## Weak Knees

### **By Ralph**

### With newer packaging concepts the solderability

Printed wiring board solderability is one of the most persistent problems in electronics manufacturing. This problem has been with us for many years, and it sometimes seems that we have learned nothing through our experiences. There are many misconceptions concerning this subject, which generally fall into three categories:

- The belief that all soldering problems are the result of failure in the production of the joint, and that if the knobs on the solder machines are twiddled enough the problem will mysteriously disappear.
- The vendor's supposition that: "The boards must be alright because you are the only company to complain."
- The customer's philosophy that the slightest deviation from perfection during solderability testing demands rejection of the entire lot of boards.

### PRACTICAL SOLDERABILITY TESTING

The truth lies somewhere within these conflicting ideas and is really quite easy to determine no matter how difficult the problem initially appears. The first step must always be to conduct the simple tests that will confirm the status of the board's solderability. The only requirement is a solder pot and some R-type flux as described in many of the solderability test documents. (Readers who would like a practical solderability test are invited to contact Wood Corp. for a free copy). Once it has been ascertained that the boards' solderability is not up to standard, they should not automatically be scrapped. The test standards were designed to employ the mildest flux and a lower solder temperature to build a degree of tolerance into the test. This gives some measure of guarantee that the boards will be solderable after a storage time of up to six months. In other words, boards may flunk the test but be perfectly usable if soldered with a more aggressive flux within a very short time.

Boards that fail the test with the Rtype flux should be retested with the same flux used in the actual soldering operation. If they pass the tests with the alternate flux and will be used within a short period of time (two to four weeks), they should be formally rejected and a written corrective action is required from the vendor to eliminate the cause of the problem. The boards can then be used without jeopardy to the reliability of the product. If they are to be stored for any period of time, there is no question they must be rejected and returned.

Boards should not be sent back to the vendor if they can be used without causing additional cost or any quality problems. Solderability testing must be done with intelligence and the recognition that it can never ensure the quality of all of the boards but can only check the vendor's level of process control. It must also be recognized that some rejection characteristics are solely cosmetic, and while they indicate an out-of-control situation which must be quickly corrected, they do not directly affect the product quality (that is, dull reflowed solder). The PCB vendor will periodically suffer processing problems; that is when the purchaser and vendor must work together to solve these problems, which can be damaging to both parties if not quickly corrected.

### **ARGUING AROUND THE SPEC**

The solderability testis essential to identifying solderability problems, and claiming that the boards are sufficient when they do not meet the requirement is futile. The specification defines the minimum requirement for solderability, and the objective must be to make boards with excellent solderability. Then we can forget the subject and get on with improving the efficiency of the fabrication process.

It costs more to argue with the customer than to make boards with excellent solderability, and there is a lucrative market for any board vendor who will guarantee that solderability will never be a problem. When the solderability test indicates a lack of excellence, it is time to review the entire process and find out where the problem lies.

### WEAK KNEES

One of our industry's most persistent problems today is the so-called weak-knee defect (Figures 1 a and 1 b). It manifests itself in the solderability test as the inability of the solder to flow over the knee of the hole. In most cases the solder will wick up the hole, but will then sit at

# and Design

### W. Woodgate problem has become dramatically worse.

the top, showing a negative meniscus that indicates an area of nonwetting around the knee of the hole. In very severe cases the solder will not even wet into the hole, but this is a rare situation.

The vendor will often argue that the board is satisfactory because the solder has wicked up the hole, and may even attempt to show that the various specs permit this lack of solderability; they do not. In reality, this is a totally unacceptable condition. Weak knees cause partial solder fillets and joint rejection, resulting in additional expense in the form of more inspection, and rework that ultimately reduces the life of the joint.

Weak knees may not affect board reliability in any way, but if the board is plated with brittle copper, resulting from a lack of control of the plating system, a similar condition will be seen. Copper cracking at the knee will prevent the flow of heat into the pad, and the solder will not flow onto the surface. This presents a reliability jeopardy, and there is no way the purchaser can visually differentiate between the two failure modes. Certainly, this is a remote possibility, but the lack of a top fillet after soldering is a rejectable condition simply because it denotes a lack of control in the manufacturing process that can quickly degenerate into more serious defects. Would you buy a TV receiver if you knew that its PWB had weak knees?





#### WEAK KNEES: TYPICAL CAUSES AND CURES

knees is too thin a coating of solder at the knee of the hole. When the solder is reflowed it forms an intermetallic compound  $(Cu_{s}Sn_{s})$  at the solder-

copper interface which will continue to grow. Once all the free tin in the The most common cause of weak solder has been consumed in this manner and the intermetallic reaches the surface and becomes oxidized, it will no longer be wetted with solder using the rosin-based fluxes. As intermetallic compound formation continues, the lack of tin changes the composition to Cu<sub>2</sub>Sn, which, when oxidized, cannot be soldered with any of the commonly used fluxes. The growth of this compound is the primary reason for finite solderable life.

The rate of intermetallic compound formation is also affected by temperature; for example, it is accelerated by baking. The tin-lead thickness is at its minimum at the knee of the hole due to the interaction of the wetting force and surface tension. As a result, the problem is always found here first (Figure 2).

The cure is simple: plate an adequate thickness of clean tin-lead over a clean copper surface. Experimental boards with 0.0003" of solder plate reflowed over clean copper have been found to be solderable after five years. Minimize any bake cycles between reflow and soldering, and do not store boards for long periods of time. Note that the intermetallic compound, the basic cause of most board and component solderability problems, continues to grow even at room temperature. In addition, storage in a vacuum or nitrogen atmosphere will not prevent intermetallic growth and has little effect on solderability life.

#### OTHER CAUSES AND CURES

In the past year, the efforts of some board fabrication facilities to produce boards of consistently excellent quality has triggered further investigations into eliminating solderability problems. These investigations have shown that weak knees can be caused by other aspects of the fabrication process. Generally, they indicate an out-of-control situation in one or more fabrication steps, ranging from contaminated rinsewater to incompatibility of chemical systems. It is believed that the failure mechanism may be the introduction of very small amounts of organic materials at the copper/tin-lead interface which con-



Figure 2. This cross-section of a PTH shows clearly that the solder has wetted up to the knee but has been unable to flow past the knee of the hole. In this case thin tin/lead was the basic cause of the solderability failure.

vert to steam during reflow. These materials then oxidize the underlying intermetallic compound, which then will not wet with solder.

It is becoming clear that this is a more subtle problem than previously realized, and factors other than solder thickness can affect the generation of weak knees, However, solder thickness is still the primary cause and the first area to be investigated when the problem arises.

### **DESIGN AND SOLDERABILITY**

Newer packaging concepts have caused a dramatic increase in solderability problems. It is not unusual to find boards that are no longer solderable after a very short period of time—in one case only three weeks. There are several reasons for this, and the designer must understand them if the problem is to be controlled.

In the case of surface-mount boards the design often specifies a minimum thickness of solder on the component mounting pads in order to provide a flat surface for component placement. The rounded meniscus of thick solder tends to make the component slide off the pad, resulting in a misaligned part.

When the board is fabricated and the solder reflowed, or when the board is hot-air leveled, the intermetallic compound is formed at the junction between the solder and the copper, as mentioned previously. This compound continues to grow, even at room temperature. If the solder is very thin the tin is soon consumed; the intermetallic compound becomes oxidized from the oxygen in the air and is no longer wettable by typical fluxes. The result is a board that will not pass the solderability test.

The vendor is now in a quandary. If they comply with the drawing regarding minimum solder thickness they will fail the solderability test. If they plate or hot-air levels a greater thickness of solder the boards will be rejected for having a rounded meniscus. The simple answer is to use the boards quickly, working on a just-intime (JIT) basis.

Alternatively plate but do not reflow the plating; this will produce a flat surface component placement and an adequate solder thickness. There may be problems involving slivering after etching, but if the boards are to be reflow-soldered the slivers will be eliminated. Otherwise, it may be necessary to consider other solderable finishes and etch resists that will not form the tin-copper intermetallic found with tin-lead. Another option is to leave the pads plain copper and perform a simple acid clean immediately prior to assembly.

In a similar manner, the use of very small via holes forces the board vendor to plate up very thin coatings of tin-lead to avoid blocking the holes during reflow, which violates many specifications. The solution here is to permit the holes to be blocked; in fact, in many cases it is preferable to have them filled with solder. In both of these circumstances the board vendor should be consulted during the design of the board, and the process limitations should be agreed upon before the drawings and specifications are completed.

### COST AND QUALITY

We will now consider board cost. In some areas of our business, there are still strong pressures to cut board prices, which all too often leads to unexpected results. The vendor has little possibility of cutting costs without reducing the control of the process or jeopardizing the ultimate quality of the product. It is the overall board cost that is more important. In one case the price of all the boards in a lot was cut by an average of \$1.25 each due to strong pressure exerted by management through a cost reduction program. Unfortunately, the ultimate result was a solderability problem which, in turn, caused an increase in inspection and rework that cost over \$6 per board. "A consistently good board shipped on schedule is worth a fair price."

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