipment. Europe has a strong position in developing new and advanced products. Advanced prototype PCBs are key for the success of the European electronics industry. This is based on new developments of advanced electronics in industrial manufactured products. Miniaturization, reliability and cost-effectiveness are vital for most of the new developments. The automotive industry has stated that more than 40% of the cost of a passenger car are related to electronic devices. The tendency will be even higher in the future when Hybrid or full electric cars are manufactured.

## Topics of the paper

- ❖ **Background about Hofmann Leiterplatten (PCBs) in Germany and the AML® Technology**
- ❖ **When was the patent filed and granted?**
- ❖ **What was the unique invention that made the process work**
- ❖ **Practical examples**
- ❖ **Developments of Standards for PCBs with embedded devices and its impact on PCBs**
- ❖ **How to manufacture PCBs with Embedded components without infringing patents of Hofmann**
- ❖ **Outlook and future developments**

## Background about Hofmann Leiterplatten (PCBs) in Germany and the AML® Technology

The Company was founded in 1988 by Thomas Hofmann. His visions for forming the company was: "Service the electronic industry through Creativity, Innovation and Efficiency using PCB Technology Goal of the company is the Support of the electronics industry in the regional area of Regensburg, Germany. and with special products support of automotive, medical and industrial electronics. Sensor technology and intelligent front panels with embedded devices are some of the products that manufactured today. In addition, fast

and reliable PCB fabrication was needed to meet or even exceed industrial fabrication standards. Development of innovative solution for new products are some additional services the company provides. Managing energy resource to reduce the CO<sub>2</sub> output of the company is also a key objective. The generation of solar energy and heat recovery system from processing equipment have resulted in a very effective energy efficiency of the company.



Above: Photovoltaic on the roof of the factory produces 200 to 350 kWh per day (depending on sun light)



Left: Heat recovery from exhaust air in the factory. Effective energy recovery > 86 000 kWh/pa

Figure 1. Photo # 1 Factory of Hofmann Leiterplatten in Germany. Top left office building with the fabrication hall in the back. Top right: Solar panels on the factory roof. Bottom left: Heat recovery system from cooling air used in the factory

## The development of embedded technology

Based on the needs of the industry and some of the key customers in the field of new product developments, the company started the development activities of embedded devices in PCBs in the early 1993. The key designers of new products initiated these activities to achieve a higher miniaturization and improved reliability through an advanced thermal management by embedding devices in PCBs.

Material	Thermal Conductivity in W/(m.K)
Acrylic	0.2
Air	0.024
Aluminum	250
Copper	400
Epoxy	0.35
Glass	1.05
PTFE	0.25
Silicon	149
Water	0.58

Figure 2 Thermal conductivity of different materials used in electronics

In addition, an improved environmental protection against contamination from dust, humidity, chemicals and human impact as well as an improved EMC shielding was achieved. This work resulted in filing the patent in 1996. The patent was granted in Germany in 2004.

### What was the unique invention that made the process work

In the patent abstract of Germany: "DE 19627543 (A1) it was described that the substrate includes multiple surface connected insulation layers with at least one inner insulation layer as a distance frame with a window (11). At least on one substrate surface side, and between adjacent insulation layers, are formed contact faces and/or conductive tracks (6-9). At least one inner insulation layer (3) forms a spacer frame with at least one window for an inner electric component (12). Both side of the window are closed by further insulation layers (2,4) adjacent to the spacer frame, whose thickness equals at least the height of the inner component. Preferably a separate window is provided for each electric component."

The description of the patent stated that special cavities in the prepreg are used as a separator between the layers of a multilayer PCB. This enables the fabrication process to use standard PCB fabrication technologies and equipment without damaging the sensitive components during multilayer lamination and pressing. In the fabrication process, the components are placed on an inner layer of the multilayer. The connection between the components and the inner layer can be made either by soldering, gluing with conductive adhesive, by welding, riveting, bonding, sintering or plating. The selected attachment technology between the conductor lines and the components depends on the type of components and the requirement for electrical and or thermal conductivity.

A specific window technology in the prepreg is used allow for a stress free embedding of different components in one pressing operation. The resin flow is sufficient and an additional underfill is not required. Here the correct opening in the spacer prepreg will provide sufficient resin to completely embed the components. A specific know-how is needed to define the correct resin content, resin type and press cycle to avoid stress at the component packages.

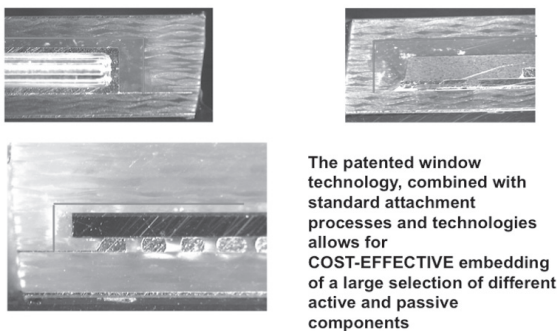


Figure 3 Different components are embedded in PCBs without the need of underfill of extra resin. The resin provided by the prepreg is sufficient for encapsulation of components and connection to the PCB

Without using the correct window and embedding technology, components have the risk of getting damaged during the placement and multilayer press cycle. This will then result as the defect that is identified in final inspection. In addition, the defect can not being repaired and the total electronic assemble will be rejected as 100% scrap. At this stage, all components are in place and the reject will be expensive. Using the correct window and prepreg technique, this defect are avoided.

By using the correct manufacturing technology, a cost-effective technology is available to manufacture electronic devices that provide outstanding protection against environmental and pollution influences. In addition, the hermetic encapsulation of the components provide an outstanding protection against moisture, water, dust, gases, chemicals and provide a reliable electrical insulation. Components are also well protected against vibration, shock, stress and strain or pressure. The reliable positioning and secure fixation of the components by embedding as well as the EMC protection using the Advanced Multilayer (AML®) PCB fabrication technique developed and patented by Hofmann Leiterplatten in Germany. The plating process of the completed module can be designed as a low cost EMC shielding protection.

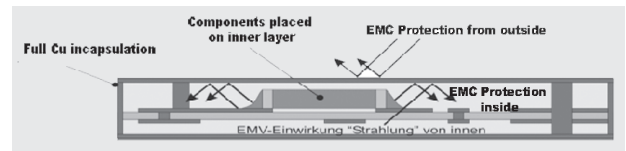


Figure 4 Embedding of components provide an excellent way to design electronic modules and assemblies with an outstanding Electron Magnetic Compatibility (EMC) by reducing the radiation impact from outside and inside that could influence the performance.

The PCB technology with embedded devices has proven a superior thermal management of the assemblies. This resulted in a lower thermal stress of the components and an improved life expectation.

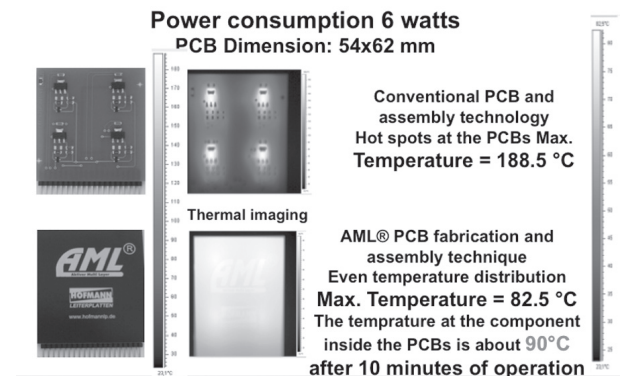


Figure 5 Embedding of components reduces the temperature at the component level on the above example be about 98°C to 90°C after 10 minutes of operation at 6 Watts. The outside temperature of the test sample changed from 188.5°C to 82.5°C.

Based on these results, a number of new products have been designed and manufactured that allow to improved reliability, miniaturization as well as for potential cost reduction in the future.

In addition, the manufacturing process using PCB fabrication processes that are tailored to use large production panel fabrication. Use lead free solder technology and suitable laminate materials shall be used. In case that reflow soldering is used, the solder past can be applied by using standards stencil printing or specific dispensing processes. The components are placed on the thin inner layer PCBs and connected using standards lead free soldering or any other suitable attachment methods. After soldering, cleaning of assembled inner layer is applied. This will avoid any ionic contamination that could lead to long term defects based on migration, electrical conductivity or e-corrosion. Also an AOI inspection with or without and electrical test will be possible. This is useful to define the position of the components, the solder fillets and the electrical functionality of the inner layer with components. Handling of such thin inner layer need some training and

experience. However, in assembling flexible circuits this are common manufacturing process. The cost-effective fabrication and testing of semi-finished products allow for high yields in final testing of the finished assembled device. Here, the option for repair in the semi-finished state allow to identify defect components, an allow to repair or replacement of the defect parts before the ML-PCB is pressed.

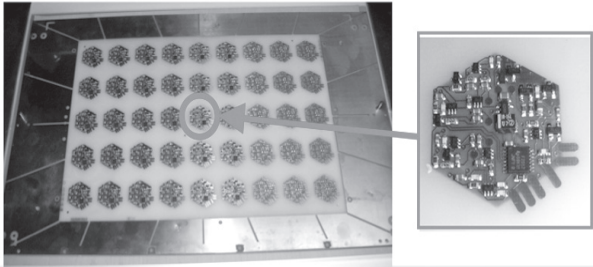


Figure 6 Large panel production allow for cost-effective fabrication in PCB processes, in the assembly line as well as pretesting of submodules

### Industry segments

The sensor- and automotive industry have seen the potential of the embedding technology for future developments.

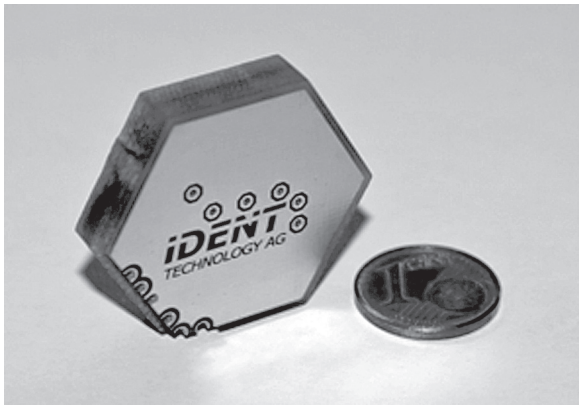


Figure 7 Sensor made by using embedded devices in PCBs. Three conductive layers are needed for connecting the components. The outside area is plated with copper and provide an outstanding shielding of the sensor electronic components.

LEDs embedded in PCBs are very well hermetically sealed so that water or any other environmental pollution could reduce functionality of the electronic devices.



Figure 8 shows an example how PCB technology supports the embedding of LEDs to improve long term performance. In this example the assembled PCBs with LEDs are placed in water for more then 4 years and have still a useful life

In automotive application, dashboard and lightening are key for safety, visibility and durability. 15 years of life expectation is typical for automotive electronics. Driving light, direction light and stoplight are factors for visibility of the vehicles. For the driver the dashboard is key to see the speed of the car and the functional performance of the engine. Good visibility of the instrumentation is vital for safe driving.



Figure 9 Cockpit display unite made by using Embedded Technology PCBs based on the AML technology developed by Hofmann Leiterplatten in Germany. Excellent readability, light weight and well protected against shock and pollution are key factors for this construction.

### Standardization of PCBs with embedded devices

For a widely utilisation of new technology, standardization is vital for a successful implementation of new technology. In 2009, the Japan Printed Circuit Association (JPCA) has submitted a standards proposal to the International Electrotechnical Commission. The JPCA Standard JPCA-EB01 – 2nd Edition is a standard on Device Embedded Substrate - Terminology / Reliability / Design Guide JPCA-EB01. This standards was submitted as an IEC Pas 62326-14 proposal in 2009. As the PCB industry in Japan is using the technology since some years, it was logical to submit the standards proposal to have the technology recognized globally.

However, by comparing the standard proposal with the existing patented process of Hofmann in Germany, it turned out that some of the examples would infringe the patent “DE 19627543” of Mr. Hofmann

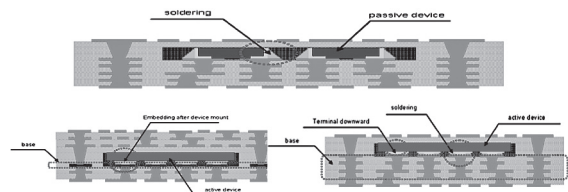


Figure 10 Typically embedded device construction as included in the JPCA-EB01 that have been submitted as a pass proposal under the IEC Pas 62326-14 in 2009.

### Patent situation for embedded technology

Standardization and patents shall not be in conflict. Under the regulation of most standard writing organisation like the IPC or the common IEC, ISO, ITU Patent Rights Policy Administrative Circular AC/10/2007 of 2007-03-23 Disclosure of Patent rights – those participating in standards development work, should draw the attention to relevant patents or pending patents as early as possible. Meetings – where appropriate a TC/SC chairman should remind participants of

the above at each meeting.

This was done during the IEC meetings as well as at the IPC Meeting where the IPC-7092 standard for Design and assembly Process Implementation for Embedded Components were reviewed. Members of the technical committees at the IEC and the IPC are well aware of the patent situation with embedded devices in PCBs in Germany.



**Positioning light made in AML Technique with embedded devices**

*Figure 11 The positioning light at the Audi R15 racing car indicates the car position one two or three in the category (racing class). Visibility is important for the spectators at the raise course*

## **Learn how to manufacture standardized PCBs with Embedded components without infringing patents of Hofmann**

### **The IEC / ISO Regulation are stating:**

“A published document for which patent rights have been identified during the preparation thereof, shall include the following notice in the introduction:

“The International Organization for Standardization (ISO) [and/or] International Electrotechnical Commission (IEC) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning embedding of passive and active divides in PCBs.

ISO [and/or] IEC takes] no position concerning the evidence, validity and scope of this patent right.

The holder of this patent right has assured the IEC that he is willing to negotiate licenses under reasonable and non-discriminatory terms and conditions with applicants throughout the world. In this respect, the statement of the holder of this patent right is registered with ISO [and/or] IEC.

Information may be obtained from:  
Thomas Hofmann,  
President of Hofmann Leiterplatten GmbH,  
Auerbacher Straße 4,  
D-93057 Regensburg, Germany  
E-Mail: [thomas.hofmann@hofmannlp.de](mailto:thomas.hofmann@hofmannlp.de)

## **Summary**

The Advance Multi Layer (AML®) process for embedded devices was developed in the mid 1990, the patent was filed in 1996 and patent granted in 2004. Standard active and passive components have been used and found suitable for the AML® process technique. The component attachment may use either soldering or gluing with adhesives or any other technology like wire bonding, plating or sintering.

Standard packages have been used for many years. The height of the components shall have a low profile to avoid a thickness increase of the PCB.

### **Embedding experience have been gained with the following parts:**

- Chips in WCSP-Technology (Wafer Chip Size Package)
- BGA components with 2.5 mm x 2.5 mm and 25 solder balls
- Component height of less then 0.5 mm have been used

### **Outlook**

- Embedding of active and passive components allow for easy miniaturization and reliable electronic devices
- Improvement in EMC protection is also achieved
- The license of Hofmann Leiterplatten will be accessible on reasonable non discriminating condition (As required by Standard development groups)
- Global manufacturing and safety standards are in a process to be established (IEC / IPC / JPCA and others)
- Some of the standardised construction may lead to patent infringements in Germany
- Getting a license is an easy and cost-effective way to overcome manufacturing and patent issues.