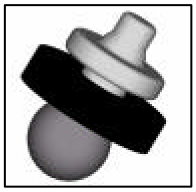
Application Note

September 2002

Application Guidelines For Surface-Mount Power Modules Using Column Pins With Solder Balls



This application note is intended to provide the user with the best information to date regarding the PCB (printed-circuit-board) mounting and assembly process of TEPS surface-mountable power modules that use Column Pins with Solder Balls. Users are cautioned to use this information as a guide only, and to use their own judgment in applying best manufacturing and assembly practices for specific applications.

1. Introduction

The Column Pin with Solder Ball (CPSB) is designed to provide compliant SMT attachment with the same pin-layout as the through-hole counterpart. It also has the ability to compensate for large coplanarity with the power module as well as for considerable non-flatness in the end assembly PCB surface. The CPSB is constructed from a solid copper column pin with an integral tin/lead (Sn/Pb) solder ball attached at the tip. The CPSB connectors are similar to the traditional I-leads or butt-leads, but are made much more robust with larger pin diameters and more solder at the tips, resulting in a more reliable connection. Figure 1 shows a picture of a TEPS (Tyco Electronics Power Systems) power module that uses the CPSB connectors, while Fig. 2 presents detailed sketches of the connector before and after reflow.

The connectors are inserted into the power module PCB by automated placement machines. The insulator, made of hard FR4 material, is designed to be the pick-and-place tab for vacuum placement. The insulator also serves as a shield in the end assembly reflow process that keeps the solder from wetting the module-side solder joint and exiting the attachment area.

The CPSB connectors are categorized by standoff height, which is the pad-to-pad distance from the power module PCB to the end assembly PCB, as shown in Fig. 2. The normal standoff height of 2.7±0.1mm (0.105" ± 0.005") is used with a pin of 1mm (0.040") base diameter. Another standoff height of 3.4±0.1mm (0.135" ± 0.005") is also available with a pin base diameter of either 1mm (0.040") or 1.5mm (0.060"). The solder balls are 1.8mm (0.071") in diameter in both cases.

2. Coplanarity Compensation Capability

Coplanarity is mathematically defined as lying or seating in the same plane. For SMD (Surface Mount Devices), lead coplanarity may be defined by one of the four descriptive schemes specified by JEDEC (the Joint Electron Device Engineering Council, JEP-95): no-datum bilateral and

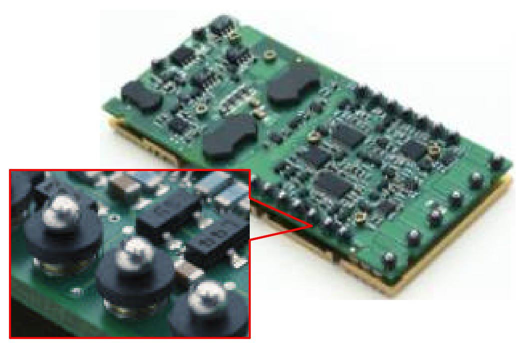


Fig. 1. Picture of a sample module with CPSB

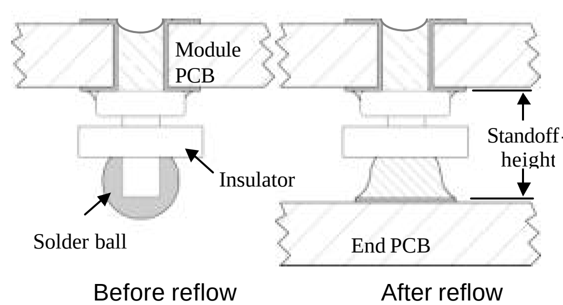


Fig. 2. Sketches of a CPSB connector before and after end assembly reflow.

unilateral, and datum bilateral and unilateral. The datum unilateral scheme, which is described as the distance between the lowest and the highest leads when the device rests on a perfectly flat surface as shown in Fig. 3, is the most widely used definition in industry.

Poor lead coplanarity may create solder wicking that could result in weak or even open solder joints. To ensure quality solder joints, coplanarity of SMT devices has to be kept under control. The most widely accepted coplanarity requirements are those established by JEDEC, which are primarily for traditional surface mount semiconductor components with small leads and small lead-pitches ≤1.27mm (0.050").

There is no applicable standard that specifically defines the coplanarity requirement for large devices like power modules. Traditionally, power module users tend to demand the same coplanarity as specified in the JEDEC standards. The power module manufacturers, however, have not been able to consistently meet those strict requirements because the size of the power modules and the leads are much larger than those of the traditional small SMT devices.

With CPSB connectors, the coplanarity problem is eliminated, thanks to their ability to compensate for coplanarity and non-flatness in the PCB. The solder ball on the CPSB connector has relatively large volume compared to standard stencil printing. Once molten, the solder easily fills in the gap between a pin and the end PCB, and forms a high-quality solder joint in spite of the coplanarity problem (as shown in Fig. 4). The amount of coplanarity compensation depends on the end PCB pad and stencil design, or the anticipated solder joint size. Figure 5 demonstrates the estimated coplanarity compensation capability of CPSB connectors with respect to the anticipated solder joint base diameter, assuming a standard 0.15mm (6-mil or 0.006") stencil printing. With the solder joint ranging from 2~3.8mm (0.080" ~ 0.150") in base diameter, the coplanarity that can be compensated ranges from 0.4~1.1mm (15 ~ 45 mils). In practical situations, the pad and stencil are so designed that the final solder joint is around

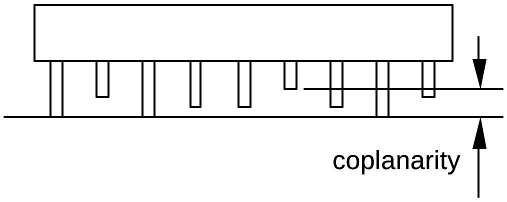


Fig. 3. Definition of coplanarity

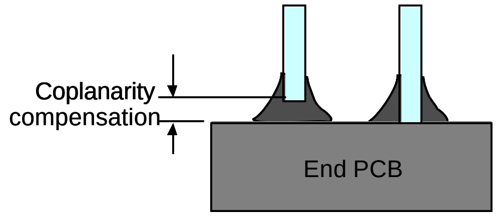


Fig. 4. Compensation for coplanarity

2.8mm (0.110") in diameter. Then the typical value of coplanarity compensation is about 0.6mm (25 mils), which far exceeds what is normally required for coplanarity of most SMT devices.

3. Solder Joint Robustness and Reliability

Solder Joint Mechanical Strength

Pull and shear tests were performed to determine the mechanical strength of the CPSB solder joints. The test samples were quarter-brick modules soldered to the test boards with a 0.15mm (6-mil) solder printing stencil. A total of ten modules were tested, each with eight CPSB pins 1mm (0.040") in diameter. Mechanical loads were applied onto the modules as shown in Fig. 6. The test results are summarized in Table 1.

Table 1. Pull and shear test results

	Attachment type	Average Kg/pin (Lbs/pin)	Std Dev Kg/pin (Lbs/pin)
Pull	Pad	7.26 (16.0)	1.09 (2.4)
Pull	Via	7.58 (16.7)	0.05 (0.1)
Shear	Pad	6.89 (15.2)	0.95 (2.1)

Shock and Vibration

Shock and vibration tests are widely accepted as standard measures of the robustness of a product.

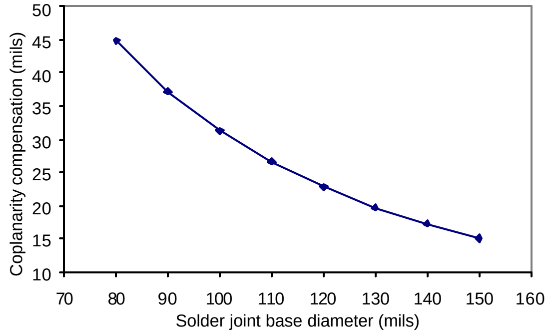


Fig. 5. Compensation for coplanarity

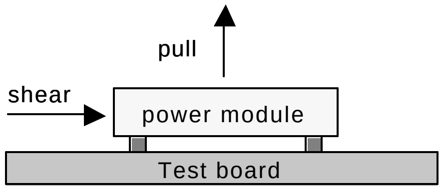


Fig. 6. Sketch of pull and shear test setup

We conducted three separate shock and vibration tests on surface-mount power modules with CPSB connectors as described below.

Test 1. Samples were quarter-brick modules that were soldered to test panels developed for the purpose of electrical and thermal performance verification. A total of three panels were fully populated with five modules each. The first and second panels were screen-printed using a 0.15mm (6-mil) stencil. The third card was not screen-printed and thus no additional solder paste was provided to the bond area for these five modules. After reflow, extruded aluminum heat sinks 25.4mm (1") in height were affixed to three of the test samples on Panel #2 and two of the test samples on Panel #3. The modules on Panel #1 did not receive any heat sinks.

Shock tests were performed per MIL-STD-202F, Method 213B. The test panels were subjected to one shock in each direction (forward and backward) along all three axes, for a total of six shocks per test panel. Each shock was 50g peak in 6ms, half sine. No visual defects were observed on any of the samples after the conclusion of the shock test.

The test panels were then mounted on a vibration table and subjected to vibration per Telcordia (previously Bellcore) GR-63-Core, Section 4.4.4. The level of vibration was 0.5g from 5 to 50Hz, and 1.5g from 50 to 500Hz. Four cycles were performed on each of the three axes. No visual defects were observed on any of the samples after the conclusion of the vibration test. A summary of the detailed test matrix and results is given in Table 2.

Test 2 is a 10g, 90-minute, random vibration test performed in a HALT (Highly Accelerated Life Test) chamber. Ten HW004A0A1-S units, five per test board, were tested. Vibration was controlled at 10g (rms) through the z-axis accelerometer mounted on the vibration plate. The test profile is shown in Fig. 7. All ten modules passed the 10g random vibration test without failures.

Test 3 is a mechanical shock (drop) test conducted per Telcordia (previously Bellcore) GR-63-Core, Section 4.3.2, Unpackaged Equipment Drop Test. The test was carried out with 25 HW004A0A1-S units. Each unit was suspended over a steel plate at a height specified in GR-63-Core (R4-43 Table 9) and dropped. This operation was performed on 5 surfaces of each unit. After each drop a visual inspection was done to determine obvious physical damage. When drop testing was completed functional testing was repeated. Each of the 25 HW004A0A1-S units was dropped from a minimum height of 100mm at five different drop attitudes. No physical damage to any of the components soldered to the circuits was observed. Retest of the units after the drop test revealed no electrical failures. The HW004A0A1-S units tested met the GR-63-Core requirement.

Temperature Cycling and Other Tests

Thermal cycling test was performed per MIL-STD-202F, method 107G. The purpose of the test is to ensure that extreme temperature changes do not damage the product. HW004A0A1-S test samples were used for the test. The test was performed for 300 cycles in the temperature range of -55°C to +125°C with a dwell time of 30 minutes at each temperature extreme. After 300 cycles, all units were inspected for physical damage and functionally tested. The acceptance criterion was that there be no evidence of physical damage or failure to pass electrical tests. All the HW004A0A1-S test samples have successfully passed the thermal cycling test.

Additionally, an operating life test was conducted at full load and at maximum operating temperature for 240 hours. Also performed was the THB (Temperature Humidity Bias) test at minimum

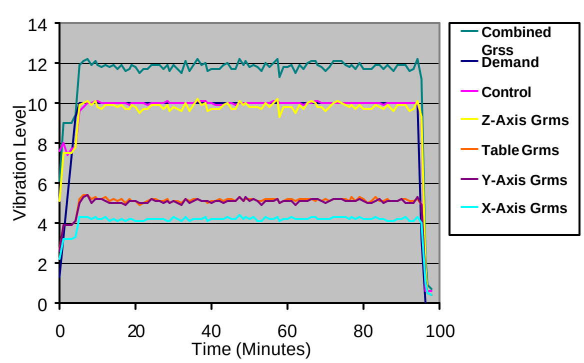


Fig. 7. Random vibration profile

load, 85% relative humidity and at maximum operating temperature. All test units passed these two tests without failure.

4. DESIGN LAYOUT CONSIDERATIONS

In order to achieve the required performance objectives for the power module, such as fast transient response, high efficiency and thermal and structural robustness, practical layout guidelines must be considered. This is of particular importance for surface mount modules, as opposed to through-hole modules, since connections to internal power layers must be made from an external pad.

For surface mount power modules with fast transient response, it is critical to minimize the loop inductance through application of practical layout guidelines. Since the modules must be soldered to pads on external layers of a circuit board, interconnection to an internal layer (power plane) is typically required. The required number and location of vias should be determined based upon electrical, thermal and reliability objectives. In practice, plating in through holes is not uniform and manufacturing variations in large lots may yield widely different via resistances than calculated estimates. Thus, it is pragmatic to use redundant vias whenever possible.

With the CPSB connectors, a solder-mask-defined pad of 2.8mm (0.110”) in diameter is used on a copper shape of sufficient size to accommodate the required number of vias. The distance between the vias and the pad must be at least 0.6mm (0.025”) from the pad to the solder-mask opening around the via, with 0.4mm (0.015”) of solder-mask between them. This is necessary to prevent solder from flowing into the vias from the CPSB.

The orientation of vias is essential. In practice, the vias should be biased in the direction of current flow. For example, if the load were to the left of the output pins, then it would be preferred to have all vias placed on the left side of output pins. For both electrical and thermal considerations, power planes should be situated as close to the top surface of the PCB as possible. When more than one pair of power planes are used, they should be interleaved to reduce leakage inductance and to improve transient response.

More detailed information on layout recommendations can be found in the TEPS Technical Note “Layout Guidelines for Surface Mount Power Modules” which will be available soon.

5. PICK-AND-PLACE OF POWER MODULES

Automated pick-and-place of a surface-mount power module can be very challenging due to its large size and weight compared to conventional surface-mount components. Depending on the

Table 2, Shock and vibration test summary

Test Unit	Stencil Thickness	Extruded Aluminum Heat Sink	Visual Mechanical Inspection	Electrical Functional Test Result
Panel 1, Unit 1	0.15mm (6 mil)	-	Pass	Pass
Unit 2	0.15mm (6 mil)	-	Pass	Pass
Unit 3	0.15mm (6 mil)	-	Pass	Pass
Unit 4	0.15mm (6 mil)	-	Pass	Pass
Unit 5	0.15mm (6 mil)	-	Pass	Pass
Panel 2, Unit 1	0.15mm (6 mil)	-	Pass	Pass
Unit 2	0.15mm (6 mil)	-	Pass	Pass
Unit 3	0.15mm (6 mil)	25.4mm (1 inch)	Pass	Pass
Unit 4	0.15mm (6 mil)	-	Pass	Pass
Unit 5	0.15mm (6 mil)	25.4mm (1 inch)	Pass	Pass
Panel 3, Unit 1	0	25.4mm (1 inch)	Pass	Pass
Unit 2	0	25.4mm (1 inch)	Pass	Pass
Unit 3	0	-	Pass	Pass
Unit 4	0	25.4mm (1 inch)	Pass	Pass
Unit 5	0	-	Pass	Pass

specific power module to be placed and the availability of pick-and-place machinery, three methods can be used to place a surface-mount power module: manual placement, vacuum nozzle and mechanical gripper.

Manual placement

Although manual placement is neither accurate nor economical, it has been the main approach in placing power modules due to the obvious advantages of simplicity and ease of use. This is especially true when suitable placement machines are not available. Usually, manual placement is limited to components with lead pitch greater than 2.5mm (0.100”). With lead pitch near or greater than 3.8mm (0.150”), all TEPS surface-mount power modules can be successfully placed manually.

Automated Placement with Vacuum Nozzle

TEPS surface-mount modules are designed for automatic pick-and-place. For automated placement with vacuum nozzles, one of three approaches is used: a designated pick-and-place device (such as the specially-designed label shown in Fig. 8), a special pick-and-place fixture (such as the cradle shown in Fig. 9), or an open area in the module’s circuit board allocated for the purpose of module pick-up.

Both the weight and size of a power module can be limiting factors in an automated assembly process. Traditionally, devices heavier than 20 grams or larger than 51mm (2”) could not be pick-and-placed by automated assembly equipment using vacuum nozzles. Advances in SMT equipment in recent times have extended their capability to handle heavier and larger devices. Special machines are available to deal with OFA (Odd Form Assemblies). Most standard mounting machines are also equipped with large diameter nozzles (up to 20mm, some with rubber tips or suction-cups) to handle devices that weigh up to 90 grams or measure up to 76mm (3”). In addition to weight and size, other factors that have to be taken into account in vacuum pick-up of power modules are: pick-up surface, center of gravity (CG) of the power module, vacuum level, nozzle tip configuration and pick-and-place motion control.

The effective pick-up surface is either a device that has a flat top surface, or a flat spot on the power module. The surface area has to be large enough to accommodate the proper vacuum nozzle that could be as large as 20mm in diameter. The pick-up point needs to be at or near the CG or center of gravity of the power module. Otherwise, the unbalanced moment of the module would require extra vacuum suction or a larger nozzle to prevent the part from falling or slipping.

Vacuum has to be at the highest level in order to handle heavy devices like power modules. Figure 10 shows the correlation of the minimum nozzle diameter vs. vacuum level for a 40-gram module. It indicates that with higher vacuum, a smaller nozzle can be used to pick-up the same part. This is extremely important for open-frame modules where a large pick-up spot is not always obtainable. For most standard placement machines, vacuum of at least 650~700 mmHg is recommended.

Nozzle tip configurations can impact the effectiveness of suction. For a given nozzle size and a vacuum source, different nozzle tip configurations result in various effective suction forces at the device to be placed. Nozzles have suction efficiencies ranging form 0.5~1.0, depending on the nozzle material and shape. The most commonly used nozzles are flat metal tip,

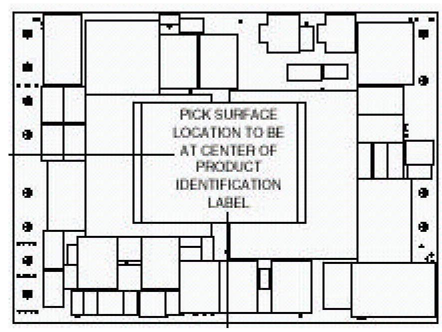


Fig. 8. Example of designated pick-and place device in TEPS power modules.

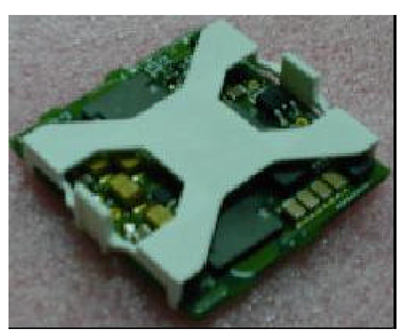


Fig. 9. Example of pick-and place fixture in TEPS power modules

tapered metal tip and rubber tip (or suction cup). Nozzles with rubber suction cup, which have high suction efficiencies, are recommended for placement of power modules.

Pick-and-place motion control includes linear speed and acceleration, and rotating speed and acceleration. For a given part, the higher the acceleration, the larger the nozzle needed to prevent the part from falling or sliding. This relationship is shown in Fig. 11. For most standard placement machines, reduced speed/acceleration is recommended. Full speed/acceleration may be achieved with special machines and nozzles that are designed to handle large and heavy devices.

Automated Placement with Mechanical Grippers/Chucks

With their larger size and weight, power modules fall into the so-called "odd-form" category. Most standard mounting machines are equipped with some type of mechanical chuck that has limited capabilities for large items. Usually, the openings of these chucks are not wide enough to hold some power modules, in which case special tools have to be custom-designed. Some advanced mounting machines are equipped with chucks that can handle parts as wide as 76mm (3").

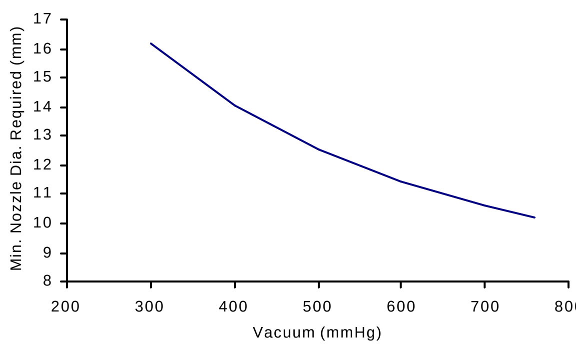


Fig. 10. Nozzle diameter vs. vacuum

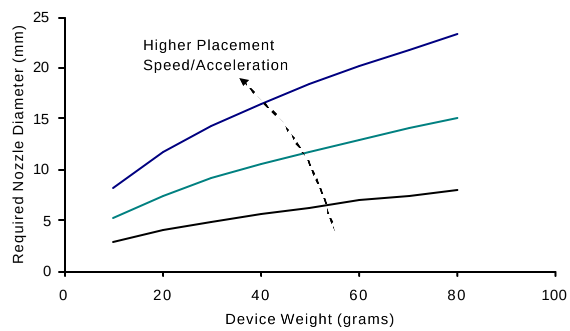


Fig. 11. Nozzle diameter vs. speed/acceleration

6. Solder Recommendations

Solder volume, one of the many parameters that directly impact the solder joint quality, is determined by solder thickness (stencil thickness) and solder area (aperture size). The correct amount of solder is dictated by component type and lead pitch. Although large in size and weight, power modules with CPSB connectors are self-sufficient in solder amount due to the attached solder balls. Therefore, special solder consideration is not required at the end assembly. Our experiments have shown that good solder joints can be achieved with stencil thickness from 0~0.3mm (0 ~ 12 mils). It is recommended that the user determine the solder printing based on the requirements of other devices and follow the standard SMT measures. A stencil of 0.2~0.25mm (8 to 10 mils) thick is common for most regular-pitch devices whereas 0.15mm (6 mils) or less may be needed for fine pitch packages.

7. Reflow Recommendations

TEPS surface-mount power modules are built with standard SMT components and assembly procedures. It is therefore advisable that all standard SMT guidelines are followed. Moreover, because they are large in size and mass, power modules heat up slower and more non-uniformly than typical SMT components. For that reason, special caution has to be exercised in reflow of power modules.

Reflow Oven

TEPS surface-mount power modules can be adequately soldered using convection or convection/IR technologies. But, characteristic reflow profiles must be developed for different reflow ovens. Pure IR (radiant infrared) without convection is not preferred due to the possible shadowing problem. Wave soldering, VPS (vapor phase soldering) and laser soldering are not recommended for reflow of surface-mount power modules.

Characterizing Reflow Profile

Reflow profile is not only product specific, but also solder paste dependent. It is therefore recommended that a reflow profile be characterized for the module on the application board assembly. The solder paste type, component, and board thermal sensitivity must be considered in order to form the desired solder joint. Parameters that are controlled in reflow profiling include: ramp-rate, preheat peak temperature, soak time, reflow peak temperature and time, cooling rate and duration. Considering the amount of mass to be heated in a power module, sufficient time must be allocated to ensure a reliable solder joint. Power module temperatures vary with many factors, including surrounding components, internal paths, and connecting paths. It is therefore very critical that the designated point be used to monitor the temperature. Figure 12 shows an example reflow profile.

Please refer to the appropriate data sheets of the particular power-module for more detailed reflow information.

8. POST-REFLOW CLEANING

Surface-mount power modules are compatible with most standard SMT cleaning processes. Please refer to applicable industrial standards for cleaning materials and procedures (such as J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies; IPC-CH-65A Guidelines for Cleaning Printed Boards and Assemblies).

For more detailed information concerning power module cleaning, please refer to TEPS Application Note "Board-Mounted Power Modules: Soldering and Cleaning" at

http://power.tycoelectronics.com/pdf_general.html

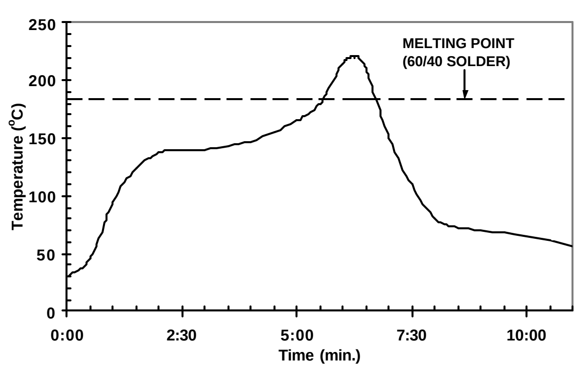


Fig. 12. Sample reflow profile

9. REPAIR/REMOVAL OF POWER MODULES

General guidelines for repair and rework of standard SMT devices apply to surface-mount power modules. Detailed removal procedures are outlined in IPC (The Institute for Interconnecting and Packaging Electronic Circuits) standard IPC-7711, Rework of Electronic Assemblies (February 1998).

Either a hot air device or a conductive tip can be used to remove a CPSB power module from the end PCB. When using hot air devices with open-fame modules, care must be taken to prevent damage to the power-module components and the adjacent components surrounding the module. It is recommended that a custom fixture be used. This custom fixture serves two purposes: directing hot air precisely towards the solder joints and shielding the power-module components. When using conductive tips, de-soldering time should be limited to prevent thermal damages.

The de-soldered power modules may be re-used. However, the CPSB connectors must be replaced with new ones before being mounted back to the end PCB.

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