

Embedding Passive and Active Components in PCB - Solution For Miniaturization

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Abstract

The miniaturization of the electronics continues and requires the utilization of inner space of a PCB for component placement. The embedding of the passive components inside the PCB has already been used in the industry. To meet the requirement of the marketplace the new technologies like embedded actives Integrated Module Board (IMB) has been developed. With traditional technologies it has become more difficult to increase the packaging density. In the Integrated Module Board technology active components are embedded inside a printed circuit board (PCB) or other organic substrate. The IMB process combines PCB manufacturing, component packaging and component assembly into a single manufacturing process flow. The embedded passive technology and IMB technology enables high interconnection density with good reliability.

The integration of components into the PCB level makes the manufacturing of the PCB challenging. In this paper an update of embedded passive technology will be presented together with an overview of IMB technology, its technological capability and electrical performance.

Introduction – The New PCB Solutions

Main drives for the embedded technology are PCB size reduction, increased functionality, improved high frequency performance, increased reliability and cost savings. The utilization of inner space of a PCB for component placement has become obvious when the packaging density is increasing for the next generation of electronic devices require. The main focus has been on increasing packaging density and on accommodating the needs of future chip packages. A key to the success is to focus on high technology, high reliability applications with high density interconnects (HDI) for different customer applications.

The miniaturization of the interconnection technology has been driving the PCB development. The main focus in our development work during the past years has been on higher packaging density and on accommodating the needs of future chip packages. In volume production, cost and performance have to be balanced. As a result, manufacturing and material yield, process automation, the cost of materials and added value technologies are key considerations in meeting the high volume requirements of the marketplace.

The ever increasing wiring density in the electronic devices is requiring new technical solutions for the PCBs. To achieve higher functionality the build-up technology and the any layer constructions with embedded passive and even active components in the HDI PCBs are needed. These technologies are giving the possibility for the designers to keep the size of the PCB same as today or even reduce it. Simultaneously we have to put more attention to the reliability, because all these new technologies have to give us high reliable end products. Working closely together with the whole supply chain - from material supplier to OEM - is now even more important than before. Because the shorter product life cycle requires good reliability testing facilities and methods, each party of the supply chain should start their work as early as possible which helps in the end to keep the tight design schedules.¹

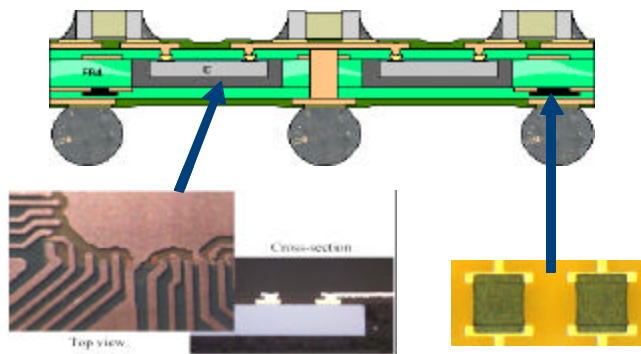


Figure 1 - Embedded Actives and Passives inside the PCB Embedded Resistors Status

There has been lots of progress in the embedded resistor technology during the last few years. Five to ten years ago there was only Ohmega-Ply® thin film material commercially available, and some early work going on around Polymer Thick Film (PTF) technology. Today there are several PTF-pastes available and used in commercial products by many PCB vendors. In addition, Gould Electronics has introduced TCR® thin film material and Rohm and Haas Electronics Materials has been introducing InSite™ material, also based on thin film technology. Some new approaches have been developed as well; MacDermid has introduced M-PASS™ plated thin film technique and DuPont has been developing Interra™ EP20x ceramic paste series (See Figure 1.)

The most attractive property of thin film materials is the long term reliability it offers. Best example of this is Ohmega-Ply® that has been used e.g. in the European Space Agency Mars Express mission, in a number of Beagle 2 instrument circuit boards.² The basic characteristics in all thin film materials are similar, e.g. the manufacturing process is basically identical. Ohmega is using NiP as the resistive alloy and the material is fabricated using electro deposition. Gould is using both NiCR and NiCrAlSi alloys and are coating the materials using sputtering technique, while Rohm & Haas uses combustion chemical vapour deposition method to coat the copper foils with Pt. Ease of fabrication and long term reliability are the advantages, but cost and limited sheet resistance values are the obstacles. This is why thin film technology is most suitable for high-end applications with not so tight cost frames. .

Division between advantages and disadvantages is almost opposite to PTF materials. Fabrication of the pastes is relative simple and cheap; paste is typically consisted out of polymeric chains, carbon powder and phenolic resin. This makes the material cost almost negligible in comparison to the relatively high price thin film materials. Long term stability is not poor, but it is typically not competitive to thin film materials. PTF resistors are also pretty straightforward to fabricate, but process requires tight tolerances and fine tuning to meet optimal values. Because of the low cost of the technology, PTF is ideal technique to high volume applications with requirements to low cost. The most well-known OEM to use PTF resistors is Motorola, who has been using the technology for quite widely in their hand held devices.

Reliability and Stability

The key to optimized reliability and stability properties is the design. As this is a relatively new technology, the design rules and tools are not optimized and this may cause some unwanted phenomena. This is why the design process would be best to carry out as a joint task between the OEM and the PCB shop. As an example, required power dissipation and tolerance of a resistor are conventionally picked to correspond some specific discrete component values. E.g. the tolerance might be “decided” to be $\pm 10\%$ and power dissipation to be 63mW as these kinds of discrete resistors are easily available. But if the real requirements would be e.g. $\pm 25\%$ for the tolerance and 50mW for the power dissipation, we would be able to create some considerable changes. In case of PTF, we would not have to use laser trimming at all to meet the required tolerances, and we would be able to reduce the required area by 20% because our power dissipation requirement is not so tight.

The most obvious improvement to the reliability of embedded resistors is the lack of solder joints, as these are typical places for the failures to occur. The detailed material properties are of course different between different materials, and that is why it is crucial to find out the real requirements when making the material selection. Table 1 describes some of the typical reliability test results for different thin film and PTF materials.

Table 1 - Reliability Test Results for Embedded Resistors

Test type	Test specification	Tested material	Result	Description
Temperature cycling test	Temperature range -40°C...+125°C Duration 1005hrs and 430 cycles	Thin Film A	-3,36 %	Average change in resistance values
		Thin Film B	0,16 %	Average change in resistance values
Thermal shock test	Temperature range -55°C...+125°C Duration 50hrs	Thin Film A	2,19 %	Average change in resistance values
		Thin Film C	1,70 %	Average change in resistance values
		Thin Film B	0,70 %	Average change in resistance values
TCR	Temperature range -45°C...+125°C	Thin Film A	227	ppm / °C
		Thin Film B	-60	ppm / °C
	Temperature range +22,4°C...+120°C	PTF paste A	-408	ppm / °C
		PTF paste B	-406	ppm / °C
Hot storage test	Temperature +120°C Duration 1 week	PTF paste A	-0,14%	Average change in resistance values,
		PTF paste B	-0,71%	measured at +22,4°C
Solder test	350 °C for 5 seconds Solder Iron (50w)	Thin Film A	0,20 %	Average change in resistance values
		Thin Film B	-0,02 %	Average change in resistance values
	260 °C for 5 seconds, solder dip	PTF paste A	-0,70 %	Average change in resistance values

Perhaps the strongest material dependency is in the ESD (Electro Static Discharge) test. Figure 2 illustrates the ESD endurance ability of different thin film materials. As can be seen, best materials can stand voltages up to 6kV, as some materials stands practically nothing as they fail already with the first 200V pulse. We were able to find out that issues like increased material thickness and increased resistor surface area improves the ESD endurance. Laser trimming e.g. decreases ESD endurance. Tests were carried out following IEC-61000-4-2 Human Body Model Standard. The requirement was set to level 1: 2kV contact discharge.

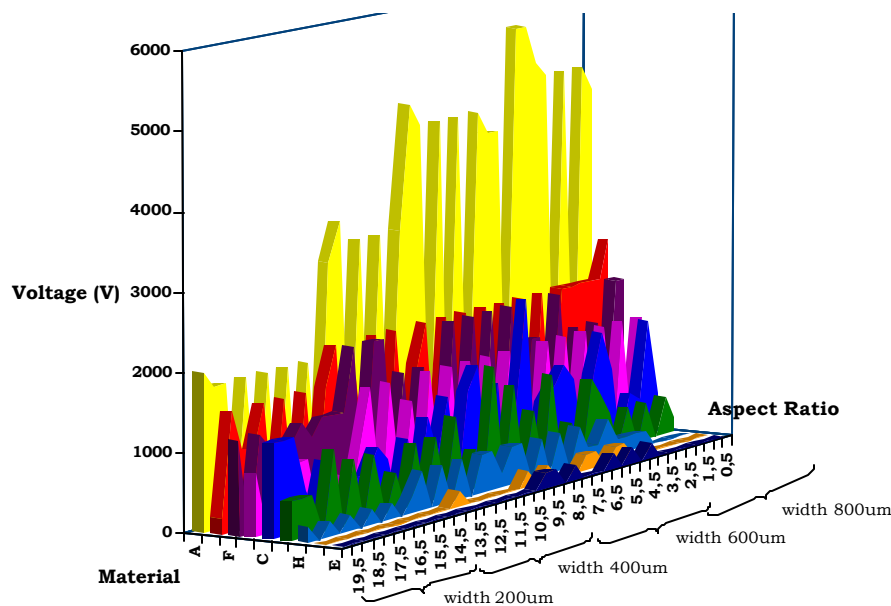


Figure 2 - ESD Endurance of Thin Film Embedded Resistors. Z-axis Gives the Maximum Voltage that Resistor is Able to Withstand without Change in Resistance

Embedded Active Components

The interest to embed active component has been increasing during past few years. One of the main reasons for this is the demand for higher packaging density and better electrical performance. In Integrated Module Board (IMB) technology the active components are embedded inside PCB or other organic substrate structure using normal PCB manufacturing process (Figure 3). The technology enables manufacturing of high density and low cost electronic modules for advanced consumer electronic applications.⁴

Compared to traditional PCB manufacturing and SMA assembly process flows, the IMB manufacturing flow is more sophisticated and shorter. The IMB process is odorless and therefore completely lead free process. The interconnection between the IC and the PWB is pure metallic and there is no intermetallic compounds formed between the bump and the conductor. These allow good reliability and electrical properties. A cross section picture from IMB interconnection is presented in the Figure 4.

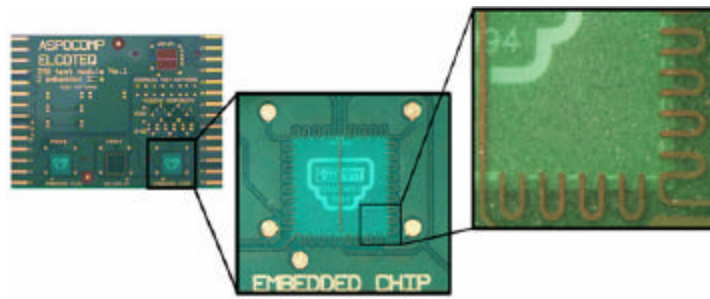


Figure 3 - IMB Test Board with Two Embedded IC's

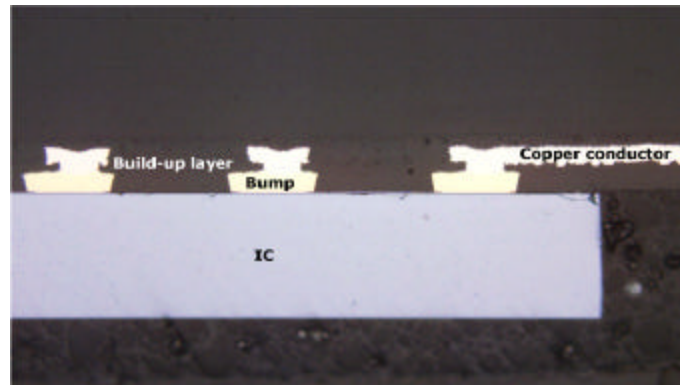


Figure 4 - Cross Section from IMB Structure

IMB Manufacturing Process

In current IMB process the components are embedded inside cavity in the PCB core layer. The components are aligned and placed inside the core layer using high accuracy flip chip bonder. After bonding the cavities are filled with molding polymer. On the next phase the build-up layers are pressed and laminated on the both surfaces of the core layer and the microvias are fabricated using UV-laser. The outer layers are manufactured and microvias are metallized using semi-additive process with pattern plating process. All components are contacted simultaneously. The manufacturing is done in large panel sizes. The outer layers are manufactured in Aspocomp Salo-plant using multilayer HDI PCB manufacturing process that is optimized for IMB process. A simplified manufacturing process flow is shown in Figure 5.

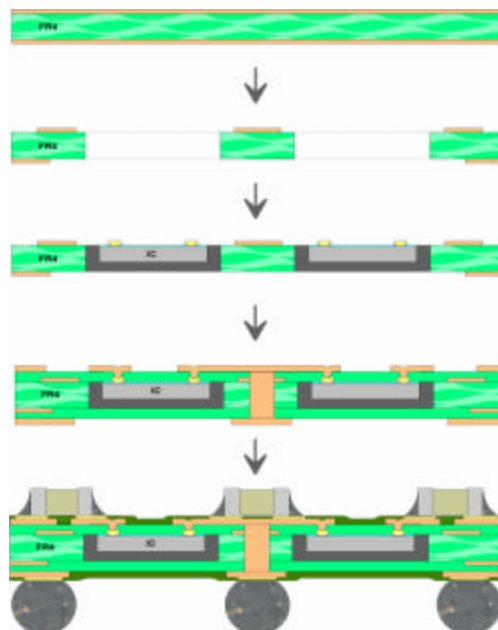


Figure 5 - IMB Manufacturing Process Flow

High Frequency Properties

The continuously increasing operating frequencies are making the standard circuit design more and more challenging. As there is only two surface layers available for the component placement, the signal routing will become very complex. There is not that much free area available in those surface layers, and the signals has to be routed via innerlayers and between top and bottom layers. This means that the signal traces are relatively long. As the inductance of a signal trace is directly proportional to the length of the trace (and inversely proportional to the width of it), the embedded resistor technology offers attractive improvements. If we are able to use embedded resistors, we have the freedom of relocating the resistors in the “component-free” innerlayers. Those layers may act as a ground or signal layer so we have to be careful in the design process, but usually we are able to re-design the work so that the length of the signal traces will decrease markedly.³

Shortening the signal traces will improve high frequency behaviour in other ways as well (Figure 6). The re-location could help us to get rid of some parallel-oriented lines, which would again decrease both the capacitive and inductive decoupling. Also the crosstalk should be minimized if we are able to get rid of the closely located signal traces.

We have performed some FDTD (Finite Difference Time Domain) –simulations to the embedded resistors using APLAC simulation tool. Prior to the simulations, we have characterized all the details of the system. This means the geometries of embedded resistors’ and its surroundings’, as well as the other properties, like dielectric constant etc. We have used these details to perform electromagnetic simulations to the structures, and to establish S-parameters to the resistors, which we have again used to find the equivalent circuits in question.

Based on our simulations, embedded resistors seem to have quite good high frequency properties. Figure 8 illustrates the S21 magnitude parameters for two 10 Ω resistors (Figure 7), one is a discrete and another is an embedded resistor. As can be seen, the signal damping does not start until around 2 GHz, and the behaviour is quite similar for both embedded and discrete resistor. The embedded resistor signal gain is even little bit better than the discrete version. This is very promising result as the signal routing has been identical in both cases. As discussed earlier, theory predicts shorter signal lines for the embedded version, which should again improve its high frequency properties.³

Laser trimming will maintain the basic properties of embedded resistors, but what we will see is some increase of parallel resonance. The trimming cut type seems not to have any impacts. Figures 9 and 10 shows the S21 magnitude and phase for two different trimmed resistors, first one is trimmed using a “L-cut”, and the another one is trimmed using a “plunge cut”. As can be seen, there is no difference.

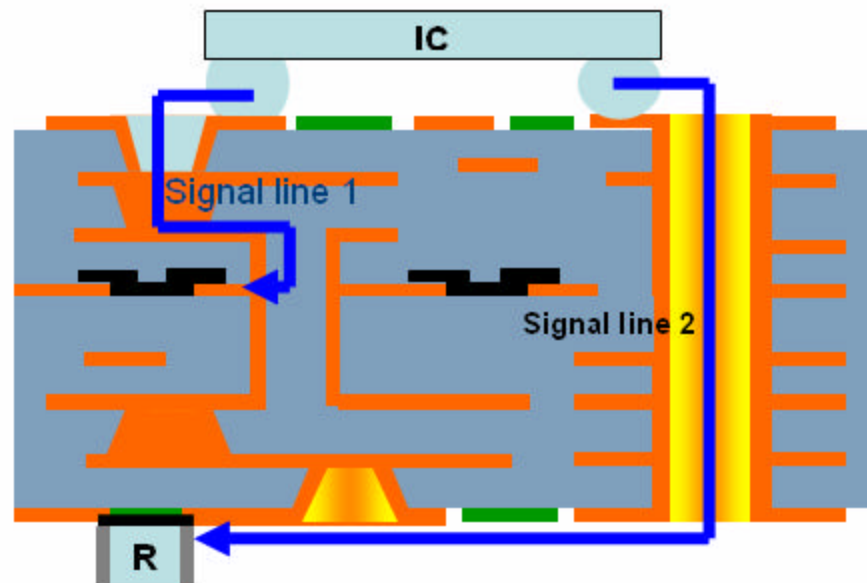


Figure 6 - In Many High Density Applications Embedded Resistor Technology Enables Markedly Shorter Signal Lines (Signal Line 1) than the Conventionally Routed Signal Lines (Signal Line 2)

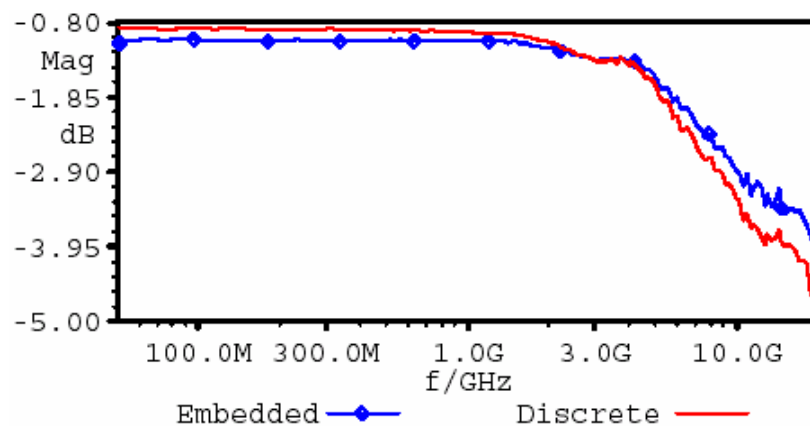


Figure 7 - S21 Magnitudes for A 10 Ohm Embedded Resistor and for a 10 Ohm Surface Mount Resistor (Simulation Tool: APLAC)

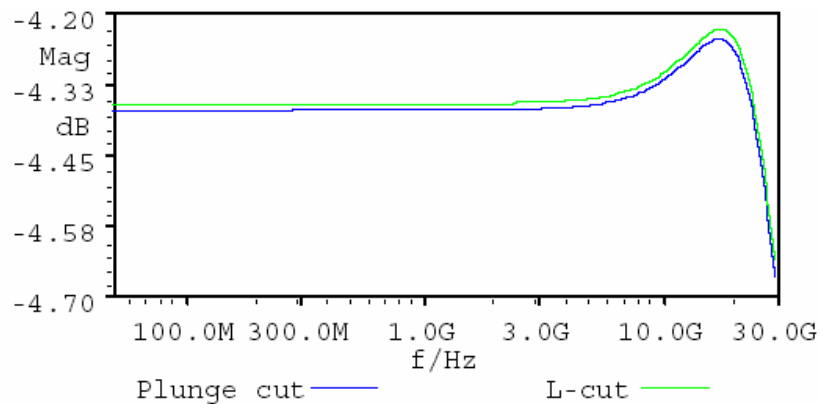


Figure 8 - Laser Trimming Cut Type Does Not Have Any Impact To The S21 Magnitude Types

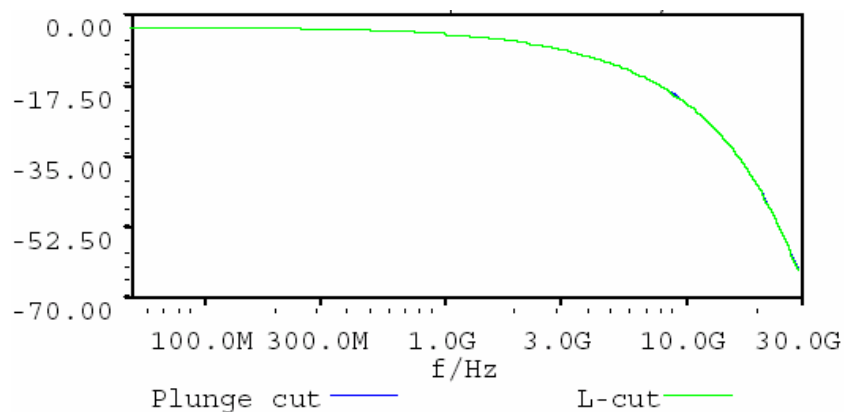


Figure 9 - S21 Phase Is Identical To Embedded Resistors Trimmed With Different Cut

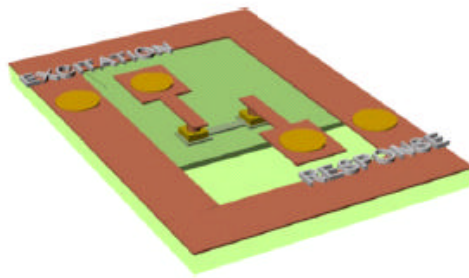


Figure 10 - Structure Used To Measure The Electrical Properties Of The IMB Interconnection.

The electrical behavior of the embedded active components using IMB technology was analyzed from 50 MHz to 20 GHz. Network analyzer was used to measure the attenuation and phase-shift of the signal passing through two interconnections and signal line in the test IC. The structure was modeled and the two-port s-parameters were plotted using the APLAC circuit simulation software.

According to the measurements the attenuation in the IMB structure was less than 0.7dB though the measured frequency range. The result shows that the electrical behaviour of the IMB interconnection is very good. Comparisons to the ACF flip chip interconnection and a wire-bonded COB shows the advantages of the IMB interconnection. The short interconnection length in the IMB structure makes the structure ideal for high-frequency applications. The small dimensions yield extremely small parasitics in the equivalent circuit describing the contact's electrical behaviour.

Summary

The functionality increase and size reduction are not the only challenges for future HDI PCBs. The increasing operating frequencies will play a more important role, and we have demonstrated that this issue can be solved as well. Embedded passive and active components do have good high frequency properties. The embedded technology is coming, not all at once, but application by application. The one important parameter in the embedded technology is the understanding the yield, it must be measured and managed in order to make the production of embedded passives economical and successful. Embedded technology can offer significant benefits of size, cost, performance and reliability for the suitable designs. We can offer the tools and knowledge to our customers. By close and effective co-operation already in the early face we can find the best packaging solutions.

References

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