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INTELLIGENT LASER SOLDERING
INSPECTION AND PROCESS CONTROL

Riccardo Vanzetti
Vanzetti Systems, Inc.
Stoughton, Massachusetts

INTRODUCTION

Component assembly on printed circuitry keeps making giant strides toward denser packaging and smaller dimensions. From single layer to multilayer, from through-holes to surface-mounted components (SMDs) and tape-applied bonds (TAB), unrelenting progress results in new, difficult problems in assembling, soldering, inspecting and controlling the manufacturing process of the new electronics.

Among the major problems are the variables introduced by human operators. The small dimensions and the tight assembly tolerances are now successfully met by machines which are much faster and precise than the human hand. The same is true for soldering. But visual inspection of the solder joints is now so severely limited by the ever-shrinking area accessible to the human eye that the inspector's diagnosis cannot be trusted any longer. It is a slow, costly, unreliable and often misleading relic of the pre-automation era. As a matter of fact, it is the only operation still being performed by humans. A solution must be found to fill this gap.

NOVEL APPROACH: THERMAL FLOW

The solution to the problem of assessing the quality of a soldered joint is based on monitoring how heat flows through the joint itself. Evidently, heat injected at one end of the joint will spread through it, reaching the other end faster or slower, according to the quality of the heat transfer path. Any obstacle along its path (voids, inclusions, discontinuities, etc.) will slow down the heat transfer from one end to the other. Figure 1 shows how this approach is applied to a "lap-joint."

A measured pulse of laser radiation is injected on the surface of a "gull-wing" wire soldered to a pad. An infrared detector measuring the temperature at the point of heat injection will "see" a temperature rise during the laser heating pulse and a temperature decay after it. The analog signal at the detector's output is called the "infrared signature" or "thermal signature" of the corresponding solder joint. It contains all the information needed to define the quality of the joint. This is because the shape of the signature is affected by the following four variables affecting the joint:

- a) surface cleanliness
- b) surface emissivity
- c) thermal mass

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d) heat sinking

Item a) is mainly reflected in the initial "rise" of the signature, and it can be caused by residual flux or any kind of deposited material or film on the joint's surface. It often results in mini-fires, so that sometimes the laser beam is automatically turned off prematurely.

Item b) gives information about cold solder joints, tin depletion of the solder bath, presence of contaminants (gold, copper, iron, etc.) in the solder alloy, and excessive intermetallic formation.

Item c) indicates either excess of solder material or insufficiency of it (because of voids, dewetting and the like).

Item d) (located at the tail end of the signature) indicates whether the solder joint is properly connected to the heat-sinks, such as the component's lead and the printed wiring leading away from the pad.

Figure 2 shows typical signatures related to some of the conditions listed above.

THE LASER/INSPECT SYSTEM

The schematic diagram of the system which developed these signatures is shown in Figure 3. It is called "Laser/INSPECT" and it utilizes a 30 watt YAG laser as the heat source, together with a 0.5 milliwatt Helium-Neon laser (coaxial with the YAG) which illuminates with visible light the point of the target being heat injected. The infrared detector is an In-Sb photovoltaic cell cooled at 77° Kelvin and made blind to the lasers' wavelengths, so that it will only receive the blackbody (or graybody) radiation between 2.5 μ m and 5.5 μ m emitted as a function of temperature by exactly the same area heated by the laser.

The p.c.b. under inspection is mounted on a very fast and precise X-Y table controlled by the computer, which is programmed to bring in rapid succession each solder joint under the focal point of the optical head. The computer also opens and closes the laser shutter and processes the signature information arriving from the detector after analog-to-digital (A/D) conversion. The computer's memory holds, for each joint, the standard signature which is used as reference against which to compare the signature of the joint being inspected. The results are printed out by a fast printer, so that every joint has its own inspection certificate on a hard copy printout.

A TV camera extracts the visible image of the area being inspected, and can be used for programming the X and Y coordinates of the joints to be inspected and also for watching the inspection process during operation.

Figure 4 shows the Laser/INSPECT system and its crew. From left to right we see the programmer, standing in front of the closed inspection compartment, containing the lasers, the optical head, and the X-Y table with the p.c.b. under inspection. The laser power supply console and the computer console are under the inspection compartment. In the center, the systems operator sits in front of the monitor with its keyboard. At far left the printouts are being read to look for indications of defective solder joints.

In Figure 5 we see how the laser beam is focused on a solder joint to be inspected. According to the type of joint to be inspected, there is a "best angle" at which the laser beam can strike it most efficiently. Accordingly, the optical head can be tilted in the four directions +X, -X, +Y, and -Y.

And what about the speed of operation? For plated-through holes, the laser pulse can take between 60 and 100 milliseconds. To these we'll have to add another 15 milliseconds for taking three readings during the signature decay, plus 50 milliseconds for the table movement to bring the next joint at the focal point of the optical system. The total time adds up to 125 or 165 milliseconds per joint, or between 8 and 6 joints/second, for plated-through holes. For the much smaller SMD joints, a laser pulse of 25 milliseconds is adequate, so that the total time to inspect one joint and move to the next position can be reduced to 90 milliseconds, which results in an operational speed of 11 joints/second. This is certainly faster than any visual inspection deserving such an appellation, since this could vary between 5 joints/second and 5 joints/minute, according to the quality requirements of the electronics to be inspected.

STATISTICAL DATA

The information supplied by the Laser/INSPECT (L/I) system can be elaborated and outputted by the computer in several different formats. A comparative evaluation program carried out by Texas Instruments is worth mentioning. In order to obtain permission by the U.S. Navy to use the Laser/INSPECT system instead of visual inspection for the electronics p.c. boards of the HARM (High-Velocity Antiradiation Missile) production, Texas Instruments (TI) ran 186,570 solder joints first through the L/I system and then through conventional visual inspection (accordingly to the prescribed MIL-SPECS).

Figure 6 shows the result of the final comparison of the two different inspection approaches. For only 57% of the joints there is agreement between visual and the Laser/INSPECT. For the remaining 43% there is total disagreement (25% visual accepts, L/I rejects; 18% visual rejects, L/I accepts). Subsequent microsectioning of the "disagreed" joints proved in every instance that the L/I diagnosis was correct, as opposed to the visual diagnosis.

On the basis of this evidence, the U.S. Navy authorized TI to use the L/I system instead of the visual inspection mandated by the MIL-SPECS. As a consequence, today TI delivers to the Navy better quality HARM electronics, while the cost of each missile has been cut in half.

Histograms are useful in processing the L/I data. They offer a quick way to verify whether the soldering process is within tight control or drifting out of it. Figure 7 is an impressive example of the large range of variations introduced by the human hand in the soldering operation.

Figure 8 shows more examples of such histograms. In all these charts, the ordinate scale indicates in arbitrary numbers the value of the peak radiation of the infrared signature, while the abscissa indicates how many times each of those values was met by the signatures of the joints under test.

INSPECTING TAB ASSEMBLIES

The Laser/INSPECT technology is applicable to most types of joints or bonds. Both the sizes of the laser beam and of the detector spot can be adjusted to meet the target dimensions. Figure 9 shows a TAB assembly whose joints were inspected by a microscopic version of the Laser/INSPECT, in which the Laser spot is .022" (or 0.05mm) and the detector focal area .044" (or 0.10mm). Figure 10 shows some of these joints.

It can be seen that seven of the joints were prevented from making electrical contact by some epoxy smear. This lack of contact is clearly reflected in the high peaks of their signatures, which contrast with the low peaks of the adjacent wires, both at left and at right in the oscilloscope display picture of Figure 11.

INTELLIGENT LASER SOLDERER

From inspection to reflow soldering the step is quite short. Just a few more milliseconds of exposure to the laser beam, and the solid solder becomes liquid. During the change of phase, the temperature won't change. Figure 12 shows an oscilloscope display of such transition, where time runs along the abscissa and temperature rises along the ordinate. The two changes of phase, from solid to liquid (at left) and from liquid to solid (at right) are indicated by the two plateaux pointed by the arrows. These plateaux are inclined instead of horizontal, because in the area viewed by the detector there is simultaneously solid and liquid material.

Ad hoc software processes the detector output and turns off the laser shortly after full liquefaction is observed. In this way every joint receives the right amount of heat, through a "custom-tailored" laser pulse precisely measured to the individual joint's needs. This is because no two joints are identical. They differ in thermal mass and in heat sinking, so that their heat requirements to achieve liquefaction are different.

This is how the Laser Reflow Soldering System works, and this is why it is called intelligent.

Besides intelligence, the system has speed. On SMD's soldering can proceed at an average speed of 4 joints/second ("average", since every joint will need a different dwell time, as dictated by the individual heat requirement).

This 4 joints/second speed might appear slow when compared with the 1000 joints/minute typical of the mass-soldering systems today in use. But in fact it is much faster BECAUSE THE JOINTS ARE ALREADY INSPECTED. Their infrared signature is already their inspection certificate.

This means that the overall speed of the combined soldering and inspection operation is faster for the laser approach.

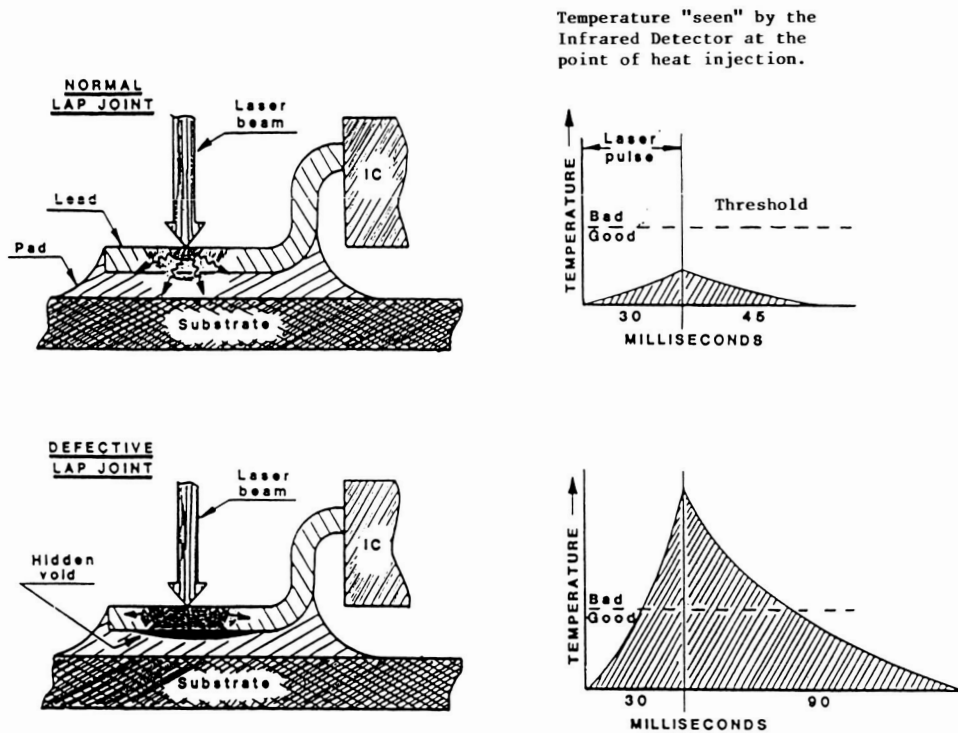


Figure 1. Behavior of normal and defective joints during laser/thermal testing.

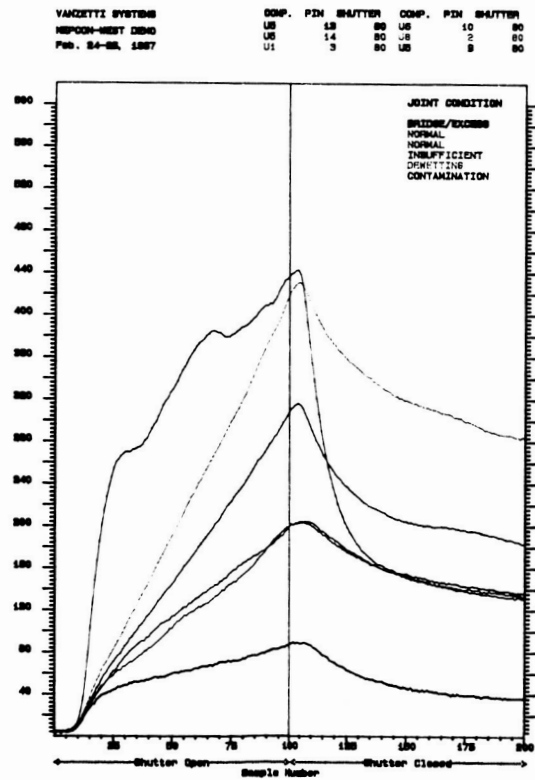


Figure 2. Typical infrared signatures of good and defective solder joints.

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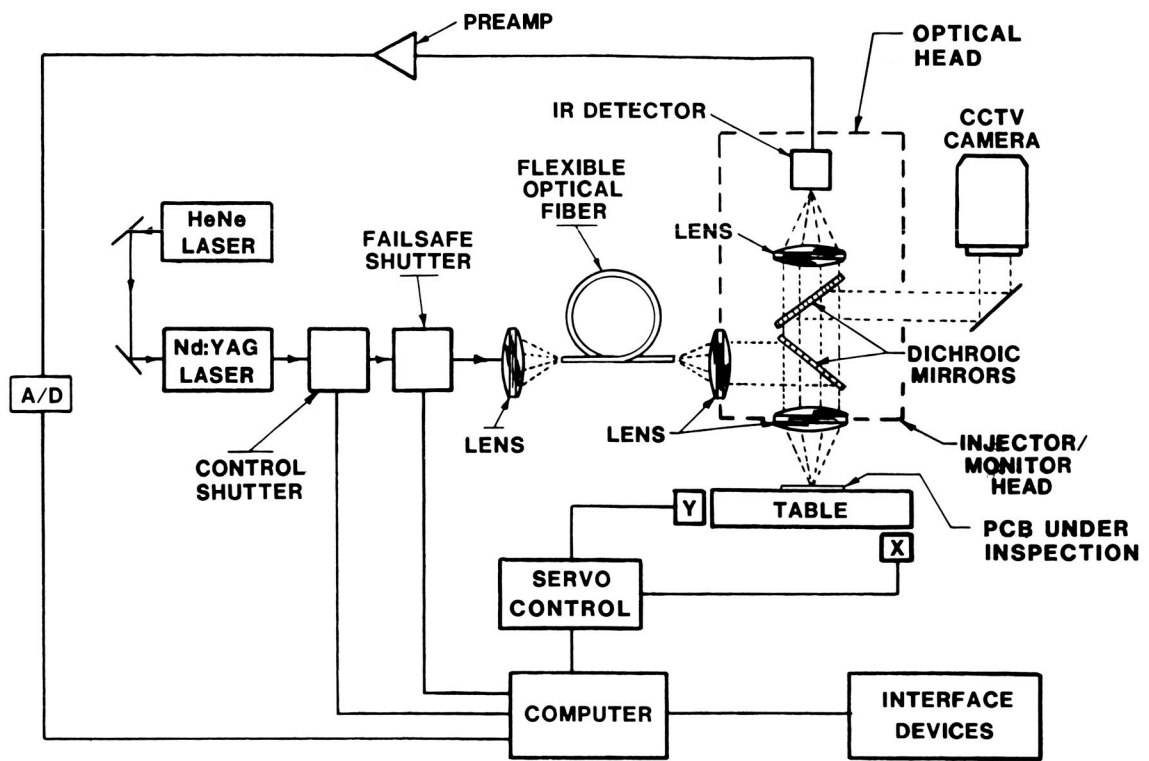


Figure 3. Diagram of Laser/INSPECT system.



Figure 4. Laser/INSPECT system.

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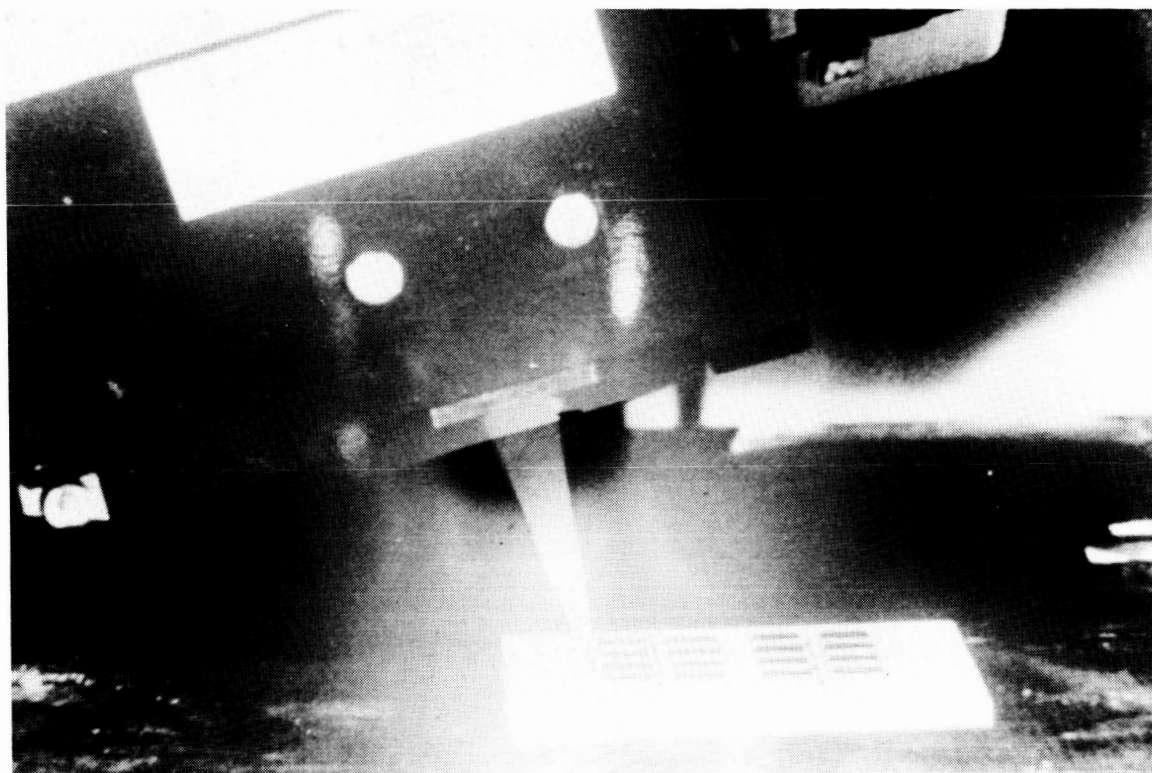


Figure 5. Laser beam exiting from tilted optical head.

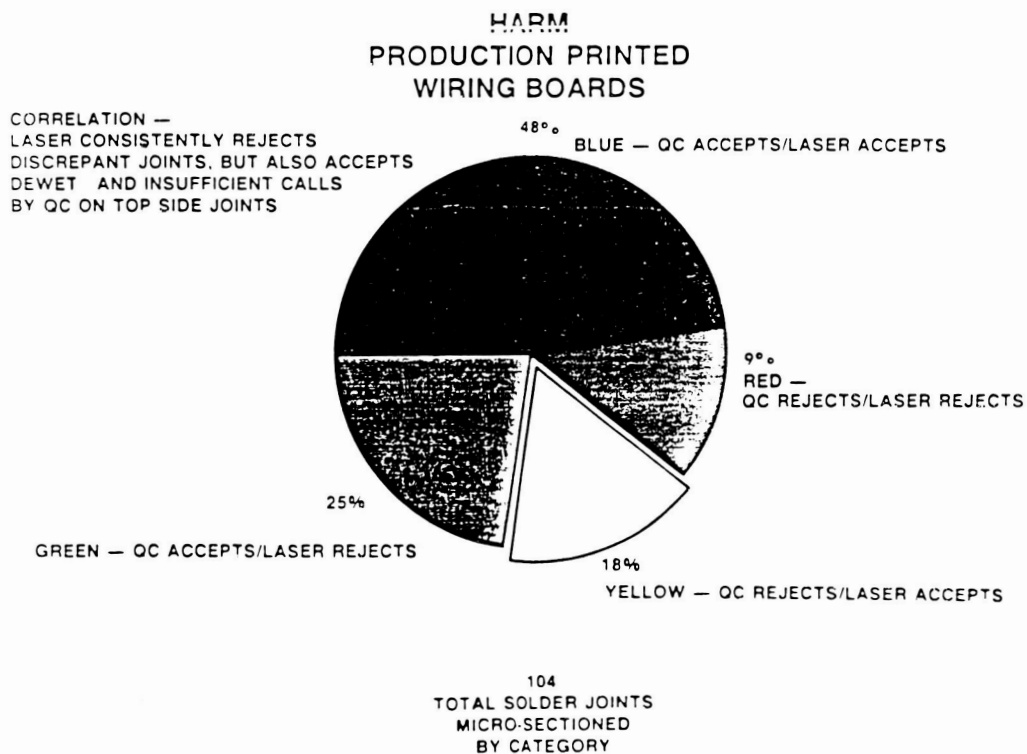


Figure 6. Comparing visual inspection versus Laser/INSPECT;
summary of 184,000 solder joints.

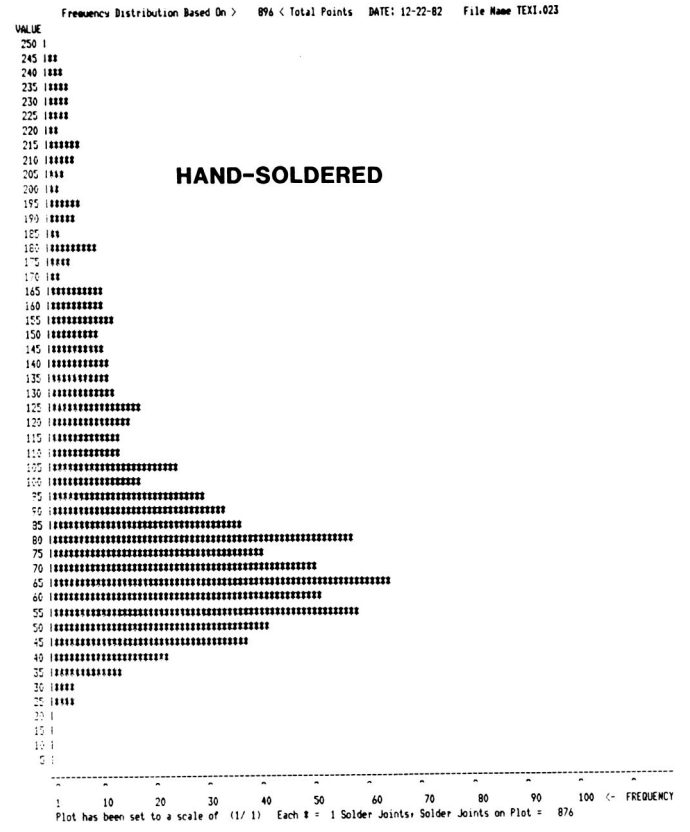
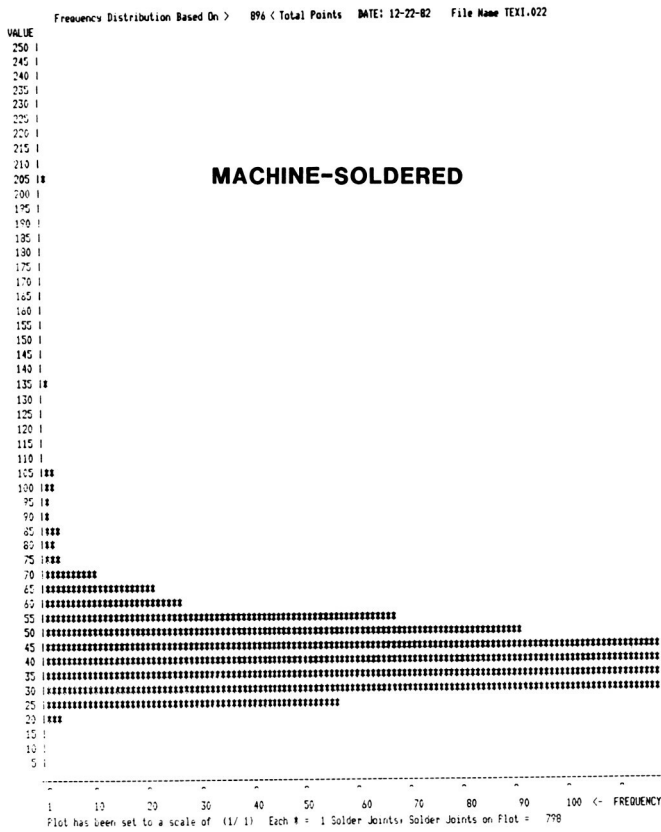
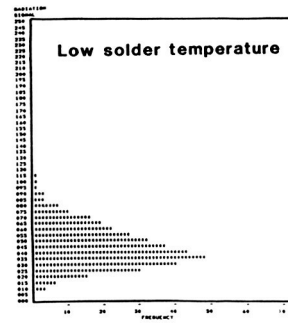


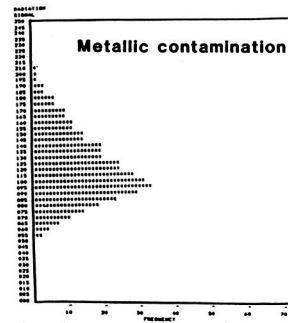
Figure 7. Comparing soldering processes: machine versus manual.



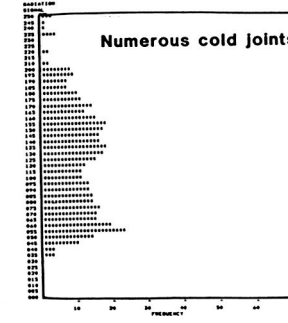
Good process control is shown by narrow frequency distribution.



Low solder temperature or too high a conveyor speed yields heavy joints.



Metallic contamination in solder causes granular or cloudy solder surfaces.



Cold joints mixed with good joints can result from a variety of causes.

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Figure 8. Histograms disclose drifting variables in soldering process.

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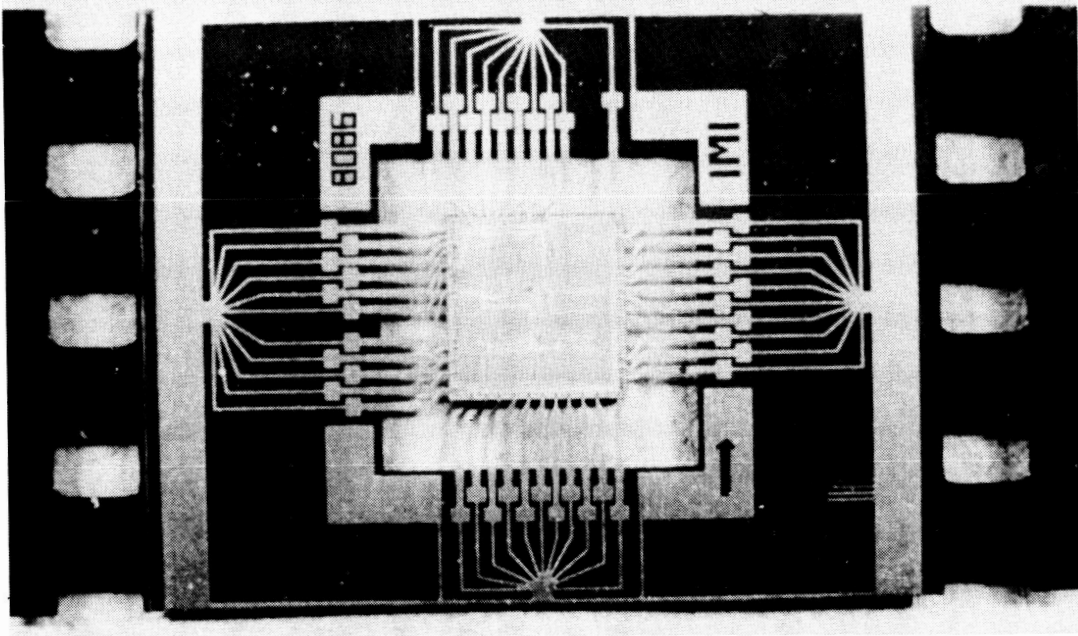


Figure 9. TAB assembly.

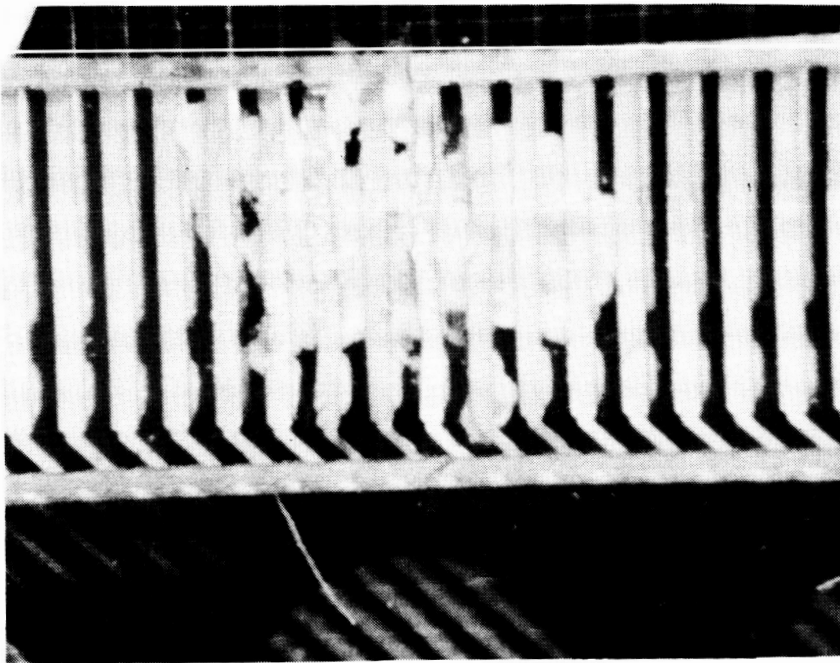


Figure 10. Detail of figure 9, with seven unbonds.

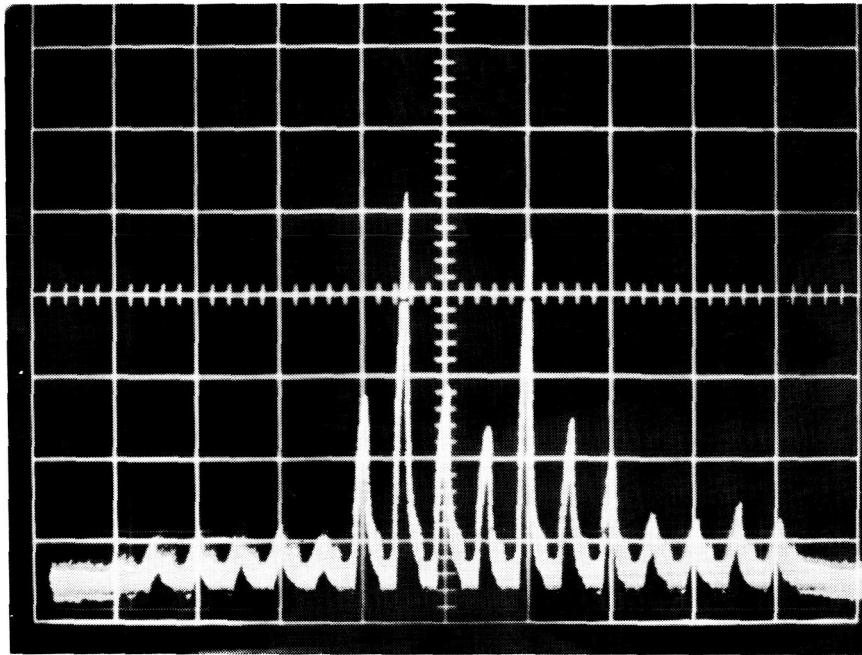


Figure 11. Seven unbonds surrounded
by nine good bonds.

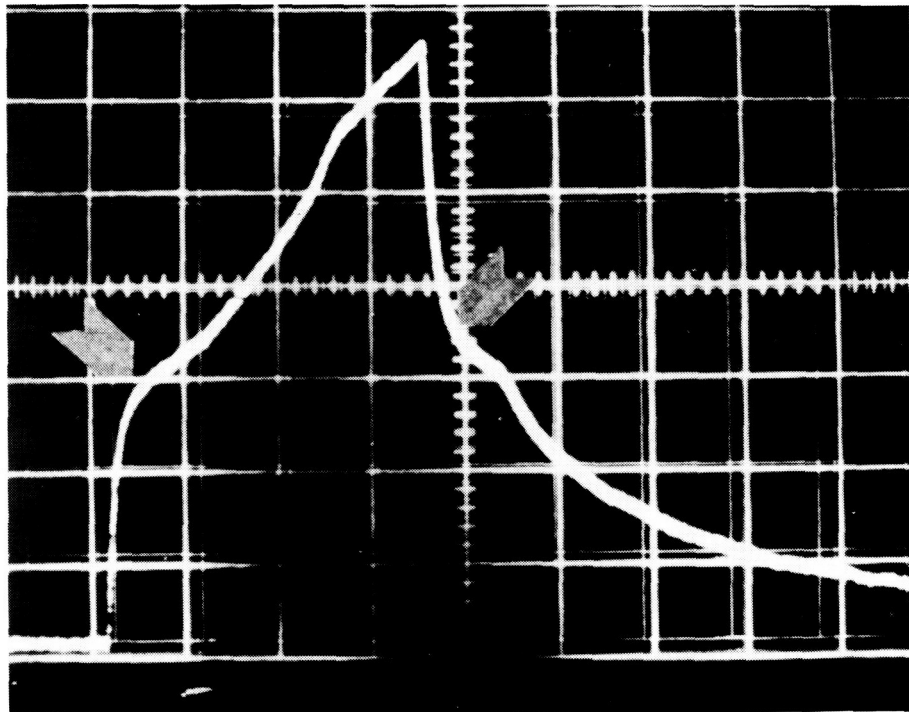


Figure 12. Solder reflow: solid to liquid to solid.
Temperature diagram.