As originally published in the IPC APEX EXPO Proceedings.

# Selective Soldering for Interconnection Technology Used in Enterprise Communication Apparatuses

Mark Woolley, Wesley Brown, and Dr. Jae Choi
Avaya Inc.
1300 W 120th Avenue
Westminster, CO 80234

**Abstract:**

At times, wave soldering or reflow involving the entire assembly are not applicable for soldering of components. Selective soldering techniques vary widely in their ability to produce high quality, reliable electrical and mechanical connections. Much of the variation occurs because the selective soldering techniques heat the pads and the materials surrounding them unevenly. It is necessary to heat the pads, contacts and solder to a temperature sufficient to melt the solder and form a good intermetallic layer at both interfaces with the solder, while at the same time not over heating and damaging the PWB and nearby components. In many cases, the heat source is from one side of the connection only which can result in a severe thermal gradient through the solder connection and within the components. The construction of the PWB itself plays a part in the heating of the structures to be soldered.

Newer, lead-free solders must be heated to higher temperatures than traditional tin-lead solders. Due to the differences in specific heat of the materials, the amount of heat energy necessary to raise the temperature and melt Tin-Lead solder can be significantly different from that of the commercial RoHS-Compliant solders used in today's assemblies. This is not a problem with reflow ovens where the heat energy is replaced as fast as it is absorbed and can be considered infinite. The heating of the assembly is driven by a temperature difference between the oven air and the components. However, in other selective soldering techniques, such as hot air or heating via a focused light beam, the amount of energy is limited and must be taken into account during the soldering process.

This paper evaluates three processes for selective surface mount soldering. A Xenon Lamp-based heating system, a hot air heating system, and a reflow oven heating system are compared for use with both RoHS and non-RoHS compliant solders. Pull strengths of the solder connections, and intermetallic thicknesses of the connections are used to evaluate the solder connections.

**Background:**

The higher melting temperatures of today's RoHS compliant solders are causing changes in the methods of selective soldering as well as reflow and wave soldering. RoHS-compliant solders have higher melting points which are closer to the thermal limits of many the components and materials. The increased heat exposure from soldering must not damage the materials on the board in order to ensure a reliable product. In some cases this has led to the adoption of different materials, such as FR-4 materials with higher glass transition ($T_G$) and degradation temperatures ($T_D$) and more stable polymers used in components.

Selective soldering is used when the total assembly cannot be subjected to the temperatures normally used for soldering such as reflow temperatures or the temperature of the solder wave. There may be several reasons for the need to selectively solder an assembly such as the presence of soldered components on the PWB, or the presence of components that cannot withstand the standard soldering temperatures. Selective soldering may also be used in cases where the entire PWB can be subjected to the additional heat during soldering, but it is preferred to not expose the entire board to an additional thermal cycle.

Industry has developed many ways to heat only a portion of an assembly to solder liquidus temperatures while maintaining a lower temperature in other areas. Protective coverings or shields may be used to shield portions of the PWB assembly, small diameter jets of molten solder can apply solder to particular areas of the assembly, or localized heating of an area using hot air or focused light may be used to solder connections, while allowing adjacent areas to remain below normal soldering temperatures.

Standard FR-4 materials can withstand soldering temperatures for a short time without significant degradation. However, long term exposure, or multiple exposures to these temperatures leads to degradation of the epoxy matrix surrounding the glass fibers and delamination of the layers. The damage to the FR-4 material can cause subsequent reliability issues through damage to vias and opening of channels between the epoxy matrix and the glass fibers. The former causes an open or intermittent connection between the layers in the PWB, while the later can result in catastrophic damage to the circuitry through the formation of a short by Conductive Anodic Filamentation (CAF).

The materials adjacent to the solder connections also can limit the maximum temperature and the methods used to form solder connections. As the temperature of a material is increased by the addition of energy, various materials' properties control how hot they get and how fast they conduct the heat away from the source. This restricts or eliminates some methods of selective soldering.

Most methods of selective heating apply energy equally to all materials within the selected area. This can result in uneven heating of the components due to conductivity (heat transfer) and the specific heat of the materials. Copper pads attached to a large copper plane may remain below the temperature for effective soldering while nearby isolated solder pads overheat and peel from the FR-4. The selective soldering system must maintain a balance in order to effectively solder connections while at the same time not overheat nearby areas.

A large PWB connector was chosen to perform the experiments. This connector has one-hundred connections to each side of the PWB. Both sides must be soldered. Figure 1 shows a view of the leads from this connector.

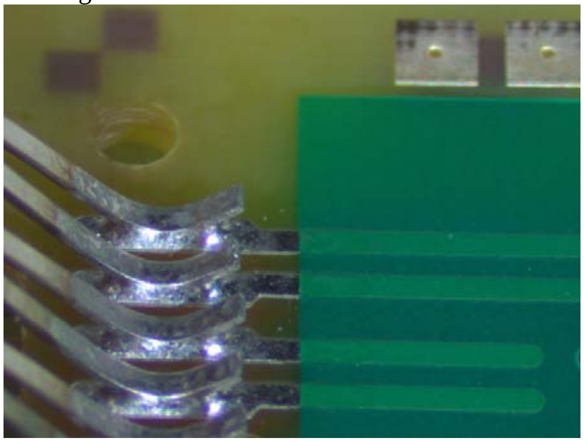

Figure 1
Leads from connector

**Cross Sectioning:**
Cross sections of the solder connections were performed by mounting the lead and PWB in epoxy, cutting through the solder connection using a diamond saw, and finally polishing the sample with successively smaller grit papers, finishing with 2400 grit paper. No etching was used to define the Intermetallic (IMC) region.

Without etching the sample after cross sectioning and polishing it, it is difficult to determine where the IMC starts and stops. However, we were able to verify the location of the using an elemental analysis technique known as line profiling. Figure 2 shows a secondary electron image with a line superimposed on it that the line profile in Figure 3 was taken from.

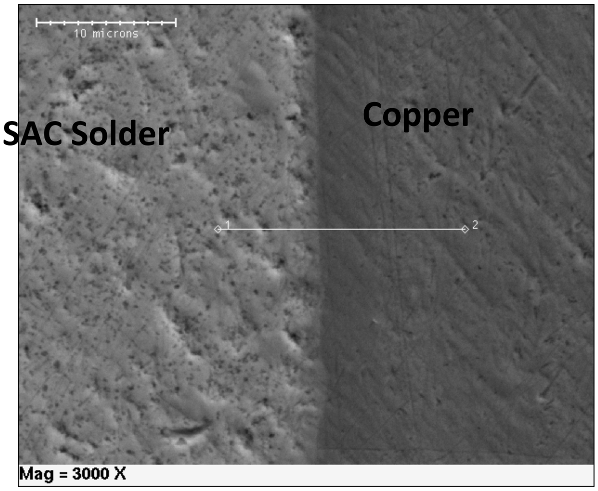

Figure 2
Secondary electron image of a typical cross section

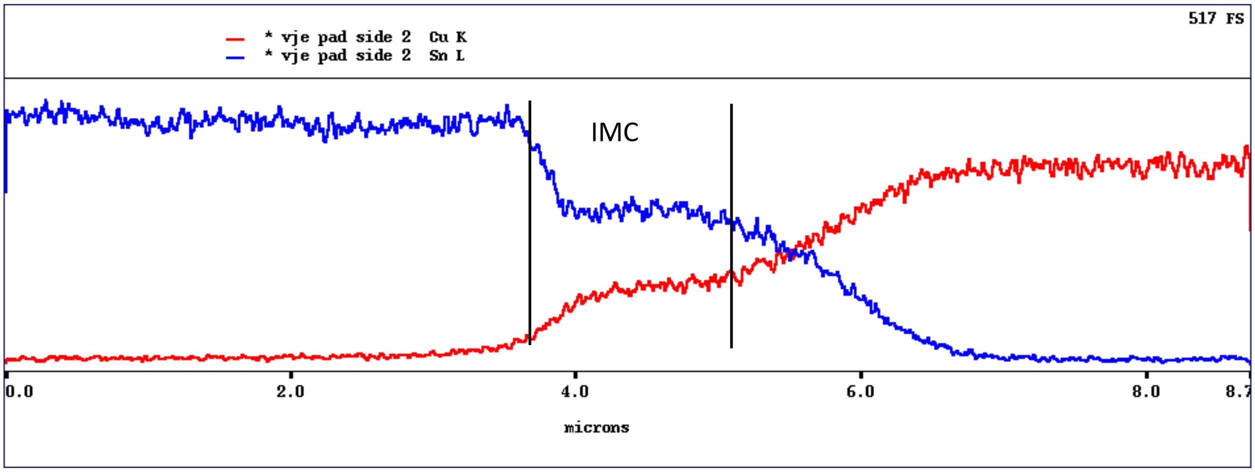

Figure 3
Line Profile corresponding to Figure 2
Copper (Red) – Tin (Blue)

A line profile is made by scanning the sample only along the line as noted in the SEM image, measuring and plotting the relative abundance of the elements along the line. The mixture of tin and copper in the IMC matrix is a fixed ratio. The thickness of the IMC can be measured using the line profile. As Figure 3 shows there is an abrupt drop in the amount of tin and a rise in copper at about 4.0 microns and a second change at about 5.7 microns along the scan line. In this particular sample the IMC is about 1.7microns thick.

The slope of the curve at the beginning and end of the IMC layer is due to the large diameter of the electron probe. The use of a smaller diameter electron beam would sharpen the edges of the layers at the expense of greatly lengthening the profile acquisition time.

**Pull Testing:**
Pull testing was performed in a modified manner due to the geometry of the connections. The pins of the connector are soldered to the board approximately 30°-60° from the flat plane of the board. The modification used pulls the solder connection apart at exactly 90°, similar to a copper adhesion peel test. In order to be mounted in the test fixture, small sections of each PWB and connector were cut out from the unit as a whole. Figure 2 shows the test setup used to pull the samples. The speed of the crosshead was 1.50 mm/s. The load cell used in the tests was a calibrated 125N (28.1 lb) load cell.

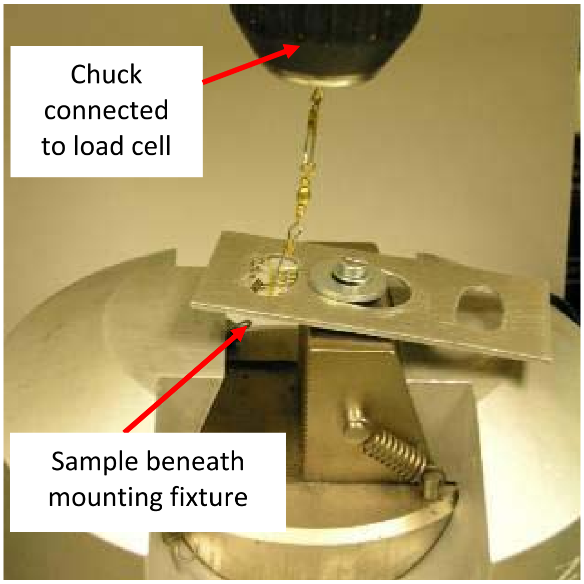

Figure 4
Pull Test Fixture

There are several different locations where the solder joint can fail during pull testing.  Depending on the strength of the intermetallic layers and the thermal properties of the area exposed to the selective soldering technique, some failure locations are more common than others.  If there are copper planes inside the FR-4 material directly beneath the soldering location, the most common failure location is the copper pad becoming detached from the PWB due to degradation of the FR4 epoxy.  In the absence of copper planes, the common failure locations are the solder-lead interface and bulk solder failure.

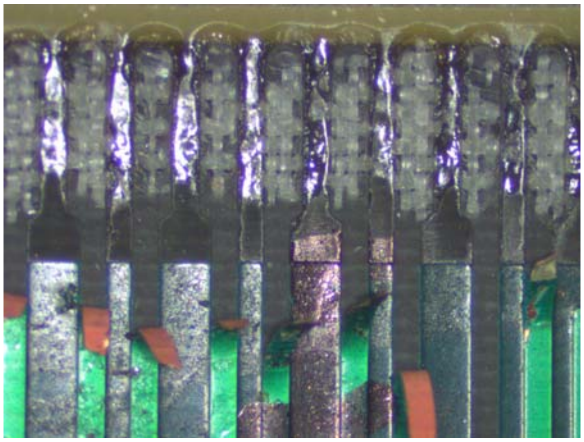

Figure 5
Copper pads detached from PWB during testing

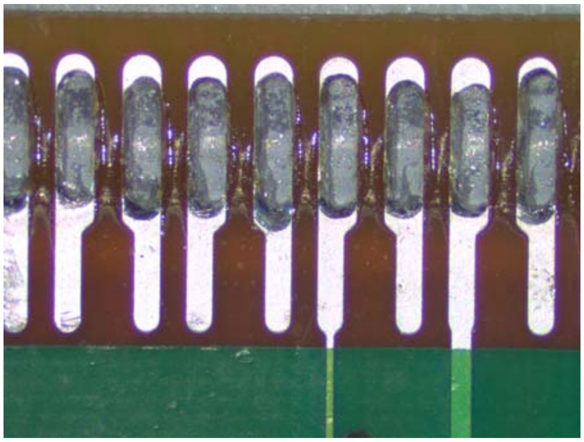

Figure 6
Failure location was primarily solder-lead interface

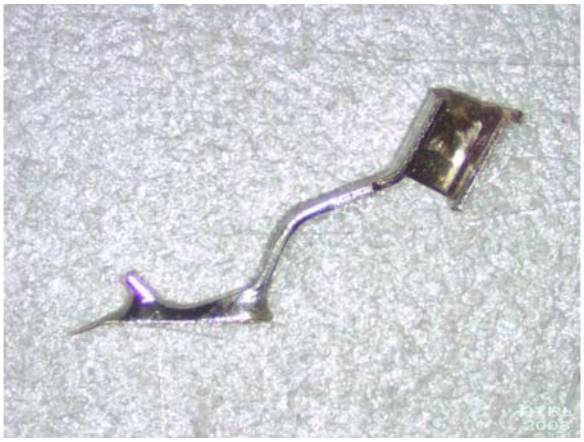

Figure 7
Typical pin with copper pad attached

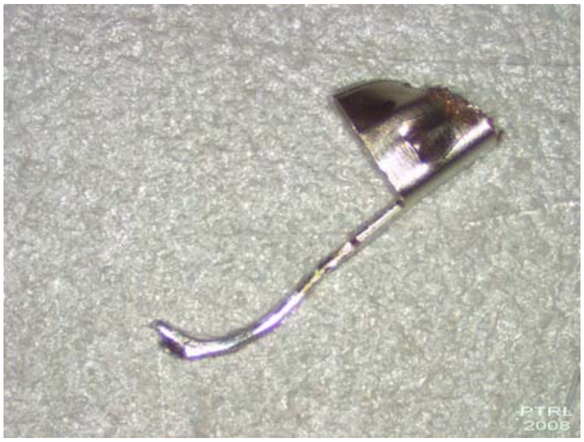

Figure 8
Typical pin with a solder-lead interface failure

**Light Source Heating:**

Infra-red or visible light can be used to effectively heat materials for soldering. A laser can also be used to heat the area to be soldered. This paper covers a process using a focused xenon light source. The diameter of the beam can be controlled by an aperture and by the degree of focusing in the soldering plane. The power output of the xenon lamp and the speed of the conveyor carrying the solder connections can also be varied to allow effective soldering of the connections.

It is important to note that this method of heating can reach temperatures far in excess of the maximum limits of the materials. The light source itself has no temperature. The light energy is absorbed by the materials and converted to heat, which raises the temperature. The only limit to temperature is the rate of convection in the material and the strength of the light beam. Different materials will absorb the energy at different rates. Shiny materials (pads, leads and solder) will reflect much of the energy, while dark, matte finished materials will absorb the most.

Solder and flux can be added during the heating process from a spool of wire solder, or solder paste can be screened and reflowed prior to selective soldering. One of the drawbacks to the light source method is spattering of the solder because the fast heating vaporizes the flux during heating causing it to explode. This can cause solder balls on the PWB. The vaporized flux will also coat the optics of the soldering system. The optics within the soldering area itself must be cleaned regularly to ensure that the beam energy at the solder connection remains constant and no energy is dissipated at the optical components. There is little or no preheating of the assembly by the light beam so thermal shock can easily occur, both when rising to the soldering temperature and when cooling back to room temperature.

The PWB material also absorbs light from the beam, causing it to heat. This effect is exacerbated by the presence of underlying copper planes which can change the pigmentation and the amount of light energy absorbed. This will cause the PWB to heat more or less during the soldering operation. Decomposition and charring of the PWB can occur if this effect is not compensated by an overall reduction in energy from the beam. The copper planes also heat up quickly due to the low specific heat value of copper, which can lead to the inside of the board remaining hotter than the components as the area cools. This action can cause delamination of the PWB material beneath the soldered connections.

The balance between the addition of energy to the area by the light beam and the temperature of the PWB and solder pads must be carefully maintained. The beam must still be able to heat the shiny copper pad and lead material above the liquidus temperature of the solder long enough to allow the formation of the IMC, without raising the temperature of the FR-4 beyond its degradation temperature. Without the formation of the IMC, a cold solder connection will form.

PWBs with and without inner copper planes beneath the connections were soldered using this method and submitted for solder connection analysis by cross section and by pull testing. The results were very different due to the degradation of the PWB caused by the dark copper planes buried within the PWB.

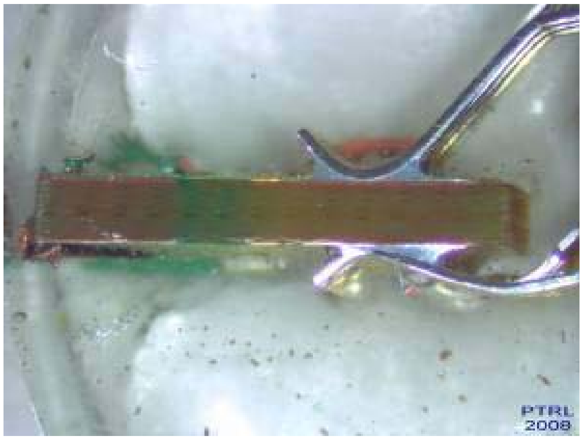

Figure 9
No copper plane beneath colder pads

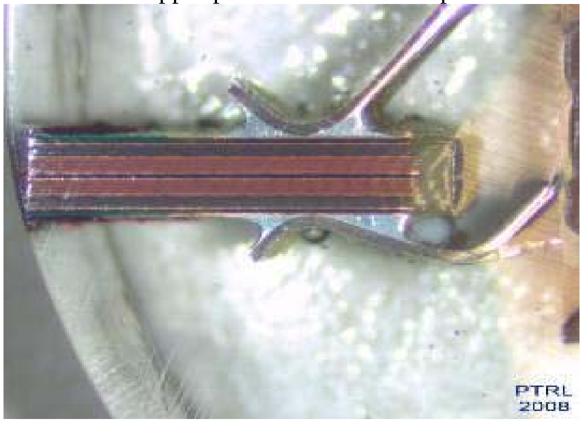

Figure 10
Copper planes beneath solder pads

**Table 1**
**Pull Strength and intermetallic measurements with light source heating**

| Sample | Solder | Copper Planes | Pull Strength (lbs) | IMC (µm) |
|---|---|---|---|---|
| Sample 1 | SN100C | No | 6.753 | 2.5 |
| Sample 2 | SN100C | No | 6.699 | 2.3 |
| Sample 3 | SAC387 | No | 5.717 | 3.6 |
| Sample 4 | SAC387 | No | 4.905 | 3.7 |
| Sample 5 | Sn:Pb | Yes | 4.470 | Not tested |
| Sample 6 | Sn:Pb | Yes | 3.921 | Not tested |
| Sample 7 | Sn:Pb | Yes | 3.563 | Not tested |
| Sample 8 | Sn:Pb | Yes | 2.625 | Not tested |
| Sample 9 | Sn:Pb | Yes | 2.381 | Not tested |

### Hot Air Heating:

A hot airstream has been used for a long time to rework selected components such as BGAs or components with a large number of leads. In general, air is heated beyond the melting point of the solder and directed at the area to be soldered. All materials within the airstream are heated and the material properties determine the rate of heating. The process used for this experiment heated and melted the solder and formed the solder connections within 50 to 60 seconds.

Among the variables that can be controlled are the temperature of the air, the amount of air flow, and the area of the shroud that limits the air flow to a specific region. There is a maximum temperature that the materials can reach. The temperature of the air that flows around the components to be soldered limits the temperature of the components within it. In order to provide enough heat energy quickly, the temperature of the air is higher than normal reflow ovens. Prolonged exposure to the higher temperature can degrade the FR-4 materials, so the hot air should only be used the minimum amount of time needed for providing quality solder connections.

**Table 2**
**Pull Strength and intermetallic measurements with hot air heating**

| Sample | Solder | Copper Planes | Pull Strength (lbs) | IMC (µm) |
|---|---|---|---|---|
| Sample A | SAC | No | 4.201 | <1.0 |
| Sample B | SAC | No | 4.174 | <1.0 |
| Sample C | SAC | Yes | 3.669 | 1.5-2.0 |
| Sample D | SAC | Yes | 3.115 | 1.5-2.0 |
| Sample E | SAC | Yes | 2.962 | Not tested |
| Sample F | SAC | Yes | 2.946 | Not tested |
| Sample G | SAC | Yes | 2.801 | Not tested |

### Reflow Heating (non-selective soldering):

A reflow technique is not really a selective soldering procedure since the entire assembly is heated to liquidus temperatures. The processing steps are incorporated into the standard reflow steps of paste screening and reflow. During this process, solder paste is screened onto the connector pads simultaneously as it is screened onto the rest of the PWB prior to component placement. The process flow is as follows:

1. Screen solder paste on the back side of the PWB including the assembly connector pads.
2. Place components on the back side – Do not place the connector.
3. Reflow the back side components in an oven.
4. Screen solder paste onto the top side of the PWB including the assembly connector pads.
5. Place components on the front side – Do not place the connector.
6. Reflow front side components in an oven.
7. Flux the assembly connector pads and place connector
8. Reflow both sides of the connector simultaneously.

Although this process seems more complex than the others, it fits well into the process line. The solder paste stencils are modified to apply solder paste to the connector pads on both the top and bottom sides of the PWB as well as to all component pads. After the solder paste on both sides of the PWB is reflowed and all components are attached, the connector pads are fluxed once again and the connector is placed with the lead on top of the solder on the pads. The final reflow re-melts the solder beneath the connector leads, wets the leads and completes the solder connection.

The downside to this process is that the PWB and the components are exposed to an additional reflow cycle. The final reflow cycle profile also has to be set differently than the previous ones due to the large thermal mass of the connector. So in addition to the extra heat cycle for the components, the final heat cycle peaks at a higher temperature stressing all components to a greater degree than in a selective soldering process.

Table 3
Pull Strength and intermetallic measurements with reflow heating

| Sample | Solder | Copper Planes | Pull Strength (lbs) | IMC (µm) |
|---|---|---|---|---|
| Sample 1 | Pb | No | 3.910 | 2.0-3.0 |
| Sample 2 | Pb | No | 3.276 | Not tested |
| Sample 3 | Pb | No | 3.264 | Not tested |
| Sample 4 | Pb | No | 3.251 | Not tested |

### Conclusion:

All of these selective soldering methods have the potential to perform well and produce quality solder connections. Each method has its drawbacks which must be balanced with the benefits. The method used to selectively solder connections to a PWB must be determined based on a number of variables. These variables include the geometry and mass of the components, and the composition of the materials surrounding the area to be selectively soldered. The expertise of the factory personnel also plays a part in the selection of the soldering methods.

Light Source Heating:

1. Efficient heating source; processing is quick
2. Several variables combine to determine the amount of heating
3. No upper limit to the temperature of the materials because the heat is generated within the materials, not directly by the light source
4. Pigmentation and finish of the materials plays a large part in the amount of energy absorbed by the materials

5. Heats rapidly resulting in thermal shock to materials.
6. Solder balling from vaporization of flux can occur
7. Optics must be cleaned regularly

Hot Air Heating:

1. Upper temperature limit is above degradation temperature of materials
2. Strict limits on the position and shape of the flowing air column must be maintained
3. Nearby components may need to be protected
4. Potential for thermal shock depending on geometries and material properties

Total Reflow Heating:

1. Additional thermal excursion above soldering temperatures
2. Thermal mass necessitates an increase in reflow temperatures
3. Additional processing steps necessary
4. Not always applicable because of components on assembled PWBs