Embedding components within PCB substrates

Max Clemons, Altium - March 19, 2014

Continued pressure for electronic devices that provide greater functionality in ever-smaller form-factors is not only providing the driving force behind developing smaller surface-mount components and semiconductor geometries, but is also fueling another trend that sees passive and active components being embedded within PCB substrates.

It is a trend that has a significant impact on the entire electronics supply chain, a challenge that suppliers at every stage are now striving to meet. Making best use of these developments falls to the design engineering team, who now need access to design automation tools that can offer greater flexibility in the way PCBs are conceived and created.

The design rules of this new paradigm present their own challenges and it is here where EDA tools vendors are now focusing their development efforts, in order to enable more OEMs to gain competitive access to this enabling and evolutionary capability.

Components

There are essentially two methods for embedding components into a substrate: formed or inserted. The former effectively uses patterns of copper plating and resistive thin film to create passive (resistive, capacitive or inductive) components on an embedded (or surface) layer. The latter is the more evolutionary, as it allows discrete components, bare die or even modules to be placed below the surface of the substrate.

There are many benefits to this and perhaps most prevalent is the greater component density it offers. An important aspect of this is the increased need for passive components, particularly capacitors which are needed in direct response to higher operating and signal frequencies. This has given rise to a trend to stack components vertically in order to minimise track lengths. Texas Instruments recently brought a 500mA step-down DC-DC converter to market using this method, to create a module measuring just 2.3mm by 2.0mm and just 1.0mm high.

Component manufacturers must constantly meet demand for new packaging options when bringing products to market, and the widespread use of surface-mount technology (SMT) particularly in passive components lends itself well to embedding components into PCBs. As SMT profiles continue to shrink, these same parts can now be mounted within or directly alongside a die embedded within a PCB; the 01005 (0402) package, for example, measures just 0.4mm by 0.2mm and can be as little as 0.15mm high.

However the method used to provide connectivity introduces further requirements. There are essentially two options here; connections formed with traditional soldering, or using copper vias. When solder is used, general-purpose tin plated multilayer ceramic capacitors can be used, but this
comes with a risk when embedding; secondary heating (when mounting SMTs on the surface, for
example) can cause the solder paste to reflow around the embedded component and introduce
possible failure.

To overcome this, the industry is beginning to displace soldering embedded components with
connectivity through copper vias, but while this scenario avoids the issue of solder reflow, the
components electrodes also need to be copper (as opposed to tin) in order to guarantee good
connectivity. As a result, the industry is now producing SMT devices with copper electrodes, such as
the GRU series introduced by Murata, which are intended specifically for embedding.

**Manufacturing**

In a traditional workflow, the manufacturing stages are often discrete; the bare board is fabricated
before being passed to assembly, where component placement machines are used to populate the
PCB.

In the embedded component paradigm this changes; these stages are no longer discrete, as
components now need to be placed within the PCB while its being fabricated. This presents
challenges for both the PCB industry and the manufacturers of production equipment.

Components that are embedded within the substrate are placed within a cavity, either during or
after the PCB substrate is fully formed; if the component can be placed after the PCB is complete the
cavity is typically open on the surface. If the component is encapsulated within a multilayer board,
the component is completely embedded and must, therefore, be placed by the PCB manufacturer,
which is creating a new market opportunity for SMT placement machine manufacturers.

Correspondingly, SMT machine manufacturers must also now consider the demands of embedded
compONENT placement. Often the cavity will offer very tight tolerances, perhaps as little as 20m,
which creates a need for greater accuracy with SMT placement. For example, the self-alignment
effect of solder paste can overcome a level of inaccuracy, but this is not the case with embedded
components.

In addition, the force with which components are placed needs to be more closely controlled;
damage to surface-mounted SMT components caused during placement can be found through visual
inspection, but embedded components are typically not visible and so any fractures incurred could
render an entire board faulty. Additional thermal events, such as reflow soldering on surface-mount
components, can also compromise the integrity of embedded components.

Suppliers of manufacturing equipment are now fully involved with the standards and best practices
emerging to ensure embedded components will continue to benefit the industry at both a functional
and commercial level.

**EDA Tools**

The electronics industry has successfully adopted the concept of embedded active components to the
point where it is becoming mainstream. Although pioneered by large-volume OEMs targeting
consumer devices, where every square millimetre is valuable real estate, support for smaller design
teams has increased in recent times, enabling OEMs of all sizes to exploit the benefits of embedded
components.

This support comes predominantly from EDA vendors; the latest release of Altium Designer (Version
14), for example, introduces advanced features for defining and implementing cavities in PCBs to
support embedded components.

More PCB fabrication flows can now accommodate embedded components through cutouts and laser drilling, as shown in figure 1. In order to exploit this capability, Altium Designer14 (AD14) supports a Region attribute called Cavity Definition, which associates a Height to regions, and allows components to be placed on any signal layer.

![Region Definition in AD14](image.png)

Fig. 1: A PCB fabrication flow that accommodates embedded components.

As well as being completely embedded, a components cavity may also extend to the edge of the PCB and therefore be open on one side. This can be particularly useful for embedding SMT LEDs in a board, for example. Figure 2 shows a cavity for an SMT LED in a round PCB, designed using AD14.
Fig. 2: Designing a cavity for an SMT LED in a round PCB.

By editing a components properties, the layer can be defined as any internal layer, while the orientation of the embedded component will be defined by the orientation for that layer (although this can be overridden by enabling the Flipped on Layer checkbox).

When a component is embedded in this way, Altium Designer 14 automatically creates a Managed Stack, which defines the board structure in the Z plane. There are now several methods for embedding active components open to developers:

Integrated Module Board (IMB); Embedded Wafer Level Package (EWLP); Embedded Chip Build Up (ECBU), and Chip in Polymer (CIP). The last process allows thin wafer packages to be integrated directly into build-up dielectric layers, rather than using cavities drilled or routed into the core material, which also supports multilayer FR-4.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Name</th>
<th>Material</th>
<th>Thickness</th>
<th>Constant</th>
<th>Rigid</th>
<th>Flex</th>
<th>Cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Top Paste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Top Overlay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Top Solder</td>
<td>Solder Resist</td>
<td>0.010mm</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Top Layer</td>
<td>Copper</td>
<td>0.036mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Dielectric 1</td>
<td>FR-4</td>
<td>0.320mm</td>
<td>4.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mid-Layer 1</td>
<td>Copper</td>
<td>0.036mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Dielectric 2</td>
<td>FR-4</td>
<td>0.320mm</td>
<td>4.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Dielectric 4</td>
<td>Polyimide</td>
<td>0.010mm</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Mid-Layer 2</td>
<td>Copper</td>
<td>0.036mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Dielectric 3</td>
<td>Polyimide</td>
<td>0.012mm</td>
<td>4.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Bottom Layer</td>
<td>Copper</td>
<td>0.036mm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Bottom Solder</td>
<td>Solder Resist</td>
<td>0.010mm</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Bottom Overlay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Bottom Paste</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
An important aspect to ensuring success when designing with embedded components includes communicating effectively with the PCB fabricator, and Table 1 outlines the recommended documentation that should be provided to the PCB fabricator, along with the design files.

While embedded components have been used for around 10 years by large OEMs in high-volume consumer applications, their availability and support is increasing throughout the electronics supply chain. This, in turn, is creating new opportunities for OEMs of all sizes, targeting a range of vertical markets, who can now exploit their advantages.

Design engineers represent the interface to this supply chain, and EDA vendors provide the tools to make that interface as seamless and effective as possible. Through adding greater support for designing PCBs using embedded components, Altium continues to enable effective electronic product design at every level.

Max Clemons is Application Engineer at Altium - [www.altium.com](http://www.altium.com)

*This article originally appeared on EE Times Europe.*