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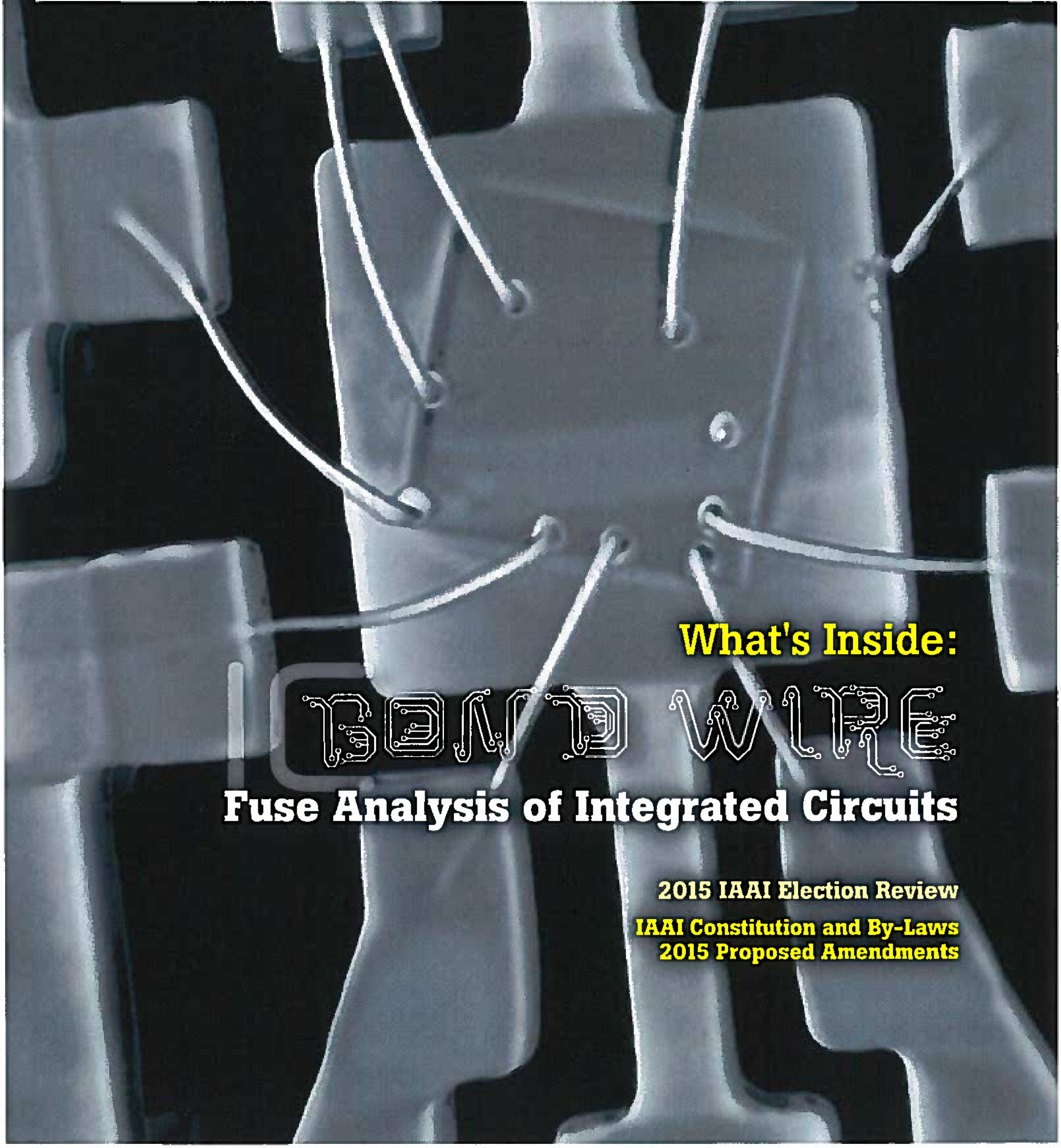

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BOND WIRE FUSE ANALYSIS OF INTEGRATED CIRCUITS

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INTRODUCTION

INTEGRATED CIRCUITS (IC) ARE USED IN ALMOST ALL MODERN DAY ELECTRONICS. THE INTEGRATED CIRCUIT WAS DEVELOPED BACK IN 1958 BY DR. JACK KILBY. DR. KILBY WORKED ON CREATING SMALLER CIRCUIT BOARD COMPONENTS. DURING DR. KILBYS EMPLOYMENT AT TEXAS INSTRUMENTS HE FOUND AND PATENTED HIS IDEA FOR "MINIATURIZED ELECTRONIC CIRCUITS."

FOR THE READER, THIS PAPER WILL EXPLAIN THE "TOP LEVEL" COMPONENTS OF THE INTEGRATED CIRCUIT. FOLLOWING EXPLANATION OF THE CONSTRUCTION OF THE INTEGRATED CIRCUIT, THE PAPER WILL WALK THROUGH A PROCESS TO DETERMINE WHETHER OR NOT AN ELECTRONIC COMPONENT WAS ENERGIZED DURING A FIRE EVENT.

THE READER MUST BE CAUTIONED THAT JUST BECAUSE THE PROCESS SET FORWARD BELOW DID NOT SHOW PROOF OF AN ELECTRONIC DEVICE BEING POWERED ON, DOES NOT NECESSARILY MEAN THE DEVICE WAS NOT ENERGIZED. THIS PROCESS CAN PROVE THE DEVICE WAS ENERGIZED, BUT NOT THAT THE DEVICE WAS NOT ENERGIZED.

TOP LEVEL INTEGRATED CIRCUIT COMPONENTS

There are four main components to most integrated circuits. They are defined below and illustrated in Photo 2.

DIE - the silicon chip, which can perform various electrical functions

LEADFRAME - holds the die, and is also where signals and power enter and leave the IC

BOND WIRES - carry signals and power to and from the leadframe and the chip

HOUSING - the molded polymeric housing, usually black, that holds the other components mentioned above in place

There are many different types and sizes of integrated circuits. They each perform a specific function. For the sake of simplicity, an 8 pin audio amplifier will be used to illustrate the different parts of an integrated circuit. The LM386, an audio amplifier, is shown in Photo 1.

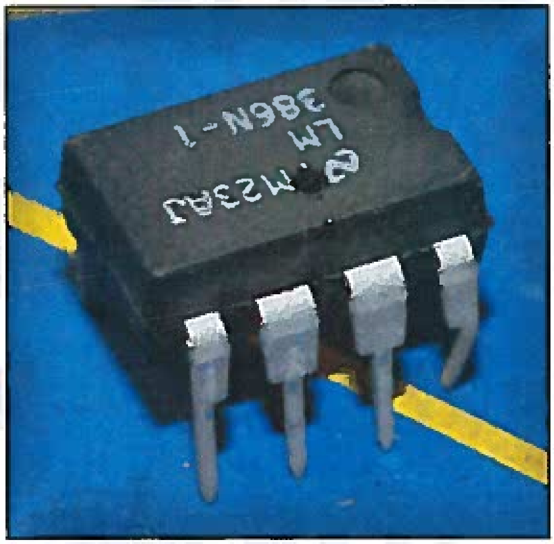

PHOTO 1 – External View of IC, LM386 Audio Amplifier.

The LM386 integrated circuit pictured above was put into a Nikon XTH-225 Computed Tomography x-ray machine. The microfocus x-ray produced is shown below to illustrate the integrated circuit top level components defined above.

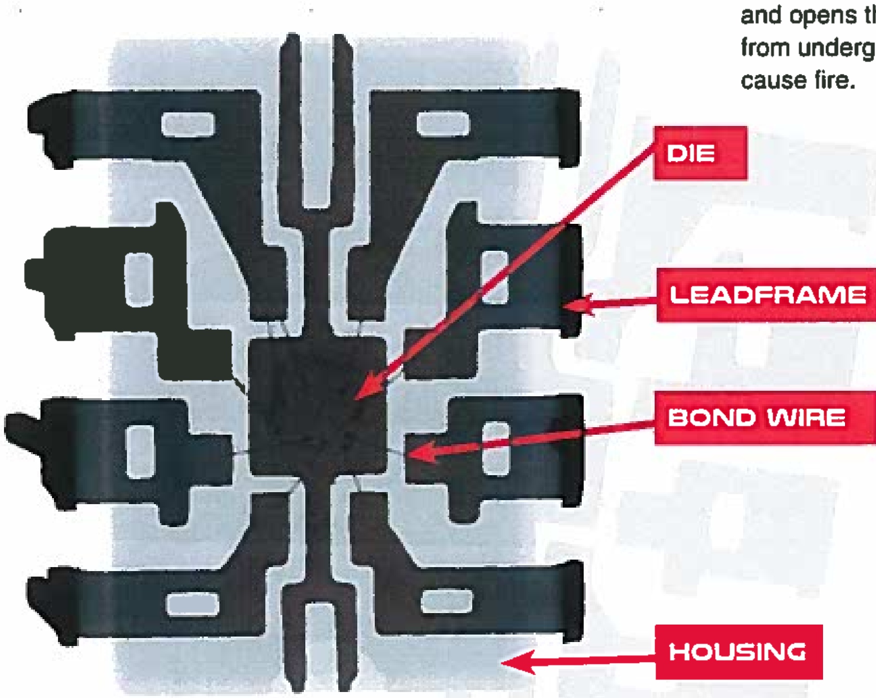

PHOTO 2 – X-ray View of IC, LM386 Audio Amplifier with Top Level Components Illustrated.

BOND WIRES

Inherent in many IC designs are the use of internal bond wires. The bond wires in an IC are made from aluminum, gold, or copper and have a typical diameter between 18 and 25 microns. The length of the bond wires vary according to the distance between the die and the leadframe.

The bond wire is secured on the chip by use of a ball bond. A welding machine, using ultrasonic or thermosonic energy, welds the bond wire to a portion of the chip called the pad. The pad is aluminum, and there are as many pads as there are signals / power supply leads entering and leaving the chip. When the welding on the pad occurs, the ball bond is created. When the same bond wire is then run to the leadframe, welding once again occurs. This second weld is called a shear or wedge bond. In use, the bonding machine at first glance appears to operate as a sewing machine.

FUSES – A COMPARISON

Electrical engineers are acquainted with fuses that are constructed by the use of thin wires. A fuse is designed and similar to a low resistance resistor. Thin metal is used to create a fuse so that when a current higher than the fuse rating flows through the fuse, the metal melts and opens the circuit. The fuse can prevent the circuit from undergoing an overloading condition which can cause fire.

Designing a fuse requires multiple considerations. For the purpose of this paper, the $I^2 T$ (Current squared Time) or melting integral is the most important. The $I^2 T$ value is proportional to the thermal energy required to melt a specific fuse element. The fuse element could be a fuse in a circuit, or a bond wire as defined above. When the $I^2 T$ value is exceeded, the fuse melts and circuit operation stops.

The authors have developed a novel technique of fire investigation that treats the various bond wires as fuses. If an electronic appliance (TV, stereo, satellite receiver) with electronic controls (some modern refrigerators, dishwashers, ovens) is in the area of a fire's origin, then the internal electronics are a candidate for this analysis.

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THE TECHNIQUE

There are basically two steps to the analysis. First, each integrated circuit in a fire damaged appliance is imaged using x-ray microfocus techniques. Second, the x-ray images are visually inspected for continuity of the bond wires. Photo 3 below shows such an x-ray. As is apparent, one of the bond wires is missing. The red arrow points to the missing bond wire. In that the bond wire is missing (IE, the fuse is blown), the IC was receiving power when the fire occurred.

BACKGROUND RESEARCH

By way of background, it is known that fires are quite destructive. When a fire occurs, p-n junctions (the basic building blocks of solid state components and integrated circuits) are destroyed by thermal energy. Dielectrics (wiring insulation) are known to fail at about 350° F. Resistors will change values during a fire. Capacitors will also change in value, with some eventually failing catastrophically. Solder pads will melt and some components may fall off a printed circuit board. In short, an operational circuit involved in a fire while powered on can develop a number of untoward events before it fails. One such event is the presence of an overcurrent condition, some of which may cause fuses to open. These fuses may be external 3AG (glass barrel) type fuses, or they may include the bond wires we are speaking of here.

Electrical engineers who find themselves examining failed electronic components have routinely compiled fuse data - blown or intact, correct rating, and nature of opening (overcurrent or short). This data can be used as an aid in determining a possible or likely source of a fire's origin. As an example, consider three small Christmas trees, each with one string of fused lights. The three trees are next to each other, all fed from the same outlet. The breaker protecting the outlet has tripped. The fuses for tree A and tree C are intact. The fuses associated with tree B are open. It is not difficult to surmise that, all other things being equal, fire was first present at tree B, relative to trees A and C.

The authors are of the persuasion that bond wires, when analyzed for electrical activity, can be viewed in a similar fashion as conventional fuses. Assume we have five conventional entertainment appliances: DVD player, flat panel TV, satellite receiver, stereo, and VCR. All are powered off the same branch circuit. No arcing is found on the numerous bare line cords to the appliances. Moreover, the main fuse, rated at 7.5 amperes, is present on the stereo and is blown open. From this evidence, it appears the fire started within the stereo. Moreover, a ball bond on each of both power output ICs is missing. CT scan confirms electrical activity on both damaged / missing bond wires. In this case, the bond wire data further supports that something has gone awry in the stereo circuitry.

In a second scenario, assume we have the same five damaged appliances and none of the appliances have damaged bond wires on their ICs. One reasonable conclusion is that all five appliances were in a standby mode, where the CPU, power supply, and remote sensor are all that is powered. A relay prevents power from reaching the bulk of the components. If a fire developed in one of the five electronic systems, then it developed in the power supply, CPU, or remote sensor sections. Prior to the development of this radiography technique, we would have known little to nothing about internal componentry beyond main fuse condition and / or power supply observations. Given the normal destruction of a fire, serious circuit analysis was not usually attempted in any great detail.

HYPOTHESES

There are three potential explanations to why the bond wire is not continuous, as follows:

1.) The IC was made incorrectly. This possibility can be rejected because the system would never have worked properly originally.

2.) External fire stress, causing mechanical stretching, thermal expansion and pulling of the wire. This was also considered and rejected as a hypothesis. Bond wires are quite malleable, and have high melting points (except for rarely used aluminum). We have never seen a failed bond wire that has fractured in afire, except when the package was severely damaged. See also further testing we have done.

3.) Electrical overcurrent is considered the most likely reason for a detached bond wire. Not rejected as explained in this paper.

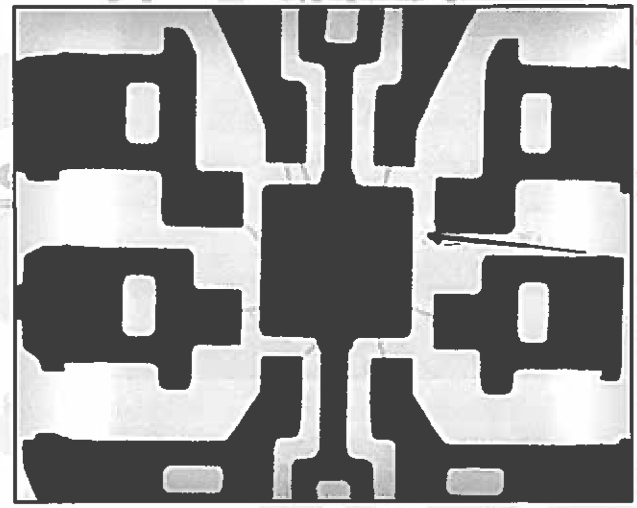

PHOTO 3 – Non-Continuous Bond Wire, Pin 6 of Leadframe to Die.

At this stage of analysis, we have useful data. But rather than stop after finding a missing bond wire, we extended the data collection by performing a CT scan of the integrated circuit. Below, Photo 4 shows the combined CT slices that have been reconstructed into a 3-D image. This image verified the indications seen in the Photo 3 X-ray. We used a software package called *Volume Graphics* to reconstruct the numerous CT slices into the CT image.

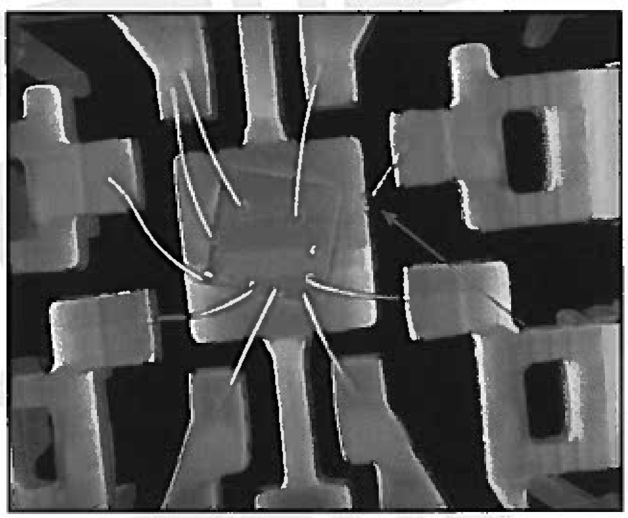

PHOTO 4 – Reconstructed CT Image, Showing Electrical Damage on Wire to Pin 6.

For purposes of clarity, the integrated circuit above failed when 40 volts was applied to the power leads. The power leads expect a voltage no greater than 18 volts DC.

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TESTING

As part of our testing, we collected a number of electronic appliances. We x-rayed the ICs in each appliance to make sure the ICs were intact. (Not all the appliances were functional prior to the fire). We then applied power to each one, and started a fire internally using denatured alcohol as an ignitable liquid. Not every appliance suffered failed bond wires on the internal ICs, but the x-ray images in Photo 5 and corresponding CT scan images in Photos 6 and 7 are typical.

Of the appliances tested, 30 percent showed one or more failed bond wires after the fire. It would be a mistake, however, to assume that 30% of all powered appliances will show evidence of damaged bond wires (one or more) post fire. Such damage will depend on line cord design, fuse sizes, circuitry design, function of the appliance, and physical layout of the appliance. What we can say, however, is that when a failed bond wire is found, one can reasonably conclude that the wire failed from electrical overcurrent.

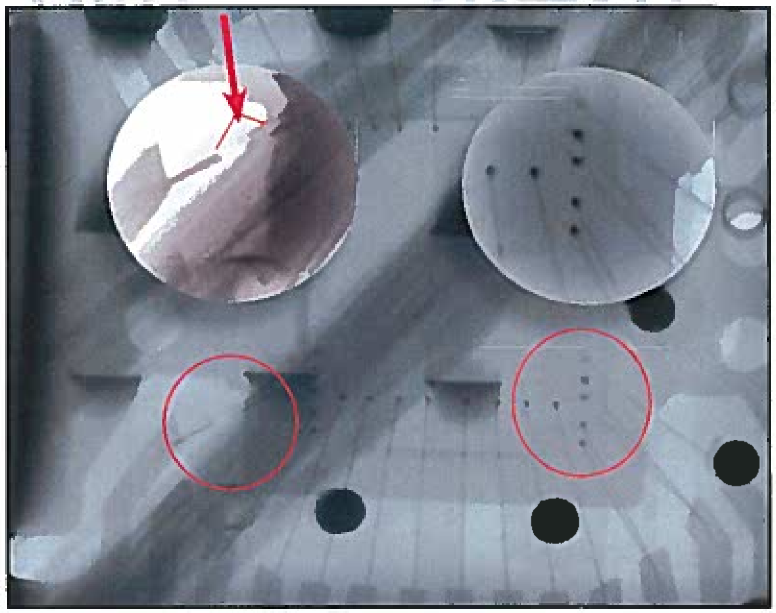

PHOTO 5 – Microfocus X-ray of Integrated Circuit from Burned DVD Player. The Two Red Circles Denote Areas Where Damage to Bond Wires Was Apparent.

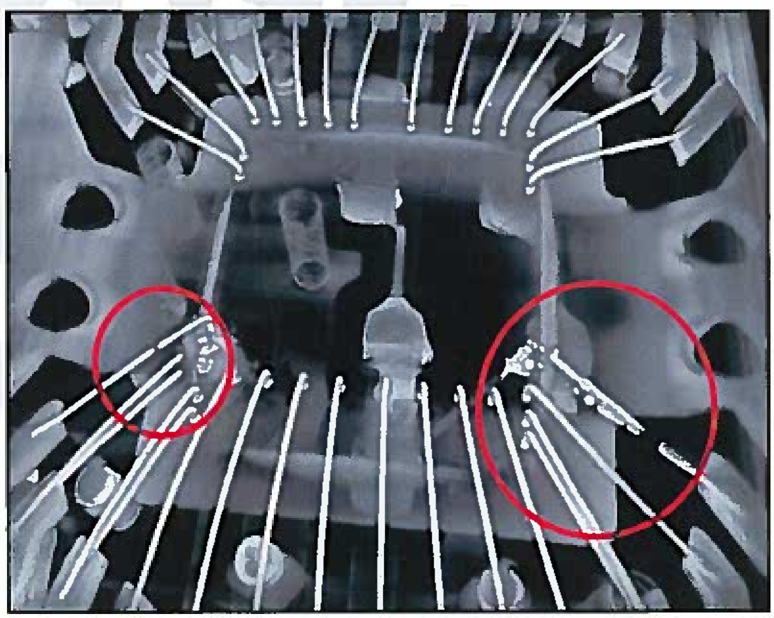

PHOTO 6 – Reconstructed 3-D Image of Internal Bond Wires Within IC, Corresponding to Damage Noted from Photo 5 X-ray.

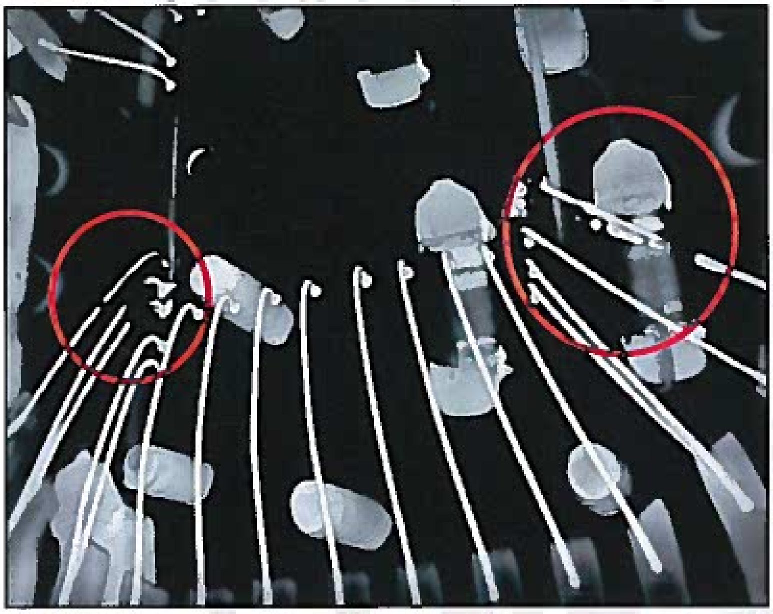

PHOTO 7 – Different View of Reconstructed Failed IC Bond Wires from Fire Damaged DVD.

To further test the above bond wire hypothesis, a propane torch was applied to several new integrated circuits after they had been x-rayed to establish a new condition reference. Afterwards the integrated circuits were x-rayed again. Photos 8 and 9 show the damage to the integrated circuit package (LM386), as well as the lack of damage to the bond wires. Clearly the integrated circuit packaging protects the bond wires from external heat effects. Furthermore, any 'suspicious' areas can be checked by CT, followed by plasma ashing and microscopy (if necessary) to better understand the potential failure of the bond wire.

PHOTO 8 – Charred LM386 Integrated Circuit.

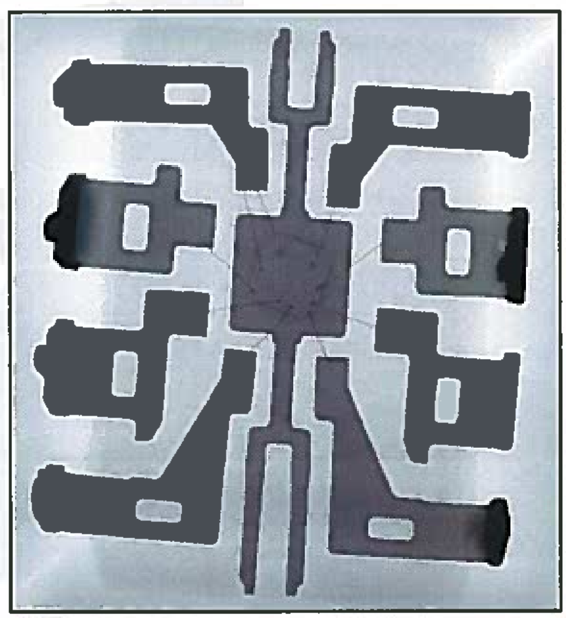

PHOTO 9 – Charred LM386 Integrated Circuit, Intact Bond Wires.

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DISCUSSION

The first (and most important) concept is that the bond wires do serve as fuses. The data these bond wires provide is important, but no panacea. Four caveats should be immediately noted:

1.) The presence of such a blown bond wire only indicated that power was on when the fuse opened.

2.) The open bond wire may or may not have indicated a particular appliance caused a fire, only that it was energized during the fire

3.) While this technique does not require knowledge of integrated circuit types to determine if power was on, the availability of such data (i.e., a good schematic) increases the knowledge that can be gained.

4.) Just because bond wires are intact, one cannot state that an appliance was not powered – as an example, maybe the appliance cord internally was the first area shorted, causing failure before the integrated circuits were damaged.

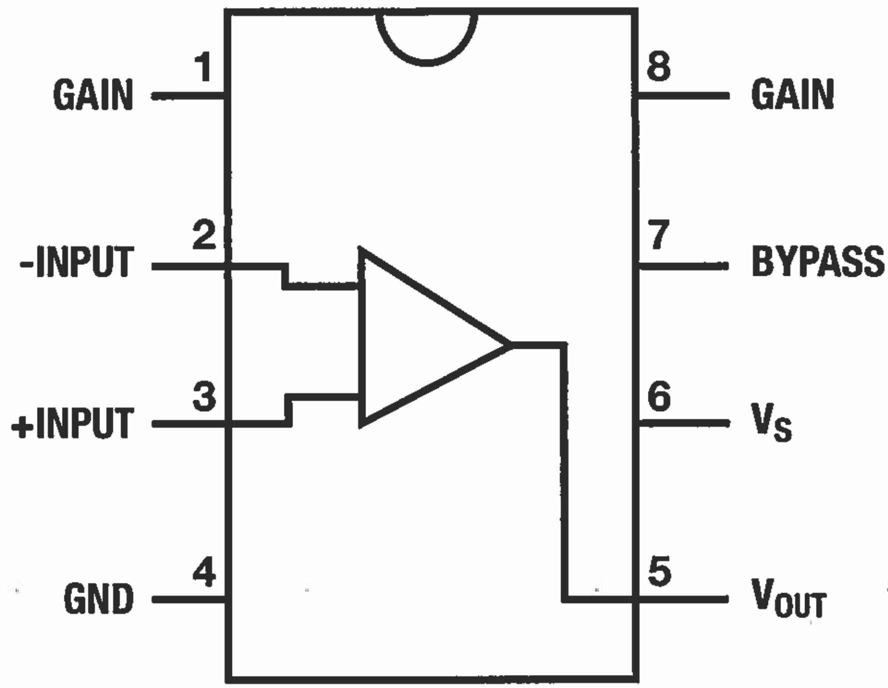

FIGURE 1
Schematic Pinout of LM386.

Caveat number one and two are related. This technique determines whether power was off or on. To carry the understanding further, extended engineering analysis is required. What other appliances were and were not on? What were the conditions of conventional fuses? Where was line to neutral arcing found? Did the breaker trip? Were appliances in a standby or full power mode? Do burn patterns reveal anything? Did flashover occur? Were arc fault current interrupters (AFCIs) involved?

The third caveat is also straightforward. Simply put, fire analysis gets better with more data. We can use the LM386 IC (tested and shown in x-rays and CTs, earlier) to illustrate this point.

The LM386 is an audio amplifier, depicted in Figure 1. There are three paths on an audio amplifier integrated circuit that concern us: the ground, the Vcc (power) lead, and the output. The input signal is high impedance (low current), so the likelihood of blowing a bond wire on pins 2 and 3 is almost zero. Pins 1, 7, and 8 have 15,000 ohm resistors associated with them internally, effectively limiting current through these respective bond wires.

Consequently, pins 4, 5, and 6 are where large amounts of current might flow, relative to the other five pins. We also note from the X-ray and CT that pin 4 uses two bond wires. By applying Kirchoff's Current Law, and knowing that for our testing with 40 volts that current entered and left by pins 6 and 4, respectively, the current on the two bond wires associated with pin 4 are half the current density J as that on pin 6. When an overcurrent situation exists on the LM386 IC, one would reasonably expect damage to bond wires on pins 5 and 6.

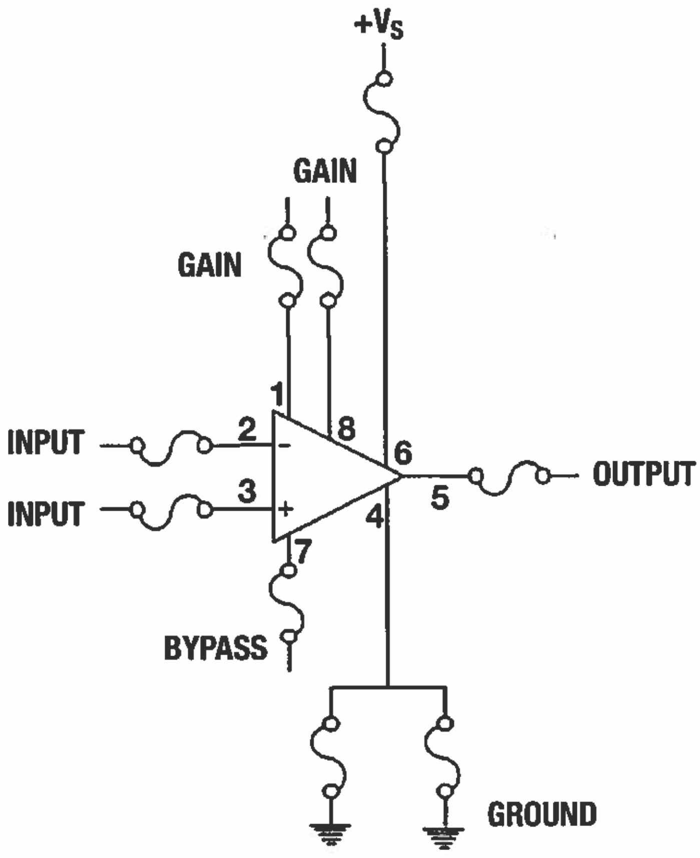

FIGURE 2
9 Bond Wires Added for 8 Pins (Pin 4 Has Double Bond Wires).

Were this IC damaged in a true fire, one might reasonably look at the primary of the AC/DC power supply. We have observed (in prior investigations) shorted turns on the primary of the associated power transformers. When this condition occurs, the output voltage from the power supply will rise, possibly damaging the integrated circuit.

We note that there are some integrated circuits which may never have damaged bond wires from overcurrent. Integrated Circuits with many data digital inputs / outputs immediately come to mind, as do chips for which overvoltage will destroy the p-n junction before an overcurrent condition occurs.

Finally, note the a *priori* condition that the appliance is presumed to be functional. If the appliance was inoperative, it raises the question as to whether the damage occurred at the time of the fire or much prior to the fire.

SUMMATION

The evaluation of fuses and their post-fire conditions has long been part of the engineer's toolbox. The technique described herein uses microfocus X-ray techniques to evaluate bond wires and their associated ball and wedge bonds. Thereafter, decisions can be made regarding the power status of an electronic component or sub assembly relative to the time of a fire event. Areas where the bond wires by microfocus X-ray to be damaged can be visually or radiographically imaged (if desired) to confirm one's conclusions.

This technique utilizes the fact that the internal bond wires of integrated circuits act as fuses. When these fuses are blown, one has reason to believe that power was applied during the fire event. The microfocus X-ray technique has the advantage that it is both nondestructive and can be used even when fire destruction prevents the identification of an IC's part number. We further note that if part identifiers are available, a greater understanding of power conditions during the fire event can be obtained. ■