July 10, 2007

Repair Solution for Xbox 360 "Red Ring of Death" Hardware Failure

Developed By Manncorp
Willow Grove, PA

Introduction

Since the product's introduction in November, 2005, a significant quantity of Microsoft's Xbox 360 game consoles have experienced a field malfunction that is indicated by three flashing red LEDs on the front of the console. This error function, which designates a critical hardware failure and renders the unit inoperable, is known among gamers as the "Red Ring of Death" and has spawned numerous user forums and web postings that claim to offer easy "fixes" for out-of-warranty units or for users who lack the patience to return their systems to an authorized repair center. Obviously, if there were an easy fix, Microsoft probably wouldn't have announced, last Thursday, July 5, their intention to spend more than $1 billion to extend warranties to three years for the nearly 12 million game consoles it has sold worldwide.

Having become aware of the Xbox failure issue prior to the Microsoft announcement, Manncorp has been actively spearheading a research effort into the causes of the problem for the purpose of providing not only a technologically sound and reliable solution, but one that is also practical and timely given the scope and magnitude of Microsoft's predicament. Research has been conducted in affiliation with Bernhard Martin, Managing Director of our SMT rework equipment manufacturer in Germany, who has been involved in similar, high-profile, troubleshooting and repair applications for high-volume consumer products with companies like Siemens and Nokia.

While our research continues, we have decided to publish our findings and conclusions thusfar, as well as our recommendations for the proper equipment and techniques needed to repair the consoles, in order to eliminate future recurrence of the problems.

Assessment of the Problem

Discussions with independent electronic repair shops and an evaluation of the extensive information available on internet user forums and bulletin boards quickly pointed toward the eleven BGA and CSP devices on the Xbox 360 motherboard as the likely source of the problem. The locations of these devices on the top and bottom sides of the board are shown below in Figure 1. The solder joints that connect BGA and CSP devices to the contacts on the PCB are made when arrays of dozens, or even hundreds, of tiny spheres of solder attached to the bottom of the device are melted during the reflow soldering process. Because these connections are located underneath the components, visual inspection is nearly impossible.

When we subjected several motherboards (from Xbox 360 consoles that suffered the "Red Ring of Death" failure) to microscopic X-ray inspection, it was determined that a substantial number of the solder joints beneath the BGA and CSP devices appeared to be of questionable quality. This was especially noticeable towards the centers of the main CPU and GPU (Graphics Processing Unit), both of which are plastic BGA components, and both of which include additional integrated components mounted to the top of the device. The additional mass of the main chip on the top of the plastic BGAs appears to have prevented sufficient heat from reaching the solder joints closest

to the center of each device. This phenomenon is usually an indication that the time and temperature parameters, used for reflow soldering of the motherboard at the point of original manufacture, did not provide a thermal profile sufficient for complete and thorough reflow at all points beneath the BGAs and CSPs on the PCB. This is quite consistent with our X-ray analysis, which also shows that most of the flaws observed (cracking, voids, etc.) are symptomatic of "cold" solder joints with a poor grain structure.

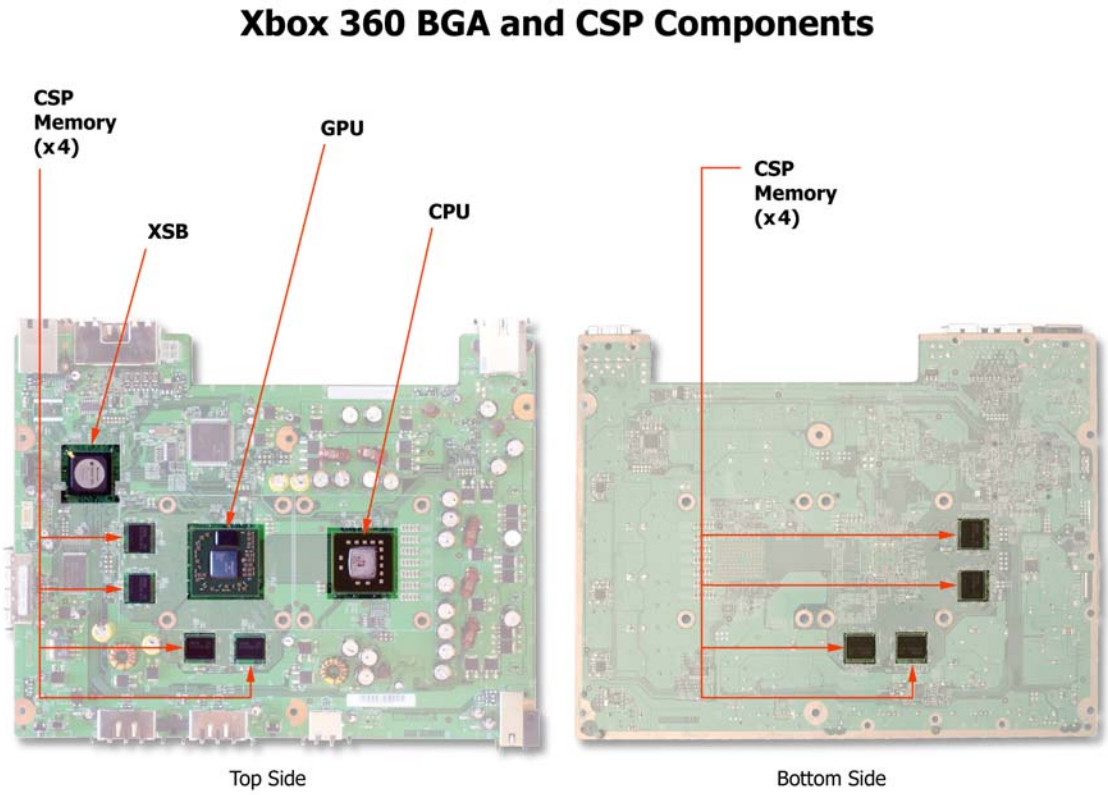


Figure 1

While a "cold" solder joint may initially provide an adequate electrical connection, long term reliability is jeopardized, especially in applications where the solder bonds are subject to wide temperature fluctuations. In such an environment, continuous expansion and contraction of materials with varying thermal coefficients will quickly destroy the integrity of a "cold" solder joint, creating intermittent problems or even complete failure. This is precisely the environment of the Xbox 360 motherboard, due to the high amounts of heat generated by the CPU, GPU and memory components when running graphics-intensive gaming applications, not to mention the fact that the great pains Microsoft has taken to ventilate and cool the Xbox chassis may all be for naught when Junior's Xbox is buried beneath dirty laundry and empty pizza boxes. This would also explain why so many consoles, that certainly would have passed Microsoft's initial QC testing, are now failing in the field.

One could also blame the "cold" solder joint problem on what, unfortunately, has become a problem for suppliers of many electronic goods other than Microsoft. As of July 1, 2006, the European Union, as part of a global environmental initiative, set strict compliance deadlines for what is known as the RoHS (Restriction on Hazardous Substances) Directive. What this meant for

electronics manufacturers was, that if a company intended to continue selling its products in the EU, it had to convert from the use of eutectic "tin-lead" (SnPb) solders to the use of new lead-free solders. Many manufacturers are still bristling over the speed at which they have been forced to implement these changes. While conventional 60Sn/40Pb or 63Sn/37Pb solders have a melting point of around 183°C, lead-free solders, which are usually 96-97% tin with the balance composed of various combinations of silver and other materials, have a melting point of 217°C. As one can imagine, the effects of this single change have had a major snowballing effect in terms of their impact on component and materials specifications, equipment capability, processing parameters, and manufacturing personnel who have been used to fundamental soldering principles that have been acceptable for nearly five decades. Technicians, who for years have been used to a shiny, silver finish as being the first indicator of a quality solder joint, are still having difficulty getting comfortable with paste manufacturer's profile recommendations that produce lead-free solder's normally dull appearance; for years an indication of a "cold" connection. In addition, the fear of over-heating may naturally make engineers lean to the low side when establishing process time and temperature parameters.

Another set of X-rays also points to the possible presence of "cold" solder joints. In the view of the GPU component shown in Figure 2, differences in the diameters of the solder spheres are clearly visible. This could be an indication that not all of the spheres achieved complete reflow, although this is assuming that all of the spheres were of the same volume in the first place. This issue is addressed further in the sections that follow.

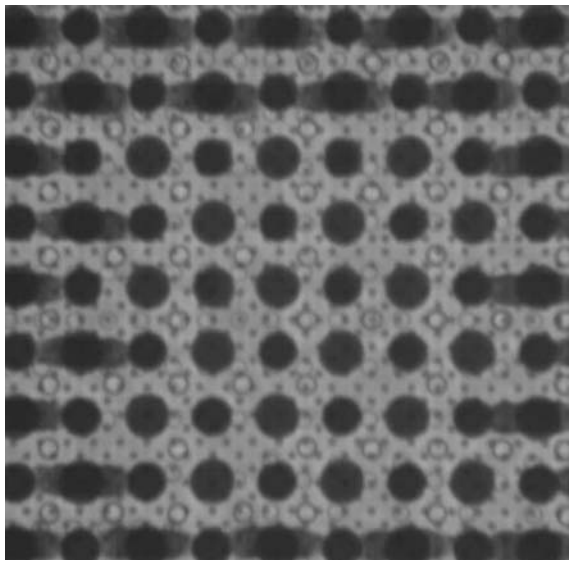


Figure 2

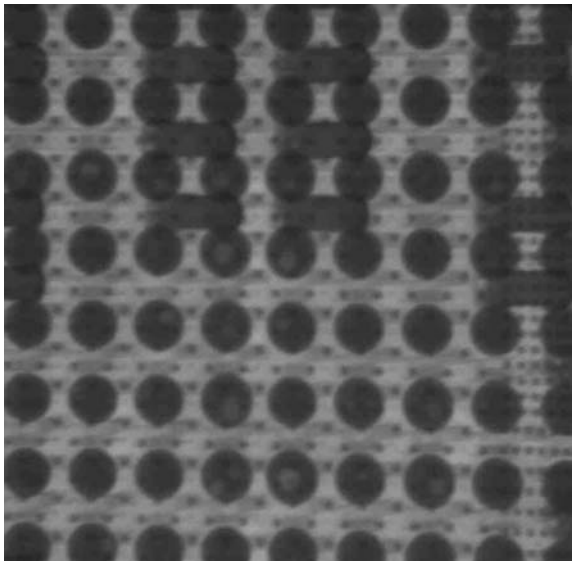


Figure 3

Developing a Solution

It is interesting to note that, although a number of the so-called "fixes" available on the internet and some of the repair methods used to "solve" the Xbox 360 problems can be termed reckless at best, most do appear to address the issue of "cold" solder joints between the CSPs and BGAs and the PCB. In addition to removing and "baking" the motherboard in a toaster oven, another remedy being sold as part of a guide on Xbox 360 repair goes so far as recommending that the unit be wrapped in towels while power is on, blocking off all the air vents and allowing the unit to overheat for 15-20 minutes; presumably turning the unit into its own, self-contained, reflow oven! In

addition to being a dangerous fire hazard, one can only imagine the additional damage to the console.

We are also of the opinion that, although some of the more rational repair approaches may appear to correct the problem, albeit temporarily, the issue is probably exacerbated by causing additional damage to other components on the motherboard that may have been working perfectly in the first place. Even some of the most experienced electronics repair professionals have expressed their frustration with the problem and are now refusing to perform Xbox 360 repair, claiming that the problem is too deeply rooted and going so far as pointing specifically to the lead-free solder used for attachment of the GPU. It also appears that warranty repairs performed by Microsoft-authorized refurbishment centers still may be a problem for precisely the reasons we've stated. A bulletin board posting on a website dedicated to the "Red Ring of Death" issue, submitted the day after Microsoft's July 5th announcement, indicated that an irate customer had recently received 3 defective refurbs from Microsoft's repair center in Texas.

Based on our tests so far, we don't believe the problem is, at all, as bad as it sounds. First of all, the time and temperature parameters of the thermal profiles used for reflow soldering at the time of initial manufacture were probably not too far off from where they should have been. This is of course an assumption, but we base this on the fact that not all of the units are defective and that most of the problems seem to be traceable to a few specific components. It is also quite possible that the composition of the solder spheres on the BGA and CSP components and the geometry of these devices necessitated a thermal profile that did not exactly match the remainder of the motherboard. In any case, we feel that most problems related to poor solder joint quality beneath the BGA and CSP components can be rectified by very precise, very localized, controlled-profile reflow soldering of these devices on the defective boards without having to remove, reball, and replace the components. According to Bernhard Martin, who has developed nearly identical solutions for cell phone repair, the key is preventing damage to neighboring components, not only from excessive heat, but also, from board warpage and thermal stress due to improper underheating. While these words may sound trite among SMT rework manufacturers, there are certain intricacies to the process that have resulted in Martin's numerous successes and other manufacturers' inability to provide viable solutions.

In tests conducted on actual Xbox 360 motherboards we have already proven that, by using the proper techniques in conjunction with the proper equipment, precision preheat, reflow, and cooling can be performed on selected components in less than 200 seconds total without any deleterious effect on adjacent parts.

Figure 3 shows the same GPU component that was shown in Figure 2, after localized reflow using our equipment. This view appears to indicate complete reflow, as all of the connections have nearly identical diameters, eliminating the possibility that the sphere volume was inconsistent beforehand. In our opinion, this view shows a considerable improvement in quality and consistency, which is why we are so encouraged by our tests.

Our Recommendations

As a result of our research and testing, we have assembled a complete equipment solution designed specifically for companies or sub-contractors performing Xbox 360 motherboard repair. The **Manncorp Expert 04.6X Gaming Console Repair Station**, which is comprised of selected components from our standard rework equipment catalog, is shown below in Figure 4. Descriptions of these components and their features and benefits follow.

Manncorp Expert 04.6X
Gaming Console Repair Station

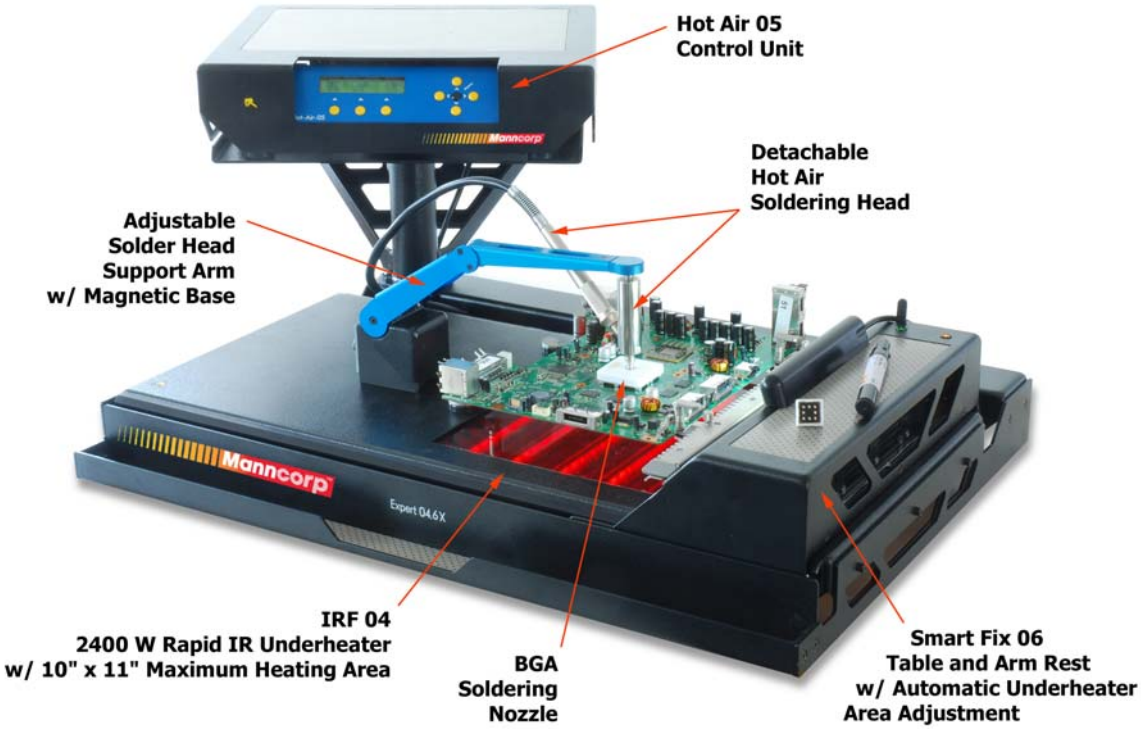


Figure 4

IRF 04 Rapid IR Underheater and Smart Fix 06 Table

Measuring only 19" long and 12.5" wide, the **Smart Fix 06 Table** and its integral **IRF 04 Underheater** provide a 10" x 11" maximum heating area; plenty large enough to accommodate the Xbox 360 motherboard. Based on our experience, the ability to heat the entire underside of the PCB uniformly is absolutely critical for successful rework. According to Bernhard Martin, steep thermal gradients across the surface of the PCB during rework operations, caused by improper underheating, are a leading cause of board warpage and degradation of solder joint integrity for other components in areas adjacent to the device being repaired. Other important issues are the ability to heat the underside of the PCB fast enough to make high-volume repair operations feasible and also the ability to raise the temperature of the PCB to a high enough (but safe enough) temperature to minimize the amount of heat energy that will have to be applied from the top side. The IRF 04 meets all of these criteria and more by delivering up to 2400 W of rapid and uniform IR underheat, needed to quickly raise the temperature of the bottom side of the PCB to between 130-160°C (recommended for lead-free solders), but also, without exceeding the 4°C ramp rate specified by most component manufacturers. Once the desired underheat temperature is attained, the extremely fast response of the IRF 04 and its controller allows the PCB temperature to be maintained throughout the rework cycle. The importance of proper underheating can not be overstated and, according to Martin, he developed and patented Rapid IR underheating because of its ability to provide superior response, uniformity, and controllability in comparison to other bottom heating methods, including hot air. Rapid IR underheating also offers a considerable advantage over ceramic and other plate-type underheaters, in that it doesn't require direct contact

with the underside of the PCB. More than an inch of allowable clearance between the PCB and the top surface of the IRF 04 allows the system to easily handle double-sided boards, especially important because of the four CSPs on the bottom of the Xbox 360 motherboard. The magnetic board supports supplied with the unit will accept the Xbox 360 motherboard when it is flipped over, should rework have to be performed on the bottom of the PCB. Another nice energy-saving feature of the IRF 04 is that when the PCB supports are repositioned to accommodate smaller boards, the arm rest of the Smart Fix 06 Table slides to the left and will automatically switch off banks of IR heaters in the IRF 04 that will not need to be used. Rapid IR is also quite safe. The surface of the IRF 04 is cool to the touch within seconds after it is turned off.

Hot Air 05 Control Unit and Hot Air Soldering Head

Simply put, the Hot Air 05 Control Unit controls the flow of air and the power to the heaters in the Hot Air Soldering Head so that specific component soldering (and desoldering) operations can match the thermal profiles recommended by solder paste and component manufacturers. The control unit features clear, user-friendly menus and will hold up to 100 different soldering programs which include time, temperature, and air flow parameters for preheat, reflow, and cooling phases, as well as variable power settings for the IRF 04 underheater. Pre-established programs for dozens of standard SMDs come pre-loaded into the unit and Hot Air 05 Control Units included in Expert 04.6X Gaming Console Repair Stations will obviously include programs specifically for the BGA and CSP components on the Xbox 360 motherboard. What's more, the thermal profiles produced using the parameter settings from these programs will be extremely precise because they were created using the actual components and the actual PCB. Naturally, all programs are editable, and SolderStar™ software and an interface cable included in the Gaming Console Repair Station package allow on-line or off-line programming on a standard PC (see Figure 5), with program upload and download capability for unlimited off-line program storage.

Another major advantage of this equipment is that we have dramatically simplified programming and operation through an auto-profiling routine that quickly, automatically, and safely generates profiles for a wide variety of applications with minimal operator input. Martin has designed the auto-profiler in a way that ensures that, when the equipment is used properly, all profiles (including those we've developed for the Xbox 360 motherboard) will conform to what he refers to as his Five Rules for Perfect Lead-Free Reflow Soldering. These are:

1. For the majority of SMDs, manufacturers specify maximum allowable temperature exposure as 240°C for 40 seconds or less, 260°C for 10 seconds or less. Since our reflow processes tend to be very short and we will almost never attain temperatures this high anyway, we set a maximum temperature limit of 250°C for all of our profiles.

2. We always want to ensure that the solder joint briefly reaches at least 230°C (minimum); the recommended temperature above the liquidus temperature of 217°C for lead-free solders.

3. Temperature above the 217°C liquidus should be maintained for no less than 25 seconds, but no more than 90 seconds.

4. The rate of temperature increase throughout the rework process should not exceed 4°C/second, based on most component manufacturers specifications.

5. The entire underside of the PCB (without the contribution of top heating) should be maintained between 130°C and 160°C throughout the process.

Bound by these rules and the functionality built in to the auto-profiling tool, it is virtually impossible to damage boards or components when the equipment is used properly.

The Hot Air 05 Control Unit supplied with the Expert 04.6X also includes a measurement module that accepts input from two K-type thermocouple sensors, also included, so that actual, real-time temperatures can be viewed, verified, and recorded using the SolderStar™ software.

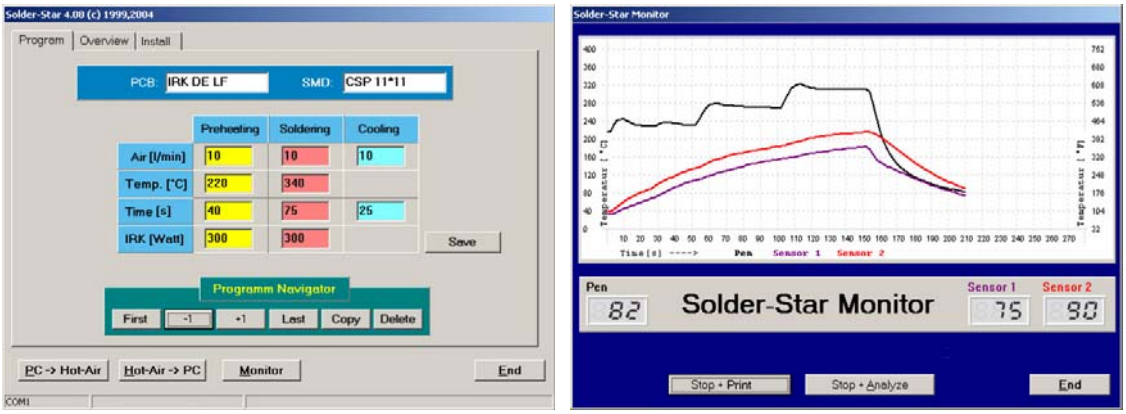


Figure 5

Nozzles and Support Arm for Hot Air Soldering Head

Expert 04.6X Gaming Console Repair Stations will also include a 35 mm x 35 mm BGA nozzle that can be used for both the CPU and GPU devices (Figure 6) and a 16 mm x 16 mm CSP nozzle for the 8 memory components. It is our impression that issues involving the XSB component are negligible, although nozzles to accommodate any of the other SMDs on the Xbox 360 motherboard can be substituted or added from a vast selection.

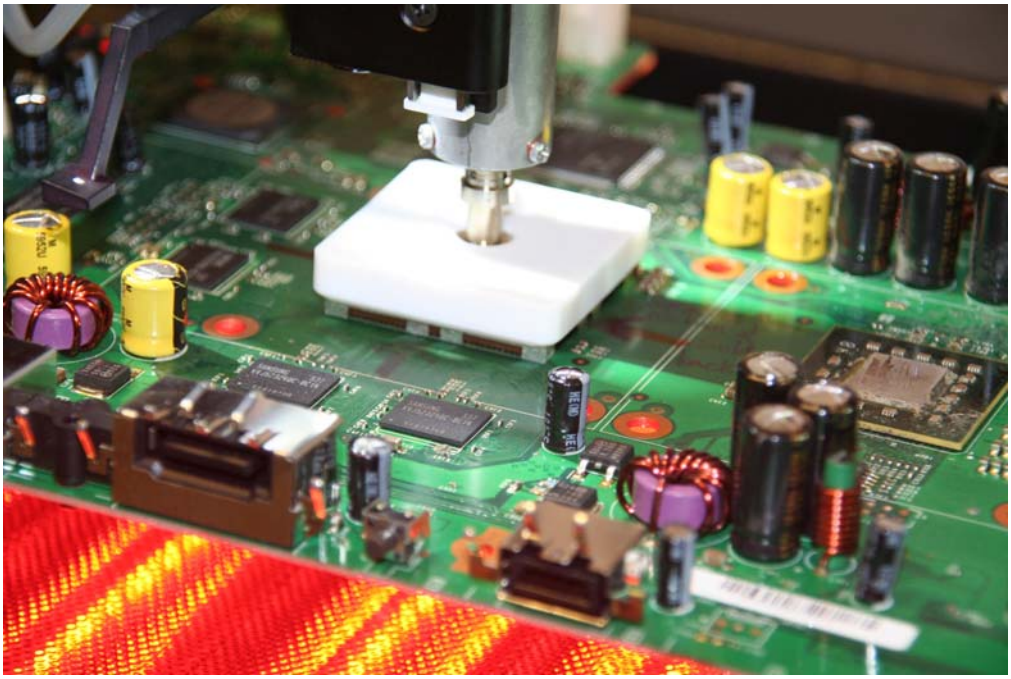


Figure 6

Nozzles simply and easily snap on to the bottom of the Hot Air Soldering Head. The head and nozzle assembly then snaps in to the Adjustable Support Arm which can be easily positioned so that the nozzle can be lowered over the component as shown in Figure 6; the entire process taking only seconds. The locking magnetic base on the support arm maintains the position of the head and nozzle assembly during the reflow process.

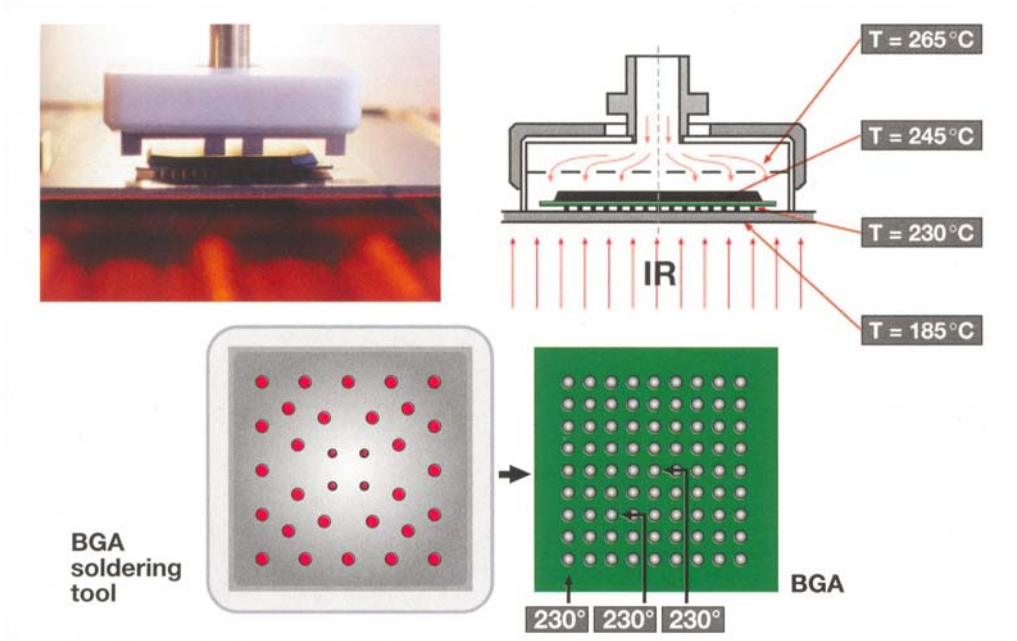


Figure 7

Figure 7, which shows both a cross sectional view and bottom view of the BGA soldering nozzle, illustrates how its baffle design promotes even dispersion of the hot air flow above the surface of the component for uniform heat distribution across the entire device footprint (when aided by even, controlled IR underheat).

Full Reporting Capability for QC Traceability

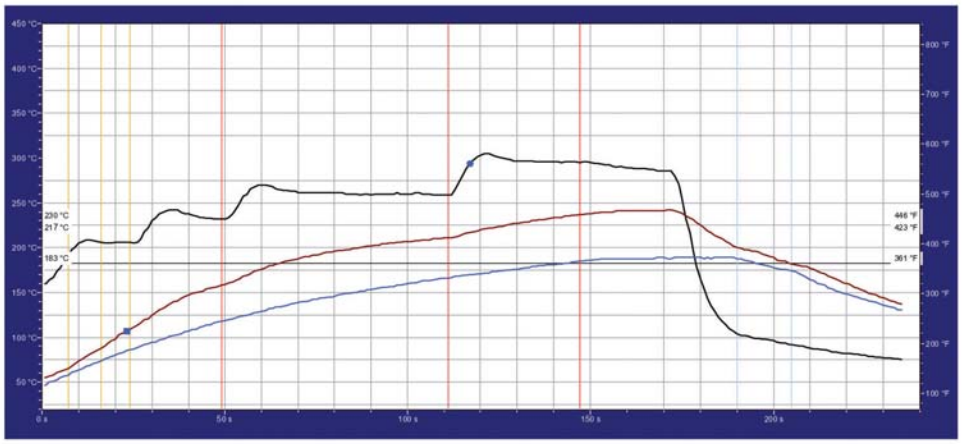
Because we anticipate that traceability will be of great importance to those performing Xbox 360 motherboard repair, we have also decided to include the full reporting option as a standard feature in SolderStar™ software included with the Expert 04.6X Gaming Console Repair Stations.

The reporting function allows PCB specific information (name, serial number, etc.) to be entered either manually or via barcode reader and linked to a file containing the actual process parameters for that particular PCB and the specific component repaired. An actual report from one of the tests performed on the Xbox 360 GPU device is shown in Figure 8. The file also includes a plot of the real-time profile measured during the operation. Files are saved in HTML format and are automatically archived each month. Individual records can be saved as PDF files which can be printed and delivered with reworked motherboards.

Expert 04.6X Repair Report

Xbox 360 Motherboard

Time: 09.07.2007 16h Process: Solder PCB: motherboard LP ID: XXXX SMD: GPU



	Preheating	Soldering	Cooling
Air [l/min]	35	35	20
Temp. [°C]	200	295	0
Time [s]	50	122	45
IRF04 Heater [W]	Rapid IR	Rapid IR	0

Username	Admin
Lead Free	Yes
Profiles have been changed	No
Profil cancelled:	No
IR Rapid technology	Yes
IR Rapid t [s]	150
IR Rapid S [W]	2400
IR Rapid E [W]	2400
IR Rapid H [W]	1800
Max. temp. pen [°C] - hot air	305.0
Max. temp. S1 [°C] - SMD	242.0
Max. temp. S2 [°C] - PCB	189.0

Max. gradient pen [K/s] – hot air	7.0
Max. gradient S1 [K/s] – SMD	2.9
Max. gradient S2 [K/s] – PCB	1.7
Process Capability Temp. pen (PCT) [°C] – hot air	260
Area over PCT pen [sK] – hot air	2127.9
Time over PCT pen [s] – hot air	91.0
Process Capability Temp. S1 (PCT) [°C] – SMD	217
Area over PCT S1 [sK] – SMD	1069.1
Time over PCT S1 [s] – SMD	65.0
Process Capability Temp. S2 (PCT) [°C] – PCB	180
Area over PCT S2 [sK] – PCB	408.1
Time over PCT S2 [s] – PCB	60.0
SMD levels:	0

Figure 8

Conclusions and Upgradeability

At this stage, as we've already indicated, we believe that the majority of the Xbox 360 motherboard failures can be corrected by simply resoldering the problem devices in place, properly, without having to completely remove them from the PCB. In tests conducted on actual Xbox 360 motherboards we have already proven that precision preheat, reflow, and cooling can be performed on selected components in less than 200 seconds total. Nevertheless, if it is determined that any of these devices are damaged beyond repair and do require removal and replacement, Expert 04.6X can be easily upgraded with the necessary accessories.

Once the BGAs and CSPs are removed from the PCB, we feel it is imperative to completely clean and re-ball the components and to remove all solder residue from the pads on the PCB. An optional reballing tool, which attaches to either of the two hot air soldering heads supplied standard with the system, and an optional vacuum wand are all that are needed.

For replacement of the components, our Auto Vision Placement (AVP) accessory, which includes the AVP 03 Positioning Arm with automatic X, Y, Z, and R axis control and Easy Solder™ software, can be added to the Expert 04.6X in a matter of minutes.

Contact Information

If you would like additional information or are interested in a demonstration, call 800.PIK.MANN (745.6266) or visit **manncorp.com**.

For over 40 years, from the early days of solid-state assembly through today's most advanced surface mount technology, Manncorp has been building its trusted reputation as an industry-leading supplier of products and equipment for all types of electronic assembly. Searching the world over for the best available technologies, Manncorp has built long-standing supplier relationships with recognized authorities, like Bernhard Martin, to bring their expertise and equipment innovations to our loyal customers.