Improved wave soldering

Solder skips and bridges are deadly for PCB quality. Wave solder technique can be a big help

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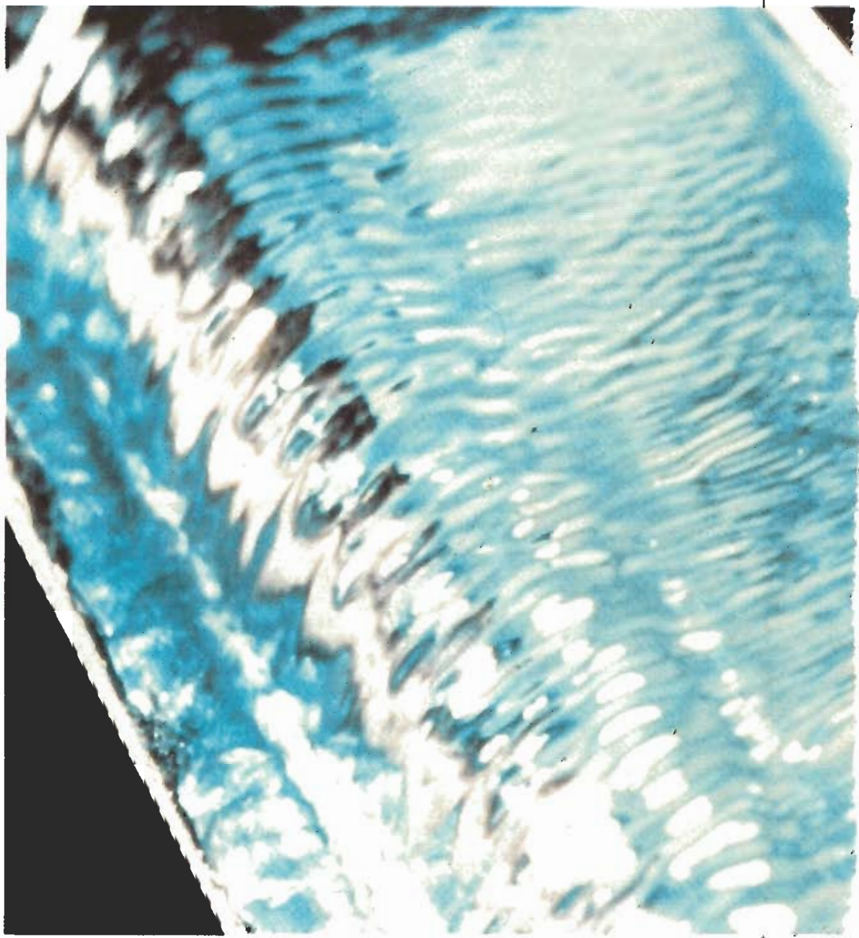
Most present-day SMD wave soldering systems employ two separate solder waves. The first wave is turbulent and forms a narrow contact area with the printed circuit board. Its function is to provide sufficient vertical pressure against the board so as to insure that all joints are wetted. The second wave is wide and characterized by a smooth bi-directional flow.

In spite of their established performance in soldering surface mounted devices, double wave systems can be somewhat problematic. Adjustment of the turbulent wave is critical as there is a delicate balance between eliminating skipped (non-wetted) joints and flooding the top side of the printed circuit assembly with solder. Space restrictions in the solder pot, and high oxide (dross) production, increase maintenance time and material cost.

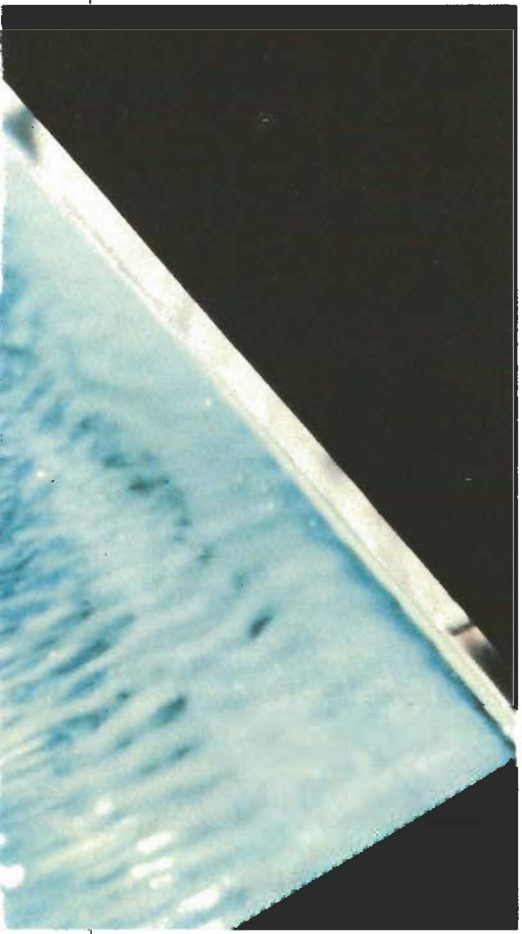
The Omega Wave is capable of soldering surface mounted devices as well as leaded components without compromising either of the two technologies; gives better performance with a single "oscillating" solder wave.

Justification for a double wave lies in its ability to eliminate solder skips (non wetted joints). Using a glass plate with SM-components glued to its bottom surface, permits observation of the process by which skips are formed. As each component contacts the solder wave, it forms a depression whose volume is larger than the component itself. This depression is attributed to the surface tension force which tends to repell solder away from the non-wetting body. The depression fills, instantly, with flux volatiles, resulting in a surrounding bubble, *Figure 1*. In a laminar wave, the gas bubble remains entrapped through the entire contact period. Wetting is thus permitted at the points where a component enters into or separates from the solder. However, due to the surface tension between solder and printed circuit assembly (laminate and components), the separation zone is irregular resulting in solder skips at some joints. Solder skips occur most frequently at SOT and SOIC joints as well as the terminations of small components which are mounted in close proximity behind much larger components. It appears that the bubbles forming around the high profile components encompass the smaller components and prevent their exposure to the solder.



Solder waves visible in Omega Wave-excited solder bath

It was originally theorized that a narrow turbulent wave would produce random agitation of sufficient magnitude to burst or displace the enveloping gas bubbles and expose the joints to the molten solder. The results were indeed positive, but a close examination of the soldering sequence reveals a mechanism which is somewhat different than theorized. While the printed circuit board traverses the wave, the turbulence is dampened and consequently has little or no impact on the entrapped bubbles. Wetting occurs on most joints at the PCB/solder entry and separation zones as the turbulence at these points encourage the exposure of terminations and pads to the solder wave. A clearer understanding of the soldering sequence led to the realization that solder skips may be eliminated without the use of a second wave. Since the mechanism of turbulence has proven effective in reducing the occurrence of solder skips, it was decided to apply a variation of this concept to the Electrovert Lambda Wave. Vibrations are introduced to the wave through an oscillating element located in the opening of the nozzle. The element displacement coincides with an axis defined by the printed circuit board travel. The vibrations are created by an electromagnetic transducer operating at a frequency of 60 Hz and a variable amplitude of up to 3mm. At an amplitude range of up to 0.4mm the solder wave remains laminar since the vibrations are not discernible. Between 0.4mm and 0.5mm the vibrations become discernible only when a printed circuit board contacts the wave surface. As the amplitude is increased beyond 0.5mm vibrations become visible as ripples in the wave-see photo. Amplitudes greater than 1.3mm are not usable with standard .062" (1.6mm) thick boards due to excessive pumping action which is created when the printed circuit board contacts the wave.



The soldering process may be observed through a glass plate populated with a variety of resistor/capacitor chips, and small outline semiconductors, SOTs, SOICs and PLCCs. As the printed circuit board moves into the vibrating section of the wave, the enveloping bubbles are broken and displaced, permitting exposure of the joints to the solder. Vibrations are most prominent at the entrance and/or exit contact points between the printed circuit board and the wave, *Figure 2*, thus assuring that all joints are wetted by the solder. The vibration zone is defined by the location of the oscillating element. When the element is located near the leading end of the nozzle opening, vibrations occur only at the entrance section. The exit section remains laminar and is effectively identical to a standard bi-directional wave. As the element is moved further towards the center of the nozzle opening, the vibrations pervade the entire contact area of the wave. Variations of amplitude and/or element location, enable optimization of wave conditions required to eliminate solder skips and bridges in a particular assembly.

A study was aimed at determining the effects of different process parameters on solder skips and bridges. We analyzed records of SMD soldering results gathered over a period of two years from customer demos and in-house tests on a double wave system. The data pool was some 600 printed circuit boards of 18 types.

Based on results, a subset of process parameters was established for use in subsequent tests:

Conveyor Speed-4 fpm (1.2 m/min).
Flux Type-RA.
PCB top Side Preheat Temperature-100°C.
Solder Temperature-250°C.
Wave height-As high as possible (for the turbulent wave).

Flux and Vibration

Two dominant factors were evaluated in order to establish a set of process parameters which would effectively reduce defects: flux density and vibration amplitude. A factorial analysis was undertaken in order to study the individual effects as well as the interaction between amplitude of vibrations and flux density. We selected a printed circuit assembly populated with a mix of resistor/capacitor chips, SOTs, SOICs and a 44 lead PLCC. Our selection criteria for the test board was a good mix of components and high population density. This type of printed circuit assembly was used for the entire study. The results demonstrated the conflicting requirements for the reduction of skip and bridge defects. Amplitude is the dominant factor for skip reduction while flux density is only marginally more important for bridge reduction. The actual defect ratios (skips vs. bridges) are relevant only to the specific printed circuit assembly used. This stresses the importance of testing each type of assembly in order to establish the dominant factors. An additional point is the indication that high solids content fluxes, which are known to increase skip defects, may be better tolerated by the Omega Wave system for SMD soldering.

Figure 1. Surface tension can cause flux volatiles to bubble around SMT components, resulting in solder skips and bridges.

SQUEAKY CLEAN

The cleanup of printed circuit boards has become a balancing act between production machinery costs, labour costs and even flux chemical content. As PCBs become ever more complex, with increasing board densities and narrow lines to some extent aggravated by the increasing use of minute surface mount components, the costs of rejection for reasons of organic flux deposits, solder bridges and poor through-hole plating, can be crippling to profitability.

Both the machinery makers and the solder manufacturers' R & D teams are doing their jobs; the Omega Wave by Electrovert, as described here, the Hollis Airknife, as described in the *CEE* May issue, and new fluxes as available from people such as Ersin Multicore Canada, are contributing largely to PCBs that are reject-low and "squeaky clean". And that means low repair and rework costs, plus a quality reputation image at the end user.

The Omega Wave, in a DuPont study, averaged a hole filling rate of 99.9% on a variety of non-populated PCBs. This was 7.7% higher than similar tests done with double wave machines.

Analysis indicated that the densely populated SMD board used was more sensitive to amplitude variations than to flux density variations. We therefore elected to concentrate on optimizing the amplitude with the aim of reducing solder skips and bridges. Previous tests have shown that an amplitude range of up to 0.4mm is ineffective for skips reduction. This amplitude was therefore selected as a starting value and a base reference for quantifying the results. Because of the conflicting requirements for skip and bridge reduction, the skip defects dropped in a nearly exponential manner while bridge defects increased linearly. The optimum amplitude for the particular SMD assembly was 1.1mm where all the defects were attributed to bridging, due to the complexity of the test assembly.

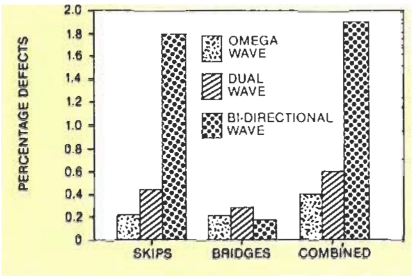


Figure 3. Solder wave performance comparison: skips and bridges

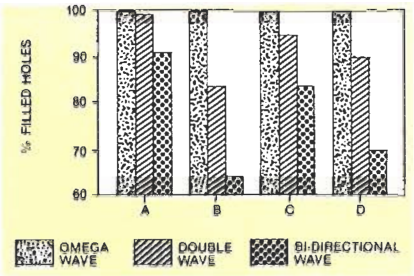


Figure 4. Hole filling performance comparison: no-lead PCB holes

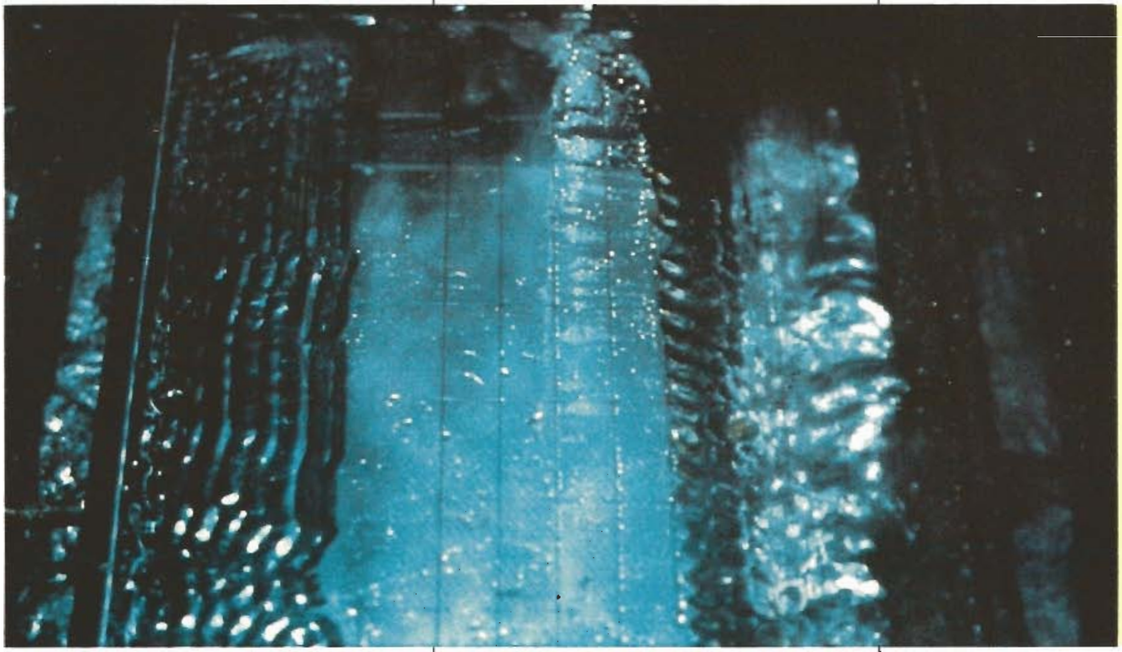


Figure 2. Entrance and exit vibrations—the Omega Wave

Solder systems

A comparison of soldering defects conducted between the Omega Wave, single wave and double wave systems, again using the same printed circuit type SMD board, makes clear that while the wave type has a large impact on skip defects, its influence on bridge defects is marginal. This also indicates that a design layout of SMD components should strive to optimize conditions favoring least bridges rather than least skips.

Hole filling

Partially populated printed circuit assemblies commonly exhibit a certain percentage of unfilled through-plated holes after a mass soldering operation. Although unfilled holes are not functional defects, they may disturb vacuum fixturing of printed circuit boards. Many companies therefore specify that all through-plated holes must be filled with solder. Missing component leads are the root cause for unfilled holes. The following list highlights additional factors which contribute to this phenomenon: large diameter through-plated holes allow the gravitational force to exceed the wetting force which acts to hold the solder into the plated barrel; high process temperatures encourage solder drainage; non-wetting or de-wetting; (the result of poor solderability and/or low flux activity) and finally, solder wave dynamics; turbulent waves aid hole filling by forcing solder up the barrel, making its rise less dependent on capillarity. However, turbulent waves cannot prevent solder drainage and will therefore not improve hole filling if the other contributing factors are predominant.

A study conducted by DuPont with the participation of Electrovert, demonstrates that the Omega Wave reduces the occurrence of unfilled holes when all the other factors are held constant. This is attributed to the pumping action which is generated in the vibrating zone of the wave. Boards soldered on the Omega Wave averaged a hole filling rate of 99.9%. This compares with filling rate averages of 92.2% for double waves and 77.1% for standard bi-directional waves.

Control

Wave height accuracy and repeatability are critical requirements in establishing a low defect process. The turbulent wave compromises these requirements by its very nature and, as such, it cannot be directly controlled by a closed loop system. Its height can only be defined by peaks in the turbulence, while amplitude variation may be well over 0.25″ (6.3 mm). Also, due to its small mass flow, the turbulent wave is quite sensitive to control fluctuations. It is therefore apparent that the turbulent wave parameters are difficult to control and difficult to quantify. The Omega Wave parameters are well defined, on the other hand, and easy to integrate to closed loop control. The wave can therefore be totally automated fitting the Omega Wave transducer into the Electrovert Century 2000-S computerized wave soldering machine: the amplitude of vibrations is defined for each printed circuit board type and stored in a data base with the rest of the parameters which determine a single process. These parameters are automatically loaded with each process run and insure the repeatability of the solder wave characteristics.

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