BENEFITS OF EMBEDDED RESISTORS - OUTLINE

• Drivers for the technology
• Introduction to different technologies
  • Thin film and PTF
• Space savings
• Improved high frequency performance
• Reduced cost
WHAT IS AN EMBEDDED RESISTOR?

- Embedded resistor is a resistor that has been fabricated into the innerlayer of a printed wiring board.
DRIVERS FOR EMBEDDED RESISTORS (1/2)

- Space limitation
  - Size of electronic equipment is getting smaller and functionality is increasing
    - By embedding the resistors we can increase functionality and/or decrease the size of the board
- Parasite elements
  - Operating frequencies and circuit densities are increasing
    - Using embedded resistors we can improve the circuit’s performance
DRIVERS FOR EMBEDDED RESISTORS (2/2)

- Reliability
  - Using embedding technology we can get rid of the solder joints
- Cost
  - In right applications we can create cost saving to OEMs
THIN FILM – MATERIAL CHARACTERISTICS

- Ultra thin
  - 0.04 µm...0.4 µm
- Three major solutions
  - NiP resistive alloy is electrodeposited on a Cu foil; continuous “roll-to-sheet” electro-chemical plating
  - NiCr or NiCrAlSi alloy are sputtered on a copper foil
  - Pt + doping is coated using Combustion Chemical Vapor Deposition (CCVD) -method
THIN FILM - PROCESS

1. Resistive material is plated on a copper foil.
2. Foil is laminated to form an innerlayer core.
3. Photoresist is laminated, exposed and developed.
4. Copper is etched, resistive material is revealed.
5. Resistive material is etched using specific chemistry.
6. Photoresist is stripped.
7. (Length definition) Another photoresist is applied, exposed and developed.
8. Revealed copper is selectively etched.
9. Photoresist is stripped.
THIN FILM – SUMMARY

• Easy to fabricate
• Limited in resistance range
  • Very high values can not be embedded
• Good reliability properties
• Cost is high
⇒ Best technology for high-end products with relatively low volumes
PTF – MATERIAL CHARACTERISTICS

- Screen printable paste (PTF = Polymer Thick Film)
  - Printed thickness 10µm...20µm
- Carbon powders with polymer chains
  - Curing in convection oven or in infra-red oven
FABRICATION OF PTF EMBEDDED RESISTORS

- Standard innerlayer fabrication is performed to form the circuitry

- Termination pads are revealed via photoresist imaging

- Pads are plated, typically with silver, photoresist is stripped

- Paste is applied and cured
PTF – SUMMARY

- Easy to fabricate
- Very wide resistance range
  - All the values can be embedded
- Reliability is good, but worse than with thin films
- Cost is low

⇒ **Best technology for high volume products with tight cost frames**
⇒ **This is our recommended technology**
OTHER MATERIAL POSSIBILITIES

Ceramic thick film
• Very stable resistors
• Complicated process
• Not commercial today
⇒ **Best material for high-end products**

Plated thin film
• Easy process
• Limited sheet resistivity
⇒ **Best material for special applications**
TRIMMING

Using laser trimming we are able to achieve tight tolerances

- Laser ablates resistive material and simultaneously measures resistance
- ±1% or better right after trimming

**Resistance value distribution**

- Post-trimmed
- Pre-trimmed

**Deviation from target (non-linear axis)**

- Frequency
SPACE SAVINGS
SPACE SAVINGS (1/2)

- Typical areas that surface mount resistors occupy from the PCB surface
  - 0805: 7,5 ... 9,5 mm²
  - 0603: 4,5 ... 6,0 mm²
  - 0402: 2,0 ... 3,5 mm²
  - 0201: 0,7 ... 2,0 mm²

Test Case
- One specific design contained 500 surface mount resistors that were able to be embedded, half were 0805 and half 0603.
  - We were able to release 3600 mm² from the PWB surface
    - 13% of the board area
      - Board size was decreased
      - We were able to have more boards up per panel
      - Routing density decreased
SPACE SAVINGS (2/2)

- Releasing PCB surface area has many benefits
  - We can make smaller boards
  - We can have more boards up per panel
    - Cost savings
  - We can add more components (add functionality) into the same size of board
  - We can decrease the routing density
    - Improve manufacturing yields

The possible benefits of the space savings are always application dependent
HIGH FREQUENCY PERFORMANCE
IMPROVED HIGH FREQUENCY PERFORMANCE (1/2)

• As we are able to re-locate the resistors into the innerlayers of a board we have the freedom to place them directly where they are needed.
  • We are able to decrease the length of the signal traces
    • Inductance is decreased
• The routing density in the innerlayers is usually much lower than in the surface layers
  • We are able to use wider signal traces
    • Inductance is again decreased
  • In some cases we are able to get rid of closely located parallel-oriented lines
    • Capacitive and inductive decoupling are decreased
    • Cross-talk is minimized
IMPROVED HIGH FREQUENCY PERFORMANCE (2/2)

- In addition to what the theory predicts, real life measurements demonstrates the improved properties in the S21-parameters.
- These tests do not include any decreased signal traces etc. Only the effect of resistor type is measured.
COST SAVINGS
Almost always the PCB cost will be higher when embedded, but in right applications the total system cost can be reduced

- The issues that are reducing the total cost are
  - Decreased discrete expenses
    - Actual component prices
    - Transportation, storage, handling, soldering, assembly, test and rework –expenses
  - Better production panel area utilization
    - More boards up per panel will distribute the total panel price per larger number of boards
COST SAVINGS (2/3)

Test case

- We converted conventional six-layer board to an embedded resistor PCB using PTF technology
  - No extra layers
  - Additional cost was introduced through investment depreciation, additional material and process cost, labour cost and decreased yield
  - We were able to decrease the size of the board so much that it was possible to have 12 boards up per panel instead of 10 up
  - Total cost was decreased through decreased assembly cost
# COST SAVINGS (3/3)

## Test case

<table>
<thead>
<tr>
<th></th>
<th>Price per panel (€)</th>
<th>Price per board (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Original price, 10 boards up per panel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Investment cost</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Increased labour expenses</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Increased process and material (inc. resistors) expenses</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Increased cost because of decreased yield</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal, Embedded price, 12 boards up per panel</strong></td>
<td>454</td>
<td>37,83</td>
</tr>
<tr>
<td>Decreased chip cost (0.1c*500)</td>
<td></td>
<td>-0.5</td>
</tr>
<tr>
<td>Decreased chip assembly+other cost (1.5c*500)</td>
<td></td>
<td>-7.5</td>
</tr>
<tr>
<td><strong>Total embedded price</strong></td>
<td></td>
<td><strong>29.83</strong></td>
</tr>
</tbody>
</table>
Ohmega-Ply® has been used for high-end products for years

- E.g. aerospace solutions
- Motorola has used PTF resistors in their products for some years
- More and more applications entering the markets all the time
Some examples:

- **Best thin films**
  - TCR: 80 ppm/°C
  - Thermal cycling (-40°C...+125°C 1005hrs): < 0,5% change
  - Thermal shock (-55°C...+125°C): <2% change
  - 85RH/85 °C: 1% change

- **PTF**
  - TCR: 400 ppm/°C
  - Reflow test (peak temperature +250°C): 3,5% change
  - Solder dip test (260 °C for 5 seconds): <1% change
SUMMARY

To meet the challenges of miniturization, new emerging technologies has to be adopted

Embedded resistors can offer:

• Size reduction
• Increased functionality
• Improved high frequency performance
• Improved reliability
• Cost reduction
SUMMARY

If you are interested, contact us. We have the capability of

• Evaluating the lay-outs
  • We can make the decisions which ones to embed and how
• Carrying out the whole design process
• Making complete cost analysis
  • PCB cost and the overall system cost
• Fabricating the boards

We also have embedded capacitor capability
THANK YOU FOR YOUR ATTENTION!

For more information, please

• Visit us in B1.475

Or

• Send me email to kimmo.perala@aspocomp.com