A REVIEW OF IC FABRICATION DESIGN AND ASSEMBLY DEFECTS MANIFESTED AS FIELD FAILURES IN AIR FORCE AVIONIC EQUIPMENT

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ABSTRACT

In December 1986, RADC initiated a microcircuit and hybrid field return and failure analysis program. Data from that program along with case studies from each of the three major failure categories are presented. Emphasis is placed on microcircuit failures that were the result of design, fabrication and assembly defects. The purpose of the RADC work is to lay the groundwork for a DoD parts return and failure analysis program and to demonstrate the importance of analyzing field failures.

INTRODUCTION

There is a serious lack of useful microcircuit field data available to industry and government. Microcircuit field failures from military systems are usually discarded or sent for precious metal recovery. Repair centers do not normally analyze field failures. Only in the event of a catastrophe do part vendors hear about failures from mature operational weapon systems. RADC in December of 1986 initiated an in-house program to remedy this situation. This program is designed to provide feedback to semiconductor manufacturers and identify the root causes of field failures so intelligent corrective actions can be implemented. The program objective is to establish within the DoD a mechanism that provides field returns, failure analysis, feedback to industry/government and implements cost effective solutions. A discussion on the deficiencies in the military field data system, the importance of failure analysis and guidelines for implementing a DoD program were presented in an earlier paper (1). The purpose of this paper is to present the current technical data collected, emphasizing those parts that had latent defects leading to microcircuit failure in fielded Air Force weapon systems.

DESCRIPTION OF DATA

All the parts analyzed were actual field failures from operational Air Force avionics equipment such as; radars, electronic warfare equipment and navigational systems. Most of the parts were collected at Robins AFB GA and Hill AFB UT - two primary Air Force repair depots. About one thousand parts were collected during CY 1987 and thirty failure analysis reports issued. The data represent a variety of part types, including microprocessors, memories, power IC's and various hybrid components. The results of the analyses

are categorized into three main areas: IC Design Fabrication and Assembly, System Application, and Retest OK (RTOK). Currently 19% of the field failures fall into the category of IC Design, Fabrication and Assembly. These are the parts with inherent flaws or latent defects manifested as field failures. About 55% of the failures fall into the System Application category. These failures are unique to the system they failed in. Electrical overstress due to poor system design or improper maintenance procedures are the principal causes of failures in this category. Retest OK is the third category, comprising 24% of the total population. Cracked solder joints, inaccurate diagnostics and intermittents are some of the causes for these type failures. Failure analysis of discrete components and circuit cards make up the remaining 2% Non-Microcircuit category. The pie graph in Figure 1 shows a breakout of the field data.

Figure 1. Failure categories based on the completed number of FA reports.

DESIGN, FABRICATION AND ASSEMBLY

Cracked Die

A microprocessor used in the Doppler radar of a strategic bomber was found to be failing in the field at a greater than 50% rate. At least half of the time this radar was returned for repair, the microprocessor was found faulty and replaced. In some cases the failure could only be reproduced after five or ten minutes of operation, suggesting a temperature dependent problem. The microprocessor is mounted on a circuit card that runs hot and probably saw at least 3000 temperature cycles prior to failure. Of the nineteen parts analyzed, six had cracks. Three of the cracks were internal to the device. Two of the cracks were near the output pins. One crack occurred at the corner of the die and correlated with some large die attach voids underneath the die. The die corner was not attached. Figure 2 shows the void extending to the edge of the die and the underside of the corner piece that has been flipped over. The die is 274 X 276 mils and is attached using a Au-Si eutectic. Figure 3 shows the X-ray of the die attach taken prior to delidding.

Figure 2. SEM photomicrograph of the die attach underneath the cracked corner. Note the large void that extends out to the die edge.

The analysis showed that voids in the die attach, especially voids that extend out to the edges of large area silicon die, can cause microcircuits to failure in military aircraft. The part manufacturer, who had already made some improvements in his die attach process, found the feedback invaluable. This type of die attach process is common to a wide variety of part types. It was therefore important to the manufacturer to see how the voiding correlated with the reliability of the part in a military application.

There is not an X-ray requirement for Class B devices. But even if this was a Class S device, it may not have been a rejectable condition based on the X-ray, which only shows the presence or absence of gold in the eutectic die bond. It appears from this example that improving the screens for die attach in Class B devices is warranted. New analytical techniques based on acoustic wave propagation and the thermal heat transfer properties of the die bond are being developed and may in the future provide a quick check for die attach integrity during the manufacturing process of Class B devices.

Figure 3. Package X-ray prior to delidding.

Aluminum Metal Line Failure

A 16 bit Ultraviolet Read Only Memory used in a fire control radar on the F-16 fighter aircraft was found to have a high failure rate. "Missing data bits" was the reported failure mode in the repair center. A different data bit failed each time. Four failures were carefully removed and sent to RADC for analysis. A voltage contrast SEM technique was used to identify the failure site. Figure 4 shows the cracks which were found randomly on the metallization runs and were clearly the cause for missing data bits. The aluminum line is approximately four microns wide. Stress cracking of the conductor line caused by poor process control was the reason for failure. The device was manufactured during 1980 using NMOS technology. It is estimated the part experienced 2016 power cycles prior to failure, based on 35 hours of operation per month, one hour and 20 minutes average flight time, etc. The aircraft during this time period was exposed to documented min and max temperatures of -50°F and 170°F, respectively. A GIDEP Alert (#F9-A-83-01) was issued for this family of parts in 1983. The part manufacturer, who is no longer in business, took some corrective actions but parts are still failing in the field. The Air Force no longer procures this product and is taking steps to correct the problem in the fielded units.

An organized field return and failure analysis program would have in this case prevented many "field

failures". Early feedback would have provided the manufacturer and the DoD the timely information needed to fix the problem. Even though the Air Force monitors GIDEP reports, it is not a fail-safe system.

Figure 4. Cracked metal lines due to manufacturing control problems such as high silicon content in the aluminum metal lines.

Solder Joint Failure

An operational amplifier that drives the Heads-Up-Display in the F-15 fighter aircraft was identified for failure analysis because of its high removal rate. It is a 3-resistor, 3-transistor, plastic-potted 8-pin cylindrical component. The failure mode was described as an intermittent. The repair technician reproduced the failure mode by simply tapping on the device. Figure 5 shows the device with the plastic potting etched away. Careful electrical testing before and after the plastic was etched away allowed for isolation of the defective solder joint. The cracked joint occurred where the lead from the TO can is soldered to the package post.

The extreme stress conditions of the field environment is what caused the solder joint to eventually fail. At 50,000 feet the ambient temperature could easily be -50°C and the F-15 aircraft probably makes that climb in less than five minutes. An aircraft sitting idle on the hot blacktop sees 50°C plus temperatures. During one mission, this part may experience ten 100°C thermal cycles. If the aircraft averages 500 hours a year and the average flight time is 45 minutes, then this part would be exposed to 6,250 thermal cycles a year or 62,500 cycles in ten years. The part is also exposed to continuous vibration. Was this part designed to withstand this type of abuse? Although designed to operate over the military temperature range, the part manufacturer's specification specifically states..."Do not expose this module to excessive shock, vibration or moisture". In this case the repair center, working in cooperation with the part manufacturer, is considering design changes to remedy the situation. As is often the case, the original part manufacturer did not understand the final use environment for his product.

Figure 5. Operational amplifier used in the F-15 HUD.

"Cold Start"

A large number of bipolar static RAMs from an electronic engine control were failing in a depot screening procedure. The equipment would soak for 30 minutes at -60°F and then the memories would fail to operate during power up. A percentage of parts would work at slightly higher temperatures. The parts failed to work because of the temperature dependence of the transistor characteristics in bipolar devices, a failure known as "cold start". An effective piece part screen exists for this type of failure. The problem has been eliminated by purchasing only those parts that have been properly screened by the original part manufacturer.

Other Field Failure Analyses

Currently under investigation are a number of power transistors in which the failures appear to be caused by corrosion of the Pb-In solder die attach. In addition, several different types of UV and EE ROM's are being analyzed because of a memory retention problem. The devices were built using NMOS technology and the field failures appear to be caused by gate oxides that fail to retain a charged state. A 1K CMOS static RAM, built to a source control drawing, is under evaluation because of high leakage currents that draw down the battery back-up when the aircraft is not in use. A number of hybrid FA reports are also nearing completion where quality and workmanship problems appear to be the primary causes of failure. Problems such as improper wire bonding, poor attach of ceramic substrates, and defective lid seals were identified.

SYSTEM APPLICATION FAILURES

As shown in the pie chart of Figure 1, most of the parts analyzed so far have failed because they have

been electrically overstressed or burned out in the system. The failures are unique system application problems. The electrical overstress is caused by poor system design, erratic power supplies or improper maintenance/operational procedures. In one or two case studies the observed failures had damage that resembled classical electrostatic discharge (ESD), however there was no conclusive evidence that ESD was the primary cause of the field failure.

In one case, a power hybrid device used in a sophisticated electronic warfare pod was tagged for failure analysis because of an extremely high removal rate. Seventeen parts were analyzed and in each case the failure mode was the same, namely, the output waveform was clipped. Visual inspection showed that the output transistor in each was blown as shown in Figure 6. A voltage controlled oscillator used on the same printed wiring board was identified as the source of the electrical overstress. An overvoltage protection device is being considered to solve the problem and will significantly improve the reliability of the fielded system. Additionally, as a result of the feedback, the hybrid manufacturer considered replacing the output transistor with one that had more current/voltage handling capacity. Information about this failure and others from the same system was used in reviewing the next generation design for this system.

Figure 6. Burned aluminum contacts on an output transistor used in a power hybrid device.

RETEST OK

Nothing is more frustrating than trying to understand why a piece of avionic equipment retests OK in the repair center, after having been identified as a failure in the field and removed from the operational aircraft. In many cases the system RTOK's because the individual piece parts resume normal operation in the benign environment of the repair depot. There are a variety of reasons why a part might retest OK after being diagnosed as a failure. In many cases the environmental conditions (e.g. temperature/vibration) that precipitated the failure cannot be reproduced. Failure isolation problems, software bugs, tester correlation problems and defective solder joints are just a few more reasons why the pie chart (Figure 1) shows a 24 percent RTOK.

In one case study a high speed J-FET switch was cited as having a 75% failure rate in a nighttime imaging camera on the B-52 bomber. RADC verified through electrical testing that the parts fully complied

with the source control drawing specification. The problem was one of poor systems spec writing. A 75 ohm (measured on-resistance) FET which was designed into the system would not operate properly. To solve the problem, the part manufacturer generously offered to exchange the product with a 30 ohm FET. But it was the engineers at Robins AFB working to understand the cause of failure that led to the corrective actions.

In many cases it is just as important to know that a part didn't fail as it is to know how it failed. In this case, the problem would have never been found without detailed electrical testing and feedback to the original part manufacturer.

SUMMARY

This paper reports on RADC's year long effort to collect and analyze microcircuit field failures. A brief description of the source of data and a relative breakdown of the failure categories were presented. Case studies from each were described to illustrate the importance of a DoD field return and failure analysis program.

The benefits of a field return program are twofold. First, the part manufacturer receives valuable feedback concerning the end use and environmental conditions that his product sees in fielded systems, permitting improved reliability in future product designs. Secondly, the military gains an understanding of the root causes of field failures and can carry out the corrective actions that lead to improvements in the reliability of fielded equipment.

ACKNOWLEDGMENTS

The author is indebted to the many people in RADC/RBR who provided the technical support for the field failure program. A special thanks to Ivars Irbe for performing internal visuals, microphotography and for his expert advice. Others who made significant contributions: N. Koziaz and W. Wong (Electrical Testing), D. Calabrese (SEM Analysis), P. Speicher (X-ray Analysis), L. Walsh (Auger Analysis), B. Moore (Residual Gas Analysis), T. Meador (Technician Support) and M. St. Thomas (Clerical Support), and thanks to Dr. R. Thomas for his program support and guidance.

REFERENCES

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2. RADC has had a quick reaction (QR) system support failure analysis program in existence since 1967. The Field Failure Program described in this paper is an extension of earlier work done by Edgar A. Doyle, Jr., Edward P. O'Connell, Daniel J. Burns and others documented in the following RADC Technical Reports titled: "RADC In-Depth Failure Analysis (QR) Reliability System Support Accomplishments". Report numbers:
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