USE OF BOND WIRES IN ICS IN FIRE INVESTIGATION

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ABSTRACT

Traditional electrical engineering analysis of household or commercial appliances has made use of arc mapping, arc sequencing, overcurrent device analysis, and conductor failures to determine whether or not a given electrical appliance was a candidate for having started a fire. These techniques, while valuable, are becoming more difficult to implement, given modern OCP schemes such as PTC devices or self-resetting thermal circuit breakers.

Conventional ICs (Integrated Circuits), with the exception of BGAs (Ball Grid Arrays), make use of gold wires (.7 0r 1.0 mil typical diameter) to connect a pin on the leadframe to the signal pad on an IC. These wires are encapsulated in the epoxy (or similar) potting material, and as such, are usually quite robust in terms of avoiding fire damage. These gold wires are termed *bond wires*.

The common 3AG fuse makes use of a long, thin element (wire) in order to protect electrical circuitry. Our research has shown that the 3AG fuse is not much different than is the bond wire used to connect a signal pad on a die to the leadframe for an IC. As such, we would expect similar behavior during some overcurrent conditions.

A group of 10 DVD players each was supplied power, and then injected internally with ETOH, 95%. A flame was applied, and the alcohol vapors ignited. After the fires were left to burn out, the PCB (Printed Circuit Board) on each DVD player was removed and inspected. The inspection made use of MF RT (Micro Focus Real Time) X-ray techniques. This allowed the gold bond wires in each IC to be seen. On several of the DVD players, the initial inspection showed that one or more of the bond wires was 'missing' from the controller IC. The ICs with 'missing' bond wires were then imaged using CT techniques, and then reconstructed using *Volume Graphics* software. The reconstructed images show that the bond wires do serve as fuses under certain conditions, and the presence of a blown bond wire is a good indicator that the appliance was powered during the fire event that caused the bond wire to electrically fuse.

We also demonstrate the actual usage of this technique. A reportedly non powered appliance was being blamed for a fire. The fire destroyed a house, and the suspected 'non powered' appliance was also heavily damaged. The ICs were recovered from the appliance, and then imaged. One IC had multiple fused bond wires, consistent only with the appliance receiving power during the fire. The belief that the appliance was not powered during the fire was disproven.

The technique is expensive in terms of capital costs, but it provides data that was heretofore overlooked. The technique is also useful because it does not require actual make or model (or even function) of a given appliance in order to carry out the analysis. However, knowing circuit parameters (component layout, schematic) will allow one to carry the analysis even further.

The technique is no panacea for all appliances. One cannot use the *bond wire analysis* technique alone to determine that an appliance failed and caused a fire. What can be said is that if the appliance was working prior to the fire, and after the fire it had failed bond wires internally, the appliance was receiving power during the fire.

IC FABRICATION

The conventional Integrated Circuit (IC) makes use of a silicon die (the 'chip') mounted on a leadframe. The signal, data and / or power voltages and currents are transmitted from the bonding pads on the chip / die to the leadframe by way of Au wires. These wires are typically pure Au, either .7 or 1 mil in diameter. Photo 1 depicts a large IC (64 pin) with the wires routed from chip to Au pads at the leadframe.

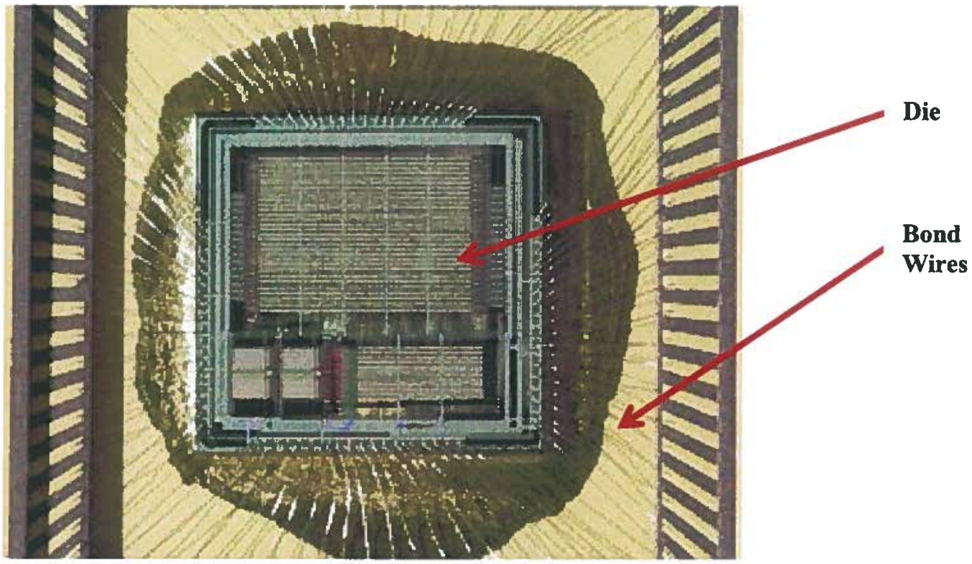

Photo 1 - Chip Within IC Showing Numerous Bond Wires

Depending on the IC, the wires can be as few as 4, or as many as 128. The wires are attached by thermosonic or ultrasonic welding processes. At the chip, the wire uses what is known as a ball bond. At the pinout or leadframe, the welding process makes use of a wedge bond. Photo 2 shows a Au ball bond, while Photo 3 shows a SEM view of a ball bond.

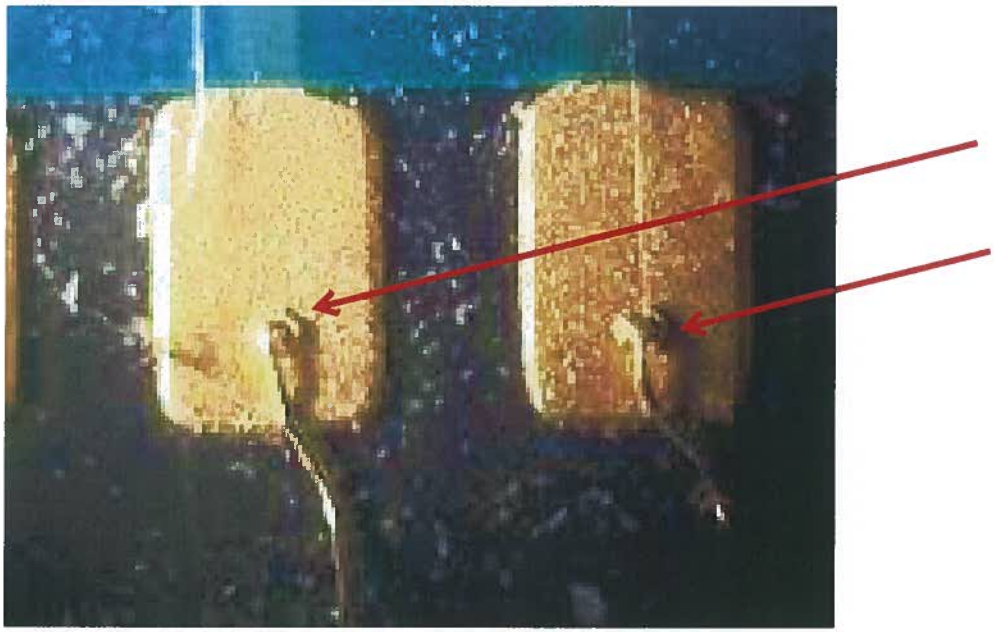

Photo 2 – Ball Bonds On Gold Pads, Indicated By Red Arrows

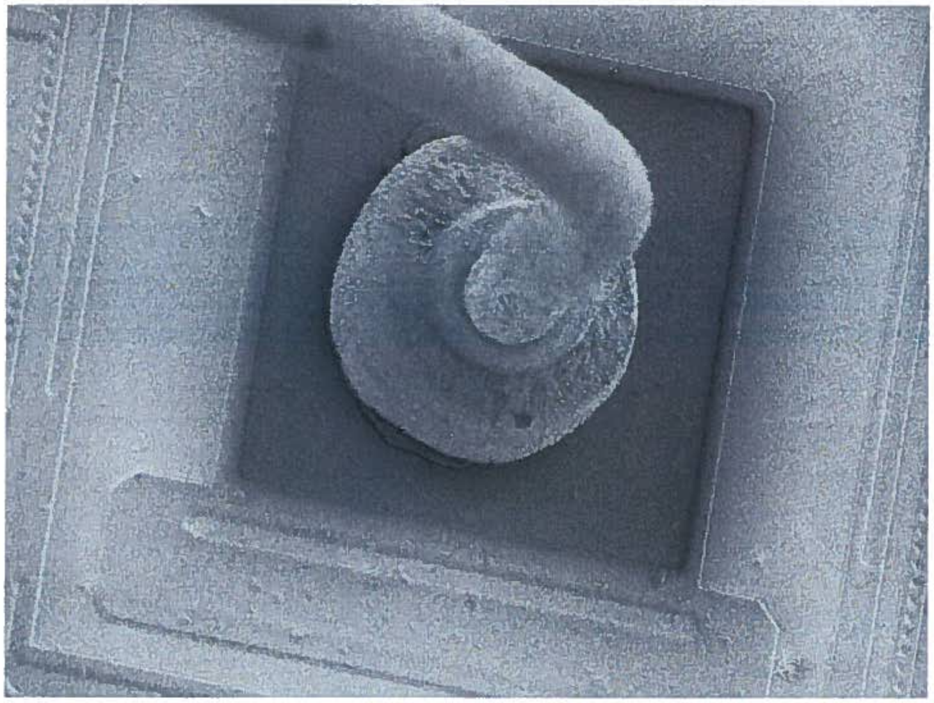

Photo 3 – SEM View Of Au Ball Bond And Bond Wire

What is important to remember is that the IC has a number long, gold wires; Photo 4 depicts such wires. These gold wires have a high melting point, 1948 deg F. Moreover, the IC housing (typically a thermoset plastic or epoxy) will shield the Au wires from the heat of the fire. In essence, each IC has a number of internal fuses which can be analyzed after a fire, to see if any of the fuses have blown.

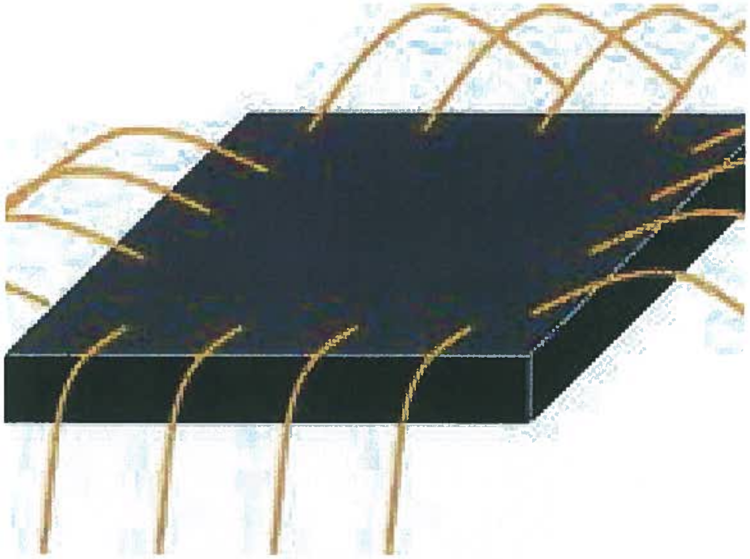

Photo 4 – Diagram Of Bond Wires On An IC

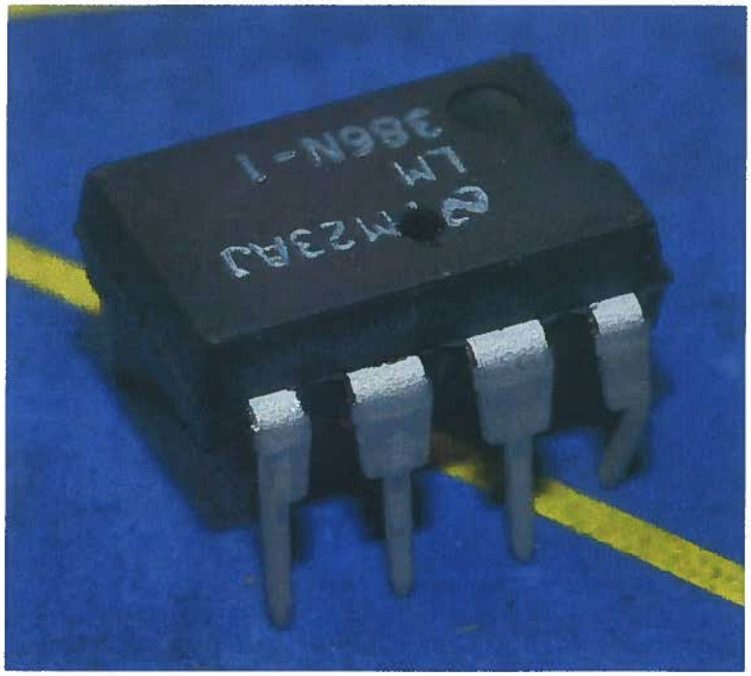

Photo 5 Depicts A 8 Pin DIP Package, With The Chip And Wires Encased In Epoxy

Photo 5 shows an 8 pin IC, known as a DIP (Dual Inline Package). The chip, wires, and part of the leads are encased in the thermoset (epoxy) plastic housing. This IC is a LM 386, which is an audio amplifier. An x-ray view of the LM 386 is shown in photo 6.

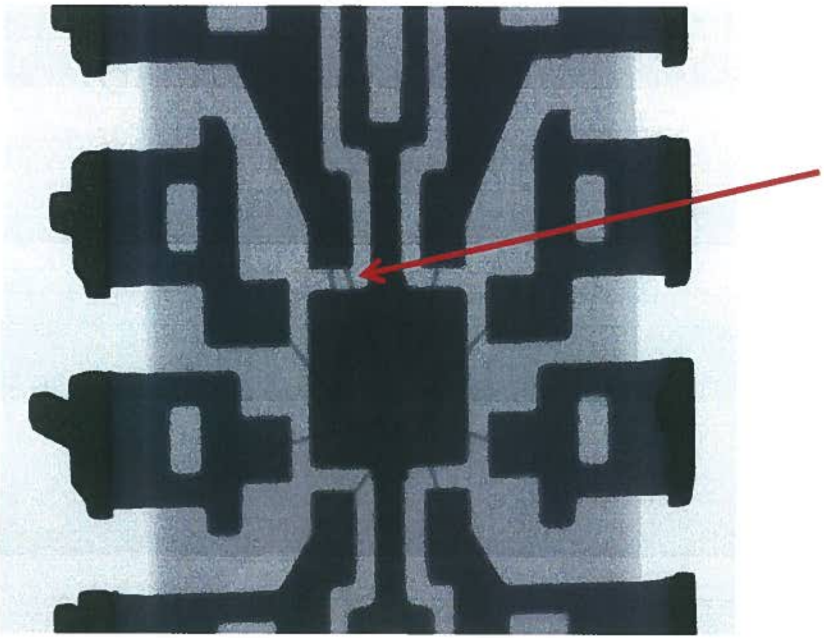

Photo 6 – X-Ray View Showing Bond Wires On The LM 386. Note The Double Bond Wire On The Ground Lead, Indicated By Arrow.

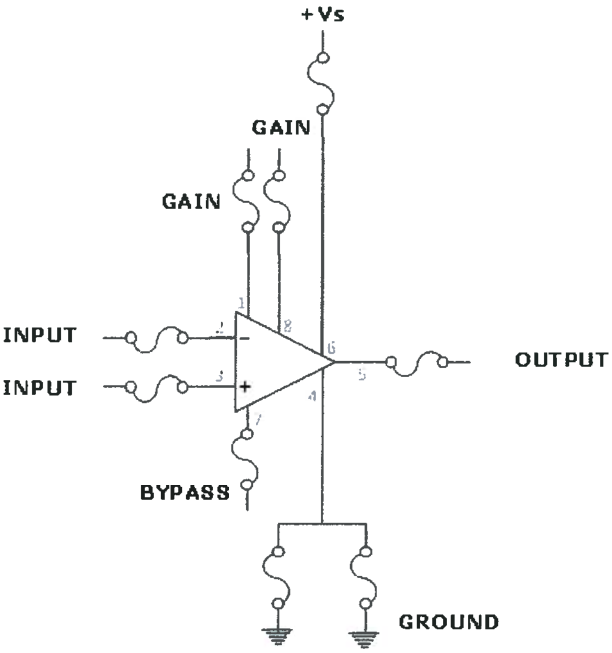

Photo 7 – Schematic Of LM 386 With Fusing, As Well As Double Fuse On Ground

RESEARCH

The hypothesis behind our research is that long Au wires which are connected to functioning electrical circuits have the ability to act as OCP (Over Current Protection) an would lend themselves to post fire analysis. If our hypothesis is proven, the electrical engineer has another data point that can be considered in analyzing whether electricity played a role in a fire's causation.

In analyzing the hypothesis, one has to consider what makes a fuse trip / open. This is brought by overcurrent which (presumably) comes from a circuit malfunction. This malfunction *may* be the cause of the fire; in the alternative, the heat from the fire may change circuit operating characteristics such that overcurrent develops and cause the 'fuses' to trip.

The first part of our investigation was to determine whether X-ray analysis would pick up such malfunctions (blown 'fuses'). We x-rayed an LM 386 and verified that its bond wires could be seen by X-ray. For this application, multiple experiments were conducted. We settled on a Nikon MF RT (Micro Focus Real Time) technique. The MF feature gives the user the clarity to see the Au bond wires (very thin) which are encased in the epoxy. Optical multiplication of the target allowed the wires to be easily discriminated. We recommend RT (Real Time) if one plans to use this technique routinely. Film *can* be used, but it is burdensome, and does not lead to the second step – reconstruction.

We took an LM 386 amplifier, and applied 36 volts to it, across the Vcc and ground terminals. Testing of the IC thereafter showed that it had failed. MF RT x-ray showed that a wire was missing, corresponding to pin 4. Photo 8 shows the location of the missing wire. After noting the missing wire, the IC was subjected to CT (Computed Tomography) and then reconstruction. For software, we used a program called *Volume Graphics (VG)*, published in Germany. Using VG, the reconstructed image was analyzed, and is shown in Photo 9. The VG reconstruction shows that the bond wire serving pin 6 has evaporated. A review of the schematic shown in Photo 7 indicates that pin 7 is Vcc, the supply pin.

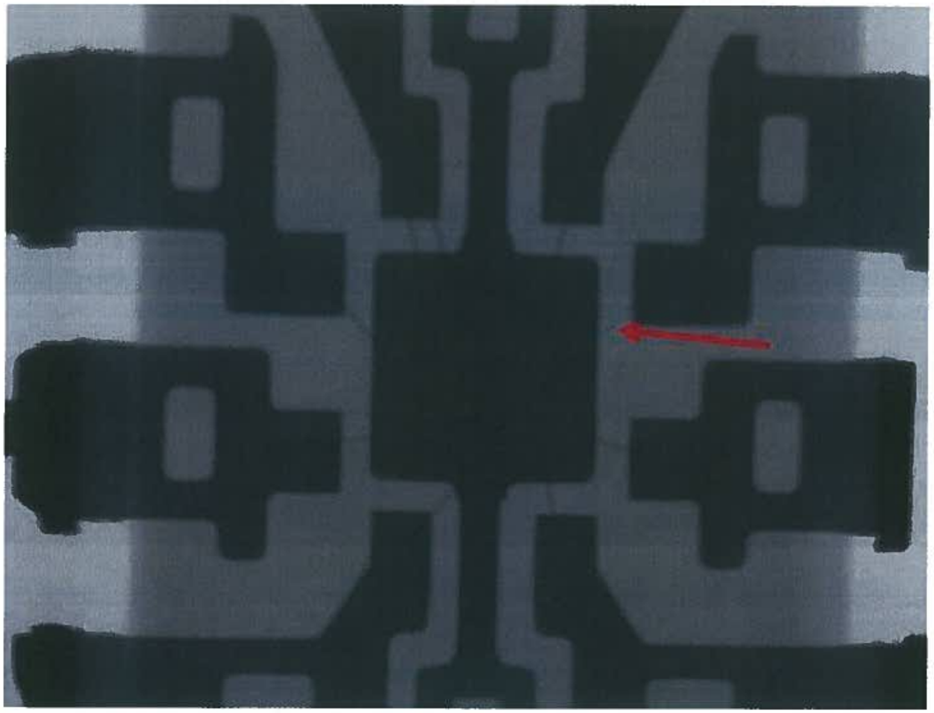

Photo 8 – Note The Lack Of A Bond Wire On Pin 6.

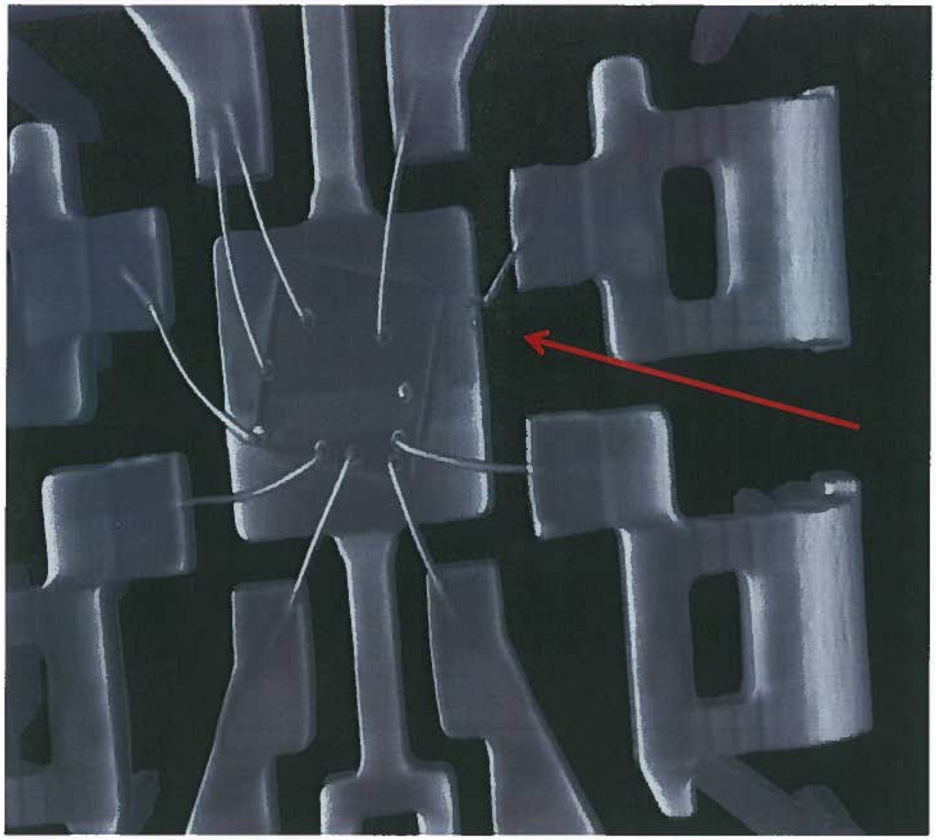

Photo 9 – VG Reconstruction After CT, Shows Remnants Of Evaporated Wire On Pin 6

We thus have confirmed that bond wires can be seen on RT MF x-ray, and that CT imaging and reconstruction will allow the missing Au bond wires to be further scrutinized.

The second part of the research involved burning live appliances. We took 10 random (but functional) DVD players bought from pawn shops, and poured 2 oz of ETOH (Everclear) in each chassis. The units were powered. Thereafter, the units were ignited and left to burn in open air. Afterwards, the PCBs (Printed Circuit Boards) were taken out and x-rayed. If a bond wire appeared to be missing, we then subjected the corresponding IC to CT imaging and reconstruction. Photo 10 shows such an x-ray of an IC, with suspicious areas (2) outlined.

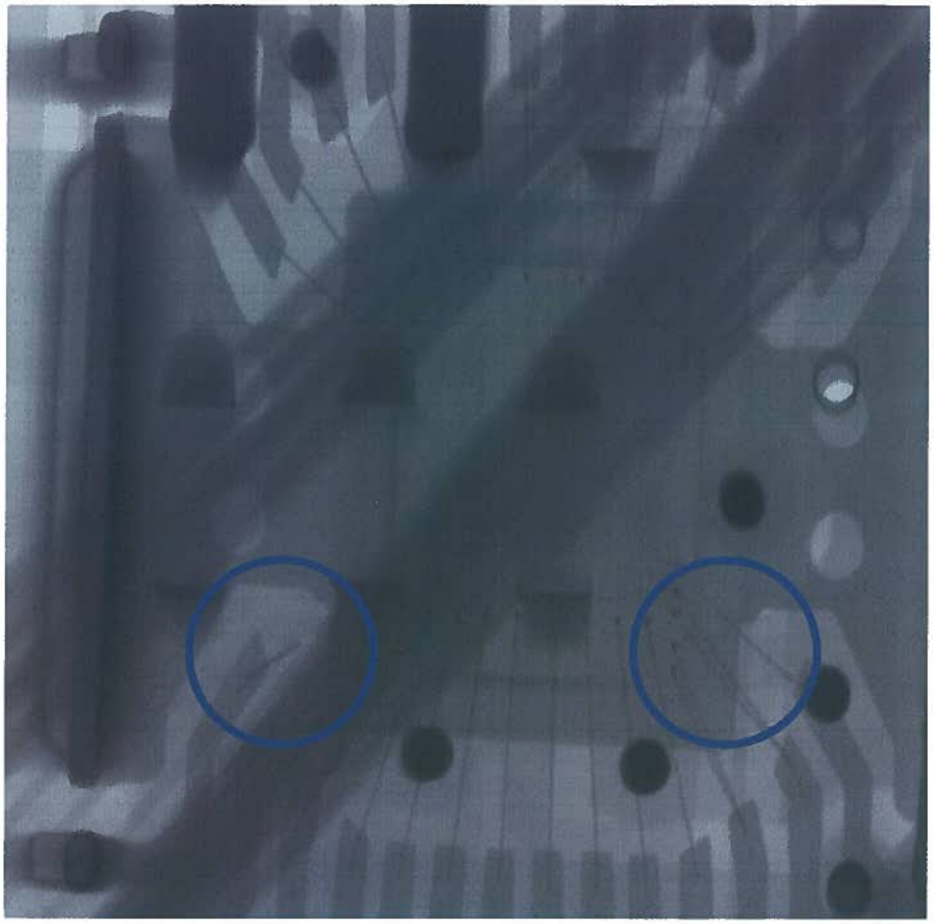

Photo 10 - Possibly Damaged IC From DVD Player – Circles Indicate Areas Of Interest

Photo 11 shows the two areas of interest, plus the other areas of bond wire interconnect on the IC. It is clear that the x-ray (photo 10) was capable of picking out and highlighting the area(s) of concern, with the CT reconstruction then verifying the damage.

DISCUSSION

In 2 of the 10 DVD players, we were able to confirm damaged bond wires. One might look and this statistic and say that the tool/ technique is useful 20 percent of the time it is used. In truth, every appliance is different, and their reactions to a fire will in part depend upon what other appliances are present (they may short out and cause a circuit breaker to trip), as well as the angle of attack of the fire.

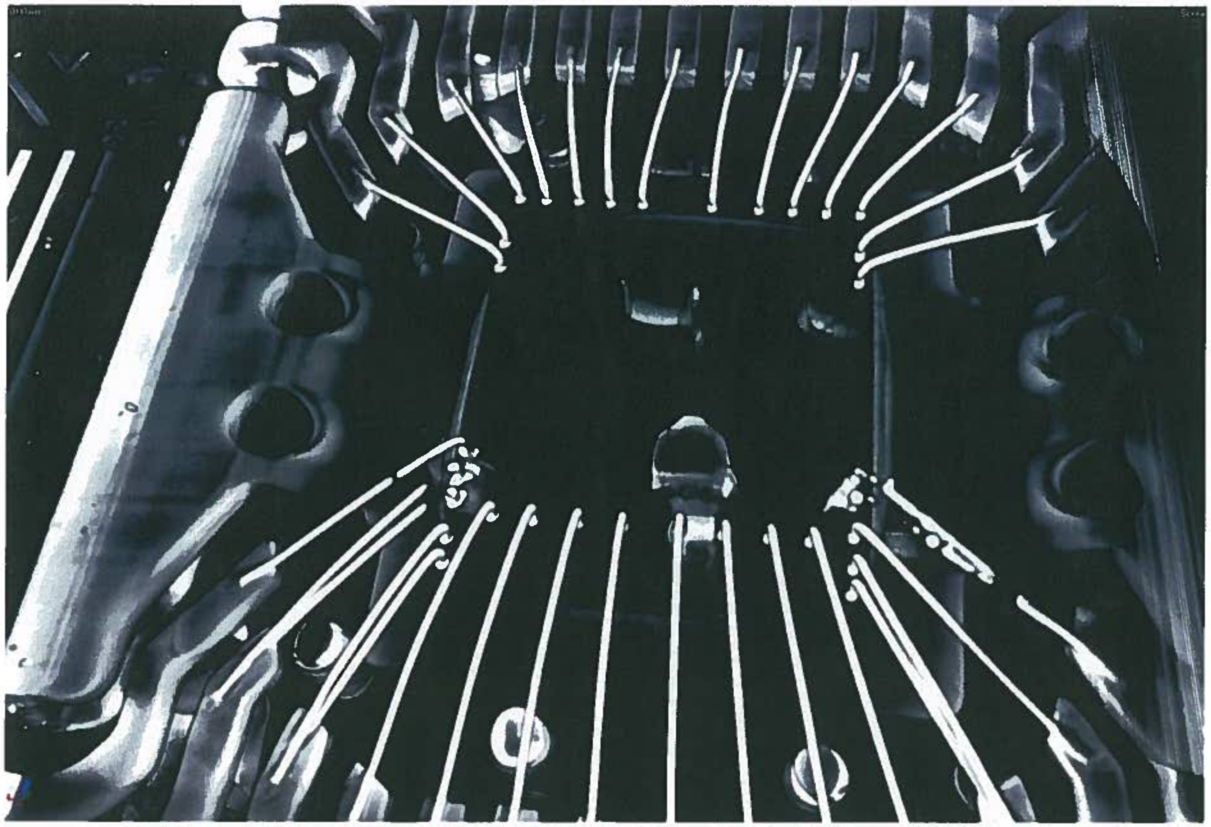

Photo 11 – VG Reconstruction Of IC After CT Scan, Confirming Damaged Bond Wires

In understanding this process, it is necessary to delineate what the findings do and do not mean. The underlying theory is that a given appliance with ICs present *may* experience overcurrent during a fire sufficient to cause ICs to fail. More specifically, the overcurrent may cause IC bond wires to separate. IF such separation occurs, what can be gleaned? What can be positively said is that the blown 'fuses' indicate power was present. To try and state that this indicates a malfunction may be overextending the value of the technique.

One of the underlying assumptions made is that the appliance was working prior to the fire. If this cannot be established, who is to state that the appliance did not fail on its own prior to the fire, albeit serendipitously?

An improper assumption made when using this technique is that overcurrent will always be present in electronics circuitry. Such an assumption is not always valid. As an example, a fire that shorts out the line cord before it attacks the electronics will have no damaging overcurrent in the electronics. Similarly, some electronics fail in a fire by thermal energy damaging the semiconductor lattices before they will allow overcurrent to flow and blow open bond wires. Likewise, as the LM 386 analysis will demonstrate, one would NEVER expect bond wires to the inputs to be damaged – the 15 K ohm internal impedances do not allow for substantive overcurrent to develop.

WHEN IS THIS TECHNIQUE USEFUL?

We feel that this technique is useful in analyzing many electronics fires. One usually does not suffer from having too much data. In a recent fire, the fire investigator had narrowed the area of origin down to a hot tub, its controls and its motors. When examined, there were no arcs found – this is not a surprise, in that the required GFCI had tripped. Moreover, in that copper wires were melted, arc damage could not be delineated. The defense maintained that the hot tub and its components could not have started the fire, as power was not present.

The PCB contained several LSI (Large Scale Integration) ICs. Each was x-rayed using a MF RT technique. Photo 12 shows the insides of the metal control cabinet and the various circuitry remains – the items are heavily damaged by heat.

Photo 12 – Internal Parts Of Hot Tub Controls

The x-rays of the ICs were examined. One IC had noticeable damage internally, as seen on photo 13. A check of the pinout for the IC verified that one of the leads of interest was a power lead (Vcc), and that it was partially vaporized.

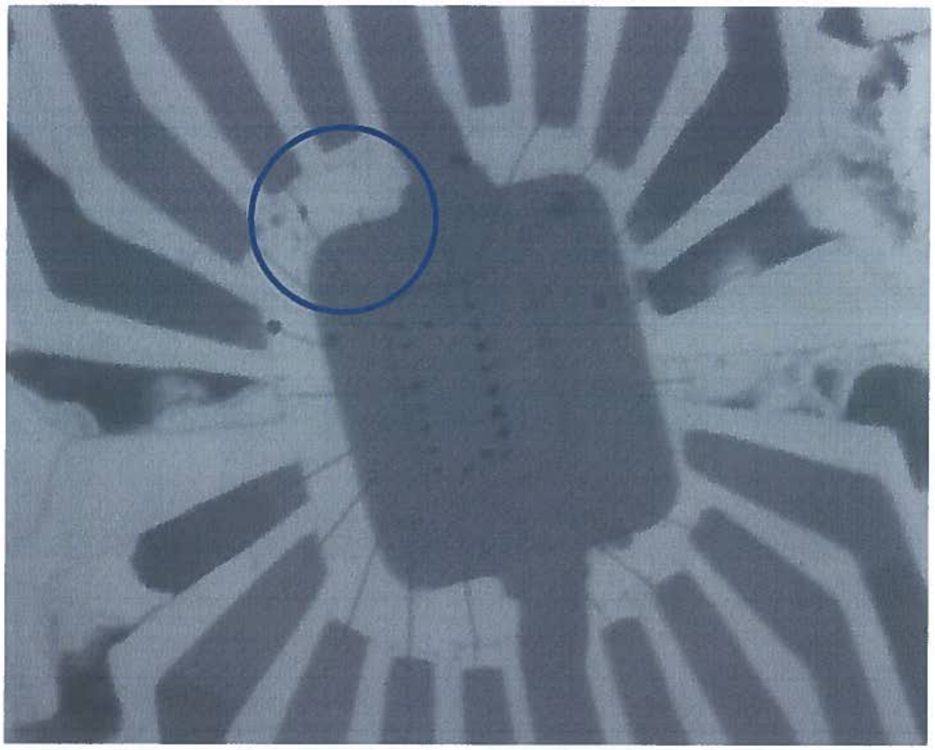

Photo 13 – Circle Denotes Area Of Suspected Damage To Bond Wires

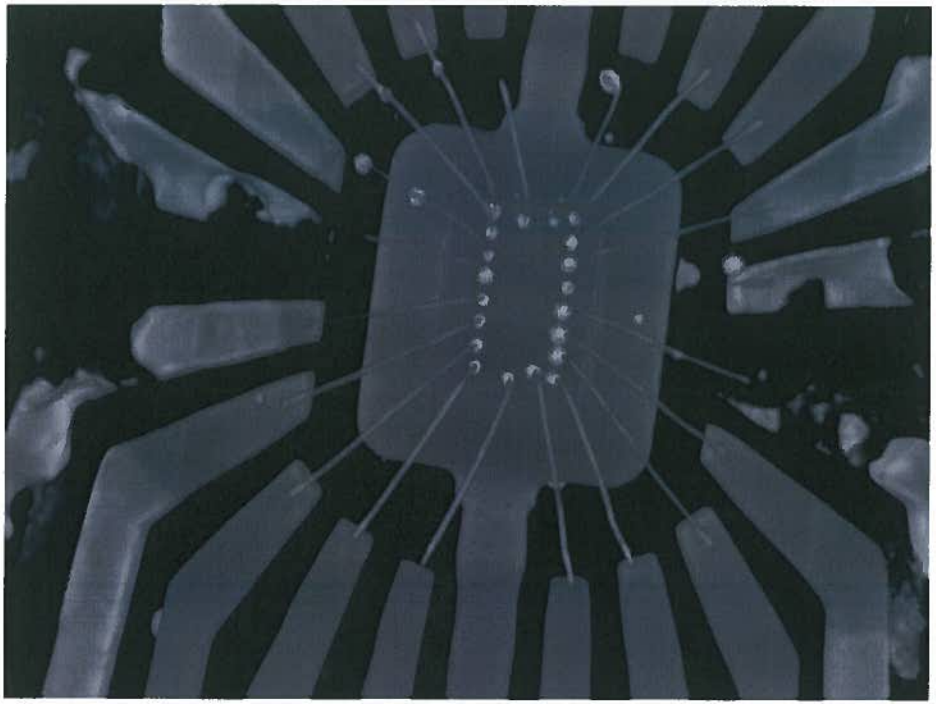

Photo 14 - Internally Damaged Bond Wires

The IC was subject to a CT scan, and the data then reconstructed. Photo 14 shows the internal layout of the same IC, after reconstruction. The Vcc lead was confirmed in terms of its evaporation. We also were able to determine that 120 volts (or similar voltages) were present on the IC, based on damage to the pinout.

SUMMATION

What has been presented is a novel way of analyzing electronics circuits to determine 'fuse' condition. The technique uses very expensive equipment ($500,000 or so for a CT scanner). The technique works by using Micro Focus Real Time x-ray to look at the internal bond wires to see if they have evaporated. If the bond wires are missing or damaged, CT is executed, with the various slices then reconstructed using Volume Graphics or a similar program. The reconstructed image can then be viewed, and decisions made about bond wire conditions. The technique requires no prior knowledge about the equipment, its internal functioning, or IC part numbers.

The data can be used to determine if power was present on a piece of equipment. The user is cautioned, however, that the lack of bond wire damage does not mean that the equipment was not powered during a fire. Similarly, there are multiple explanations for blown bond wires, and the user is cautioned to be judicious in determining the meaning of such open bond wires.

ABOUT THE AUTHORS

Mark Goodson received a BSEE from Texas A&M in 1979, and is licensed to practice engineering in numerous states. After engineering school, he attended UT Southwestern (Dallas) in a forensic medicine track. He was the first PE to serve on the State of Texas Electrical Board. From 1989 to 1991, he served as a Court Special Master. He is the PE selected to sit on the Texas State Fire Marshal Science Advisory Workgroup, SAW. He is a member of the Editorial Review Board for the *Fire & Arson Investigator*
Mr. Goodson is the principal in the firm Goodson Engineering of Denton, Texas. He holds 3 patents on fire safety, and has 4 more pending. He has published 35 peer reviewed technical articles, with 30 of them dealing with fire science. He has published in the *Fire & Arson Investigator*, *Journal of Forensic Sciences, American Journal of Forensic Pathology*, and the *Forensic Sciences Gazette*. Mr. Goodson serves as a consultant to many Medical Examiners' Offices in Texas.

Lee Green is a Mechanical Engineer who is licensed to practice engineering in ten states. His BSME degree was received from Oklahoma State University and has completed two master's degrees; one is Systems Engineering and one in Engineering Management, from Southern Methodist University. He currently works for Goodson Engineering performing failure analysis. Lee has performed root cause failure analysis on many items large and small from wind turbines and vehicles, to residential appliances and plumbing systems. The majority of failures have resulted in personal injury, water losses, and even fires. His previous employment was at Peterbilt in which he designed front engine accessory drive componentry.

Michael Shuttlesworth is a Mechanical Engineer who is licensed to practice engineering. His BSME degree was received from Oklahoma Christian University. He works for Goodson Engineering performing failure analysis on residential appliances and plumbing systems. His specialty is in Mechanical and Electrical failure analysis instrumentation.