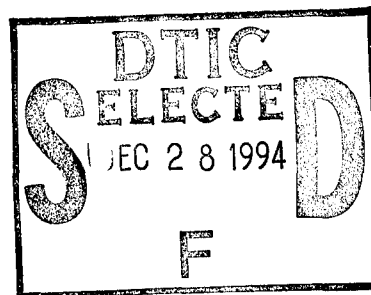


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20 December 1994

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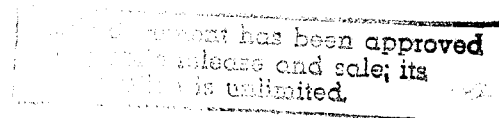
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Sincerely,

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Paul R. Capozzola
ASEM Program Manager
Loral Federal Systems Company - Manassas



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ASEM Final Technical Report

December 14, 1994

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Loral Federal Systems Company, Manassas, Virginia

ASEM Final Report Table of Contents

PREFACE	v
EXECUTIVE SUMMARY	vii
STATEMENT OF WORK CROSS REFERENCE	xi
1.0 INTRODUCTION	1-1
2.0 DESIGN SYSTEM	2-1
2.1. Trade-off tools	2-1
2.1.1. Introduction	2-1
2.1.2. Trade-Off Tool Requirements	2-2
2.1.3. Evaluation Domain Overview	2-4
2.1.4. Tool Evaluation Summary	2-7
2.1.5. Tool Effectiveness Results	2-9
2.1.6. Conclusions	2-9
2.2. Design Kits	2-13
2.2.1. Design System Requirements	2-14
2.2.2. MCM-D Design Kit Specification	2-20
2.2.3. Cadence MCM-D Design Kit	2-28
2.2.4. Mentor Graphics MCM-D Design Kit	2-35
2.2.5. Design Kit Section Conclusions	2-43
2.2.6. References	2-45
2.3. Design System Foundry Interfaces	2-47
2.3.1. Communication Channels	2-47
2.3.2. Specification Interface	2-48
2.3.3. Logic Interface	2-48
2.3.4. Physical Interface	2-50
2.3.5. Conclusions	2-53
2.4. Direct Release	2-55
2.4.1. Introduction	2-55
2.4.2. Architecture and Objectives	2-56
2.4.3. Implementation	2-56
2.4.4. Demonstration	2-66
2.4.5. Direct Release Conclusions	2-87
2.5. Framework	2-89
2.5.1. Introduction	2-89
2.5.2. Framework Evaluations	2-90
2.5.3. Implementation	2-94
2.5.4. Conclusions	2-98

A-1

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3.0 MCM TEST	3-1
3.1. Test Environment	3-3
3.1.1. MCM Testing Challenges	3-3
3.1.2. MCM Test Categories	3-3
3.1.3. Captive vs. OEM Foundry Test Environment	3-6
3.2. Test Methodology	3-8
3.2.1. Assumptions	3-8
3.2.2. Basic Approach: Distributed Testing	3-8
3.2.3. Implementation Aspects of Test	3-14
3.2.4. Diagnostic Implications	3-15
3.2.5. Methodology Conclusions	3-16
3.3. Interconnect Test Implementation	3-17
3.3.1. Software Platform	3-18
3.3.2. Flexible Fixturing Hardware	3-20
3.3.3. Database	3-21
3.3.4. Test Vector Generation	3-22
3.3.5. Test Database Verification	3-23
3.3.6. Interconnect Test	3-24
3.3.7. Test Implementation Conclusions	3-25
3.4. Known Good Die	3-26
3.4.1. Introduction	3-26
3.4.2. Parameters for KGD Implementation	3-26
3.4.3. Known Good Die Test and Conclusions	3-30
3.5. Data Integrity	3-32
3.5.1. MCM Environment	3-33
3.5.2. Data Integrity Methodology	3-35
3.5.3. Data Integrity Conclusions	3-38
3.6. MCM Case Studies	3-39
3.6.1. Demonstration Vehicle Test Summary	3-39
3.6.2. Benchmark Results	3-39
3.7. MCM Test Conclusions	3-42
3.8. References	3-43
 4.0 HYBRID (C4, WIREBOND, AND TAB) INTERCONNECT TECHNOLOGY 4-1	
4.1. MCM Test Vehicle (Technology Demonstration Vehicle)	4-2
4.1.1. MCM Test Vehicle - Methods	4-2
4.1.2. MCM Test Vehicle - Results	4-4
4.2. Physical Testing	4-9
4.2.1. Physical Testing - Methods	4-9
4.2.2. Physical Testing - Results	4-9

4.3. Cost Reduction Results	4-11
4.3.1. Cost Reduction - Methods	4-11
4.3.2. Cost Reduction - Results	4-12
4.4. Conclusions	4-16
5.0 INFRASTRUCTURE	5-1
5.1. Application Demonstration	5-1
5.1.1. ISI /MOSIS	5-1
5.1.2. Mayo Foundation, Special Purpose Processor Development Group	5-2
5.1.3. Hardware Standards	5-3
5.1.4. Industry Conferences and Meetings	5-3
5.1.5. Application Demonstration Conclusions	5-4
5.2. CAD Infrastructure	5-4
5.2.1. ASEM Alliance Results / Standards	5-4
5.2.2. Other organization Support	5-4
5.2.3. Industry Conferences and Meetings	5-5
5.2.4. CAD Infrastructure Conclusions	5-5
5.3. Module Test / Known Good Die	5-6
5.3.1. MCM Test	5-6
5.3.2. Known Good Die	5-6
5.3.3. Other Organization Support	5-7
5.3.4. Module Test / Known Good Die Conclusions	5-7
5.4. Interconnection Technology	5-7
5.4.1. Industry Conferences and Meetings	5-7
5.4.2. Other organization Support	5-9
5.4.3. Interconnection Technology Conclusions	5-9
5.5. Infrastructure Conclusions	5-10
6.0 APPLICATION DEMONSTRATION	6-1
6.1. Customer Survey	6-2
6.1.1. Selection Criteria	6-2
6.1.2. Methods of Customer Contact	6-2
6.2. Selected Applications Overview	6-4
6.3. Sun Microsystems	6-5
6.3.1. Product Development	6-5
6.3.2. Sector Activity	6-6
6.3.3. Conclusions	6-15
6.4. Sacramento Air Logistics Center (SM-ALC)	6-16
6.4.1. Product Development	6-16
6.4.2. Sector Activity	6-16
6.4.3. Conclusions	6-20
6.5. National Semiconductor	6-21
6.5.1. Product Development	6-21

6.5.2. Sector Activity	6-22
6.5.3. Conclusions	6-26
6.6. Application Task Conclusions	6-27
7.0 OVERALL ASEM CONTRACT CONCLUSIONS	7-1

PREFACE

Disclaimer

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The Technical Teams were made up of IBM Microelectronics personnel and Loral Federal System Personnel in order to deliver contract objectives. IBM Microelectronics personnel were temporarily transferred to Loral Federal Systems Company for administrative reasons. The teams were staffed as follows:

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(note LFS indicates Loral Federal Systems Personnel, IBM indicates IBM Microelectronics)

The whole ASEM team would like to acknowledge:

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The people at IBM Microelectronics who built, assembled, and tested the demonstration vehicles

These people were invaluable in steering the activity and making this program a success.

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EXECUTIVE SUMMARY -- ASEM FINAL REPORT

Background

Loral Federal Systems Company (formerly IBM Federal Systems Company) and IBM Microelectronics combined efforts in an Advanced Research Projects Agency (ARPA) Application Specific Electronic Module (ASEM) contract to establish low volume, Department of Defense (DoD), application access to IBM's high volume foundry which had historically been a captive supplier. The contract called for development of design kits and a multi-entry design system, hybrid (C4, wire bond, and TAB) interconnect technology development for MCM-D, sharing IBM MCM experience with others in the ASEM infrastructure, and demonstrating capabilities in real applications.

ASEM General Objectives

This contract was defined as part of ARPA's efforts to fulfill objectives of the ASEM Program and more globally it's Packaging Strategy.

The Packaging strategy is made up of four major points.

- Re-establish U.S. leadership in high value-added packaging technologies.
- Exploit packaging technology discontinuity (single chip to Multichip).
- Focus on end-product markets where the U.S. has a strong presence (i.e., computers, telecommunications, automotive, aerospace).
- Establish a strong domestic, dual-use merchant infrastructure.

The ASEM Program, as outlined by ARPA, has five main program objectives. These objectives are:

- Develop advanced MCM technologies to meet future DoD requirements.
- Reduce non-recurring engineering (NRE) cost and cycle time by 10 fold with first pass success on designs.
- Reduce the total recurring module cost for current technologies by an order of magnitude.
- Develop applications which stimulate demand for MCM technology.
- Provide DoD access to robust manufacturing capabilities.

The resources for execution of this contract came from two corporations, Loral Federal Systems Company and IBM Microelectronics. The general description of the contribution of the companies were:

- Loral Federal Systems, Manassas, VA: Loral has extensive experience managing technology development contracts with the government. The program management and contract fulfillment was the responsibility with Loral. Software skills from Loral were also used to support contract deliverables
- IBM Microelectronics, East Fishkill, NY: IBM offers the DoD the world's largest MCM production facility where a sizable investment has been made in microelectronics packaging for both single chip and Multichip products. Personnel from IBM were

temporarily transferred to Loral to support technical management, technology development, and design deliverables.

ASEM Contract MDA972-93-C-011 Objective

The specific objective of this contract is to provide low volume (low-cost/volume QTAT) access to a high volume, commercial MCM foundry, at IBM. This led to the generation of a list of tasks and milestones that were defined and achieved to help ARPA achieve its objectives. In addition to providing foundry access, effort was also put towards cycle time reduction and lowering costs.

The rest of this section briefly describes the specific tasks and accomplishments, all of which were delivered on or ahead of schedule.

Tasks and Accomplishments

The following are the major task listings from the statement of work along with the accomplishments achieved over the course of the contract.

Provide design kits and customer-foundry interfaces to support multi-entry point designs

Trade-off tools requirements were defined and a list of existing tools were evaluated against those requirements. MCC's MSDA tradeoff tool offering comes closest to meeting the requirements for an MCM tradeoff tool. However, major deficiencies remain to be addressed. These include establishing a comprehensive component library and developing standard interfaces to detailed EDA tools. Recommendations for future trade-off tool development are also included in the details.

The foundry's capability to support multi-entry design points was demonstrated (both logic and physical design entry into the foundry). Physical entry is Customer driven logic and physical design from Cadence and Mentor Graphics tools. In this scenario IBM would simply deliver the module designed by the customer. In Logic entry, the customer completes the logic design and passes the specifications, netlist information, and constraints to IBM. The IBM foundry then completes the physical design and fabricates the module.

To enhance customer access to the foundry, MCM-D kits were developed for the Cadence and Mentor Graphics design tools. These supported mainly physical design but also provided some support for the logic design and specification phases of MCM design.

With test being such a significant aspect of MCM development, foundry MCM test experience and recommendations were compiled in a 'Testability Strategy and Guidelines' document. This strategy was implemented and found to be effective in dealing with the demonstration vehicles produced during the contract period.

The contract also supported study of the release process of custom MCMs at IBM to facilitate reduction of cycle time and errors. The information developed assisted in the redefinition of release for prototypes such that manufacturability checking and release was complete in a few days instead of weeks.

Another accomplishment was the integration and automation of certain design and release steps in a framework. This was initiated in ongoing efforts to reduce cycle time and NRE within the process.

Develop hybrid (C4/wire bond/TAB) die interconnect procedures on MCM-D substrate.

Mixed interconnect technology had been seen as a necessity for the emerging MCM market since die have to come from a variety of manufacturers and these die may not always be available in the format desired.

Mixed interconnect technology (C4/wire bond/TAB) on ceramic substrates had already been demonstrated by IBM, but the same capability was not available on MCM-D. An MCM-D module was designed that incorporated standard wire bond die with 280 pads on a 2 mil pitch, an advanced TAB part with 328 leads on a 2 mil pitch, a C4 (flip chip) die with 2401 pads, and two inverter chips to form a ring oscillator. It was encapsulated with a hermetic kovar cap. A number of passive structures were also included in the design to measure technology characteristics.

In developing this module, a metallurgy structure was developed that simultaneously supported all three types of interconnect technology, thus cost reducing this technology capability.

Modules were electrically and environmentally tested at IBM and 40 pieces were delivered to RELTECH for their evaluation. All results met or exceeded expectations.

Collaborate with industry/consortia to formulate standards for CAD, KGD, MCM/Packaging applications and test.

A number of infrastructure activities were supported during the contract including MCC known good die (KGD) studies, ASEM Alliance MCM standardization efforts (in Foundry Interfaces specification, EDIF activities, and Design kit activities), and industry conferences. Many papers were presented on various topics including materials development, reliability, MCM test methodology, design kit development, and application successes. The details can be found in the Infrastructure section of the full report.

Fabricate and test a MCM to demonstrate a full-service foundry capability.

Three MCMs were developed under the contract. A SuperSparc module was developed with Sun Microsystems and a 'CLAY' Processor module was developed with National Semiconductor. These two modules demonstrated the logic design entry path into the foundry. A data transfer module was built for McClellan Air Force Base (Air Logistics Center) which demonstrated the physical design entry path.

Both the SuperSparc and 'CLAY' modules began with die developed for wirebond applications and converted to flip chip form factors to reduce module size and enhance thermal performance.

SuperSparc module was successfully fabricated, assembled and interconnect tested. Module functional test was not requested by Sun.

The 'CLAY' module was successfully fabricated and assembled. National Semiconductor did not require functional or interconnect test.

The data transfer module, for McClellan Air Force Base, required die in the wirebond format. This module was successfully fabricated, assembled and tested in less than 8 weeks. Some functional test was possible since the Customer supplied the necessary patterns.

Summary

All contract tasks were completed successfully, on-time, and to cost. Significant progress was also shown towards achieving the global ARPA objectives for the ASEM program.

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STATEMENT OF WORK CROSS REFERENCE

This section is intended to help direct comparisons of the ASEM Contract statement of work to this final report. The outline of this section directly corresponds to the statement of work with the items having identical task numbers. Each section introduces the requirements, repeats the statement of work, describes the approach and methodology used in satisfying the requirements, and refers to the sections of the final report that demonstrate that the requirements have been satisfied.

Design System (Task 2.1.1)

Design Kits, Interfaces, Tradeoff Tools, and Test (Task 2.1.1.1)

Design Kits (Task 2.1.1.1.1)

Requirements

In order to achieve low volume access to a high volume foundry, reduced design cycle time and non-recurring engineering costs (NRE), and to routinely achieve first pass success on new designs, design kits were developed.

Design kits describe information to improve the effectiveness of an engineer in understanding and implementing solutions in a particular technology that will be built at an ASEM foundry. The information needs to be both general, as in a technology text, and specific, as in design tool parameters to force conformance to technology requirements. This combination allows for quick transfer of engineering knowledge, definition of customer-foundry interface requirements, and instantaneous tool set up to speed design decisions and implementation.

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.1):

1) Create MCM-D electronic design kits. The design kits will be based on standards and will be as CAD tool independent as possible. The design kits will contain different sets of information for the physical design level, the logic design level, the specification level and the trade off tool level.

Approach

MCMs, like early ASICs, have been used for a long time by companies who developed experts who were capable of understanding and implementing solutions in this beneficial technology. However, for MCMs to become a general solution, a method had to be developed to easily convey the information needed to the general design engineering community. For this objective, the MCM Design Kit was developed. It was presumed that if design kits were successful, more design engineers would be able to design in MCM technology.

Since no literature existed on MCM design kits, discussions were held with Commercial Electronic Design Automation (EDA) companies, MCM Foundries, and MCM Design Engineers. For the kit to be successful it was decided that the most important information to be verified was the information that supports physical design. If physical design was not possible, all information developed for the other design phases would be much less useful.

To bound the effort in the contract, the primary technology was chosen to be MCM-D. To bound the problem of design tools to be addressed, two tool sets were chosen for the MCM design kits (CADENCE™ and Mentor Graphics Corporation^(R)). The Cadence and Mentor Graphics tool sets were documented in the 'Design System Requirements' report.

A design kit specification was desired to provide a standard description of what was to be in a kit.

Finally, the kit would be distributed to customers for use and feedback and initial updates to the kit would be supported. Full usefulness of these kits is dependent on the foundry's continued offering of the products supported by the developed design kits and customer response to the kits.

Cross Reference Sections

The results of this activity is described in sections:

2.2. Design Kits

- 2.2.1. Design System Requirements
- 2.2.2. MCM-D Design Kit Specification
- 2.2.3. Cadence MCM-D Design Kit
- 2.2.4. Mentor Graphics MCM-D Design Kit
- 2.2.5. Design Kit Section Conclusions
- 2.2.6. References

Design System Interfaces (Task 2.1.1.1.2)

Requirements

Design Interfaces are the interfaces between phases and tool sets used in design. They require specific sets of information to be exchanged for the interface to operate efficiently. For software tools to work efficiently, the format of the information also needs to be specifically defined. In order to reduce design cycle time, and the corresponding NRE, these interfaces needed to be studied, defined, and exercised to prove the effectiveness of the definitions. The scope of this effort mainly supported the interface between completed physical design and the foundry, but also allocated some effort to the logic to physical design phase, and minimally addressed the specifications interface to logic design.

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.1):

2) Design and document interfaces needed between the customer and the IBM foundry; a.) at the specification level, b.) at the logic design level, and c.) at the physical design level. Develop test cases to cover entry into the foundry.

Approach

This work was initiated with an understanding of the IBM foundry requirements and preferences. It was also deemed important to try to define an interface that customers would recognize as similar across many MCM foundries. For this reason there was significant interaction between the interface activity and the ASEM Customer Foundry Working Group associated with the MCC ASEM contract.

Another starting point for the interfaces was the current experience base of Gerber and GDS2 as formats for artwork data exchange. This in conjunction with industry standards such as EDIF were to be the focus of the study. These standard formats were chosen in order to help customers see 'standardization' similarities of the interfaces regardless of the MCM foundry they may be choosing.

With these situations in mind, the requirements were documented in the "IBM MCM Foundry Interface Specification" CLIN 0002AG. Given a documented interface, test cases were developed to help further understand and demonstrate the capabilities described in the interface specification. Focus was on the Logic and Physical interfaces because these were the ones that needed most enhancement to support the commercial market.

Cross Reference Sections

The results of this activity is described in sections:

2.3. Design System / Foundry Interfaces

2.3.1. Communication Channels

2.3.2. Specification Interface

2.3.3. Logic Interface

2.3.4. Physical Interface

2.3.5. Conclusions

(see the section on the demonstration of the release section 2.4.3 for operational results)

Trade-off tools (Task 2.1.1.1.3)

Requirements

Trade off tools are used to help make early decisions about specific alternatives and their impact to product objectives, even during the product definition phase of a program. For this reason it was determined that an investigation of existing tools should be made in order to determine the degree to which they could be supported near term.

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.1):

3) Study Trade-off Tools, specifically those of (a) MCC, (b) Mentor, (c) Cognition, (d) "SUSPENS", a tradeoff tool from Stanford University, (e) "AUDiT", a tradeoff tool from Cornell University and (f) "PEPPER", an IBM tradeoff tool, and recommend for ARPA approval the best tool selection for use in the foundry interface.

Approach

The study identified various trade off tools, described requirements for the tools, established a list of domains that were important to MCMs, evaluated the tools, and described their effectiveness.

The general domains of the study were cost, turn around time, substrate and chip selection, package selection, power dissipation, frequency performance, packaging delays, testability, reliability and manufacturability.

Cross Reference Sections

The results of this activity is described in sections:

2.1. Trade-off tools

2.1.1. Introduction

2.1.2. Trade-Off Tool Requirements

2.1.3. Evaluation Domain Overview

2.1.4. Tool Evaluation Summary

2.1.5. Tool Effectiveness Results

2.1.6. Conclusions

Testability Strategy and Guidelines (Task 2.1.1.1.4)

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.1):

4) Develop a testability strategy and guidelines to support entry points into the IBM foundry at various design levels.

Approach

The approach used to meet the objectives was to develop a strategy which was appropriate to the business and customer environment with respect to design ownership and tasks. The second element of the approach to meeting our goals was to install appropriate tooling and business processes to validate the selected test methodology. The third element in our approach was to benchmark progress in lowering our turn around time (TAT) and NRE cost by monitoring the effort spent in performing test on real MCMs. The results of the bench-marking actual application vehicles would verify that the implemented test strategy was in fact producing lowered TAT and costs.

Cross Reference Sections

The results of this activity is described in sections:

3.0 MCM Test

- 3.1. Test Environment
 - 3.1.1. ASEM Testing Challenges
 - 3.1.2. MCM Test Categories
 - 3.1.3. Captive vs. OEM Foundry Test Environment
- 3.2. Test Methodology
 - 3.2.1. Assumptions
 - 3.2.2. Basic Approach: Distributed Testing
 - 3.2.3. Implementation Aspects of Test
 - 3.2.4. Diagnostic Implications
 - 3.2.5. Methodology Conclusions
- 3.3. Interconnect Test Implementation
 - 3.3.1. Software Platform
 - 3.3.2. Fixturing Hardware
 - 3.3.3. Database
 - 3.3.4. Test Vector Generation
 - 3.3.5. Test Database Verification
 - 3.3.6. Interconnect Test
 - 3.3.7. Test Implementation Conclusions
- 3.4. Known Good Die(KGD)
 - 3.4.1. KGD Process
 - 3.4.2. Parameters for KGD Implementation
 - 3.4.3. Known Good Die Test and Conclusions
- 3.5. Data Integrity
 - 3.5.1. MCM Environment
 - 3.5.2. Data Integrity Methodology
 - 3.5.3. Data Integrity Conclusions
- 3.6. MCM Test Results
 - 3.6.1. Demonstration Vehicle Test Summary
 - 3.6.2. Benchmark Results
- 3.7. MCM Test Conclusions
- 3.8. References

Direct Release (Task 2.1.1.2)

IBM had developed a release system strongly directed towards the standard module families used by many of the internal IBM product lines that the foundry traditionally supported. This focused

on quick release of routing interconnect layers that were compatible with pre-designed redistribution and power layers for a given chip set.

This existing release system was not suited to handle the custom MCMs typically required in the merchant market. Custom MCMs require that all layers of an MCM be designed and released concurrently. In addition, specifications and drawings are generated concurrently with the design so traditional work sequencing that was incorporated into the IBM standard module family release process appeared as product delays and bureaucracy in the custom MCM environment. For this reason activity was defined to enhance the release process to meet the ASEM goals of providing low volume access to a high volume foundry, reducing cycle times and NRE, and routinely achieving first pass success on designs.

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.2):

- 1.) Integrate direct release tools to reduce cycle time by fifty percent and reduce direct release defects by fifty percent by developing the system architecture and additional tools needed to support objectives. Encapsulate all tools into the IBM Application Framework.
- 2.) Install and demonstrate system at IBM's E. Fishkill facility.

Approach/Method

The approach was to evaluate the custom MCM and prototype requirements in relationship to the existing release capabilities. With the requirements defined, an architecture could be proposed that would be a model of an ideal release system. The task envisioned that improvements could only come in a framework integrated environment, another alternative was identified later in the program which led to a more cost effective approach towards achieving the objective.

Implementation of the release system referenced the information uncovered in the evaluation phase and the ideal release architecture. Regular measurement of the release problems created the right focus and priority for solving current OEM release problems.

The system was exercised to demonstrate the increased effectiveness of the release system.

Chapter-Section Cross Reference

The results of this activity is described in sections:

- 2.4. Direct Release
 - 2.4.1. Introduction
 - 2.4.2. Architecture and Objectives
 - 2.4.3. Implementation
 - 2.4.4. Demonstration
 - 2.4.5. Direct Release Conclusions

Framework (Task 2.1.1.3)

The framework activity in the contract was identified because of the recognized importance of data integrity and process management in assuring first pass design and release success. This activity also recognized that the design and release process at the beginning of the contract operated on information from a number of different platforms and sources and, from the custom MCM perspective, many of the steps in the process were performed using manual (data transfers and paper driven) point tools. The intent was to use some framework to begin to link and automate the

steps of the process. By linking and automating pieces of the process, it would not only run faster but reduce errors and learning curves associated with staffing these processes.

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.1.1.3):

- 1.) Complete and document IBM USER Framework communication message classes necessary to complete framework/framework communications.
- 2.) Demonstrate framework/framework communications between the IBM design tool set and direct release system and the Cadence design tool set at the specification, logic, and physical design levels.

Approach/Method

Utilizing a framework was considered an activity that needed evaluation because of some primary benefits of reduced cycle time and errors. Framework integration allows a reduction in the distribution of cycle time and errors between 'experienced' personnel and 'novices' by helping novices through the process and automating various process steps for all personnel.

Initial work involved investigating Framework capability and estimating efforts and pay back involved in integrating the design and release process in a framework.

Requirements and architecture descriptions were created which defined an ideal integrated design system. This was written relative to IBM ProFrame capabilities with CFI 2.0 extensions. Then alternatives were reviewed against that definition.

There were three areas to consider:

1. Framework capabilities and extendibility
2. Process flexibility and maintainability in the Framework
3. Maximizing industry benefit from the integration activity

Conclusions drawn from this activity determined an integration approach which was demonstrable.

Cross Reference Sections

The results of this activity is described in sections:

- 2.5. Framework
 - 2.5.1. Introduction
 - 2.5.1. Framework Evaluations
 - 2.5.2. Implementation
 - 2.5.3. Conclusions

Hybrid (C4, Wirebond, and Tab) Interconnect Technology (Task 2.2.1)

MCM Test Vehicle (Task 2.2.1.1)

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.2.1):

2.2.1 C4, Wirebond & TAB Integration.

This task is to establish and demonstrate the processes required to mix C4 finished die, TAB and Wire-Bond chips onto MCM-D thin film substrates.

This task will include the following:

1. MCM Test Vehicle

Design and build a Technology (Process) Demonstration Vehicle (TDV) consisting of a thin-film MCM-D substrate with C4, wirebond and TAB attached chips co-resident upon it. Electrical testing to validate the attach processes will be performed.

2. Physical Analysis

Perform a destructive physical analysis on the Technology Demonstration Vehicle. Quality and reliability tests will be performed on the attach processes. The test results will be documented in a physical analysis report.

3. Qualification (UN-PRICED OPTION)

IBM will perform a qualification of the combined die attach processes using the Technology Demonstration Vehicle. Qualification hardware and test results will be provided.

Approach/Method

The approach is fairly well defined by the statement of work. Work items 1.) and 2.) correspond to the similar section headings. Report section 4.3 is a summary of activities oriented towards the ASEM cost reduction objective.

Cross Reference Sections

The results of this activity is described in sections:

4.0 Hybrid (C4, Wirebond, and Tab) Interconnect Technology

4.1. MCM Test Vehicle (Technology Demonstration Vehicle)

4.1.1. MCM Test Vehicle - Methods

4.1.2. MCM Test Vehicle - Results

4.2. Physical Testing

4.2.1. Physical Testing - Methods

4.2.2. Physical Testing - Results

4.3. Cost Reduction Results

4.3.1. Cost Reduction - Methods

4.3.2. Cost Reduction - Results

4.4. Conclusions

Infrastructure Support (Task 2.3.1)

Infrastructure activities were structured to insure that knowledge was shared with the rest of the industry.

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.3.1):

IBM will actively participate with MCM industry groups and consortia to develop and formulate standards for Known-Good-Die, CAD, MCM packaging, test and reliability.

1.) IBM will participate in government and industry sponsored committees. IBM intends to perform a leadership role in the area of test, packaging, and flip chip reliability in concert with the IEEE Test Standard Committee, the JEDEC Solid State Products Engineering Committee and the NASA- Industry Design Standards Group, respectively.

2.) IBM will participate as a core team member of the proposed MCC ASEM Technology Standards and Specifications Alliance to address MCM issues. IBM chair focus/working group(s) and will take the lead role in drafting standards for the ASEM Foundry group. IBM will also work with the MCC KGD Study Group and will coordinate the implementation of KGD requirements.

Approach/Method

The approach is fairly well described in the statement of work. There was significant participation in a variety of organizations. Leadership was shown in many of these organizations including chairing the ASEM Customer/Foundry working group of the ASEM Alliance. Details of the various contributions are segmented by subject matter.

Cross Reference Sections

The results of this activity is described in sections:

5.0 Infrastructure

5.1. Application Demonstration

5.1.1. ISI/MOSIS

5.1.2. Mayo Foundation, Special Purpose Processor Development Group.

5.1.3. Hardware Standards

5.1.4. Industry Conferences and Meetings

5.1.5. Application Demonstration Conclusions

5.2. CAD Infrastructure

5.2.1. ASEM Alliance Results / Standards

5.2.2. Other organization Support

5.2.3. Industry Conferences and Meetings

5.2.4. CAD Infrastructure Conclusions

5.3. Module Test / Known Good Die

5.3.1. MCM Test

5.3.2. Known Good Die

5.3.3. Other organization Support

5.3.3. Module Test / Known Good Die Conclusions

5.4. Interconnection Technology

5.4.1. Industry Conferences and Meetings

5.4.2. Other organization Support

5.4.3. Interconnection Technology Conclusions

5.5. Infrastructure Conclusions

Demonstration Vehicles (Task 2.4.1)

Requirements

From ASEM Contract; MDA972-93-C-0011 (SOW 2.4.1):

2.4.1 DEMONSTRATION.

IBM will incorporate activities from the above three tasks into an application demonstration vehicle.

This task will include the following:

1. IBM will survey industry and government programs in the areas of HPCC, HDS and military programs and will identify candidates.
2. IBM will meet with potential application partners to establish a demonstration plan for DARPA review and approval. This plan will include;
 - a. application description
 - b. hardware description
 - c. description of demonstration system
 - d. description of the Known-Good-Die, Design-for-Test plan.
3. IBM will perform an full service, foundry demonstration and will provide prototype hardware and documentation.
4. IBM will accept a design and will implement the design on a demonstration prototype MCM module.
5. IBM will assemble and test the MCM using C4/TAB/WB, as required.
6. IBM will demonstrate the MCM in an application environment, as required.

Approach

The approach is fairly well described by the statement of work. In order to see improvements in a more timely fashion, an incremental demonstration approach was taken that spread demonstrated improvements across a number of vehicles.

Statement of work items map to correspondingly named sections for items 1.) the survey and 2.) the application plan. The 3.) foundry service is demonstrated by the Sun and National Semiconductor demonstrations. The 4.) accepted design is demonstrated by the McClellan Air Force Base (AFB) Air Logistics Center (ALC) module. The 5.) assemble and test is demonstrated in the Sun and McClellan AFB ALC demonstration. Finally, 6.) application environment was demonstrated in the test of the Sun module.

Cross Reference Sections

The results of this activity is described in sections:

- 6.0. Application Demonstration
 - 6.1. Customer Survey
 - 6.1.1. Selection Criteria

- 6.1.2. Methods of Customer Contact
- 6.2. Selected Applications Overview
- 6.3. Sun Microsystems
 - 6.3.1. Product Development
 - 6.3.2. Sector Activity
 - 6.3.3. Conclusions
- 6.4. Sacramento Air Logistics Center (ALC)
(Also known as the McClellan Air Force Base Air Logistics Center (ALC))
 - 6.4.1. Product Development
 - 6.4.2. Sector Activity
 - 6.4.3. Conclusions
- 6.5. National Semiconductor
 - 6.5.1. Product Development
 - 6.5.2. Sector Activity
 - 6.5.3. Conclusions
- 6.6. Application Demonstration Conclusions

1.0 INTRODUCTION

The content of this document satisfies the requirements of line item 0002AU - ASEM Final Technical Report which is described as:

This report, prepared in accordance with DATA Item DI-MISC-80711, shall document the results of the complete effort. Title pages shall included a disclaimer worded... (see Preface)

The Final Technical Report summary shall include:

- Task Objectives
- Technical Problems
- General Methodology (i.e., literature review, laboratory experiments, surveys, etc.)
- Technical Results
- Important Findings and Conclusions
- Significant Hardware Development
- Special Comments
- Implications for Further Research
- Standard Form 298, September 1988

This introduction is meant to give readers an understanding of the organization of this document. This final technical report was written from a compilation of reports delivered over the course of the ASEM Contract which was roughly between January 1993 and December 1994. Some of the sections are direct copies of information from the individual reports. Where necessary, information bridges were written to tie separately written texts together for a more readable text.

Each section is written to be readable within itself for people interested solely in the section content. However, a reader will be referred to other sections for details determined to be only loosely linked to the main subject of the section or when information seems too repetitious.

1.1 Objectives

ARPA set a number of specific goals for the ASEM program. Globally, the objective is to reduce development costs and design-to-product-delivery cycle times by a factor of 10 from the 1992 state of the art.

1.1.1 MCM Environment

MCMs have been used by IBM and others in the industry for over twenty years. MCM usage was possible because of engineers in these companies who specialized in understanding the technology and tools necessary to make MCMs effective for their product needs. Today, a wider range of products are finding MCM technology attractive for its competitive advantages.

Wider use of MCMs was necessary to bring down MCM costs and cycle times. Also, lower costs and shorter cycle times were necessary to bring in additional applications. Work was pursued to improve both these situations.

1.1.2 Specific MCM Focus Areas

The specific objective of this contract is to provide low volume (low-cost/volume, quick turn around time (QTAT)) access to a high volume, commercial MCM foundry, at IBM. In addition to providing access, effort was also put towards achieving the objectives of reducing cycle time and cost.

1.1.2.1 Foundry Access

Enabling multi-use entrance (military, commercial, and university; chip, substrate, and package supply) to the foundry via industry standard interfaces.

Provide DoD access to robust manufacturing capabilities.

1.1.2.2 Cycle time

Limiting turn-around time to 1 month, or less.

Reducing design to product cycle time by 10 fold.

Routinely achieving first-pass success on new designs.

1.1.2.3 Cost

Ensuring that non-recurring engineering costs do not exceed \$25K per design.

Reduce the total recurring module cost for current technologies by an order of magnitude.

1.2 Organization

1.2.1 Technical Areas

The overview of the program and the intentions of ARPA can be seen from the Executive Summary that precedes this section.

Sections of the report detail the results and experience gained as a result of the activity. As seen in the table of contents the major topics are:

- Design System
- MCM Test
- Hybrid (C4, Wirebond, and Tab) Interconnect Technology
- Infrastructure
- Application Demonstration
- Overall Conclusions

1.2.2 General Descriptions

1.2.2.1 Design System

This section compiles a variety of tasks related to design requirements, methodologies, and tools. The specific subsections are:

- Trade Off Tools - the study of the tools that were available at the beginning of the contract and their capabilities to assist in design decisions.
- Design Kits - the kits developed to support the IBM MCM-D technology in the Mentor Graphics and Cadence design tool suites. Design tool requirements and a kit specification are also presented.
- Interfaces - the definition of foundry interfaces for entry into the foundry at a completed specification, completed logic design, and completed physical design state.
- Direct Release - the study of product release requirements and improvements that were made to more effectively handle MCM prototypes therefore reducing cycle time and costs associated with these programs.

- **Design Framework** - the study of integration requirements and results of integrating design and release tools.

1.2.2.2 MCM Test

This section describes the developed test methodology and guidelines for MCMs along with the description of the test challenges, implementation results, and related findings.

1.2.2.3 C4, Wirebond, and Tab Interconnect Integration

An MCM-D test vehicle was built and physically analyzed that contained a mixture of the three types of interconnect. A summary of activities related to reducing cost is also provided.

1.2.2.4 Infrastructure

Throughout the contract significant effort was placed on sharing the knowledge gained in the contract. Areas of substrate standardization, computed aided design issues, module test, and interconnect technology were supported throughout the contract period.

1.2.2.5 Application Demonstration

In support of demonstrating progress on a number of contract objectives, MCMs were fabricated, assembled, and tested for three customers. This section describes, the application survey, customer selection overview, and the individual demonstration vehicles.

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2.0 DESIGN SYSTEM

This section provides insight into the specific aspects of:

- Trade-off tools
- MCM Design Kits
- Multi-entry foundry interfaces
- Direct release of products to the foundry
- Integration Frameworks

2.1 Trade-off tools

2.1.1 Introduction

This subsection was created from the full report on trade-off tools which was submitted as a contract deliverable: "Trade-Off Tool Recommendations Report", CLIN 0002AE.

Trade-off tools are used to help make early decisions about specific alternatives and their impact to product objectives, even during the product definition phase of a program. For this reason, it is believed that a trade-off tool would be very useful for reducing costs, throughput time and decreased time to market. Therefore a survey and evaluation of existing tools was made in order to determine the degree to which they could be supported near term.

A set of requirements has been established for an MCM Trade-off Advisor and is described below along with the results of comparing existing advisors against the requirements for a range of domains. The details of this is described by the rest of this section.

2.1.1.1 List of Tools

The following tools were evaluated in detail:

1. Cornell University's AUDiT Trade-off Tool
2. IBM Corporation's PEPPER Trade-off Tool
3. MCC's MSDA Trade-off tool
4. Stanford University's SUSPENS Trade-off Tool
5. Cadence Corporation's Thermal and Reliability Advisors
6. Cognition's Manufacturing Cost Advisor

Stanford University's SUSPENS trade-off tool is no longer supported and is no longer in use. Therefore, a report on this tool is omitted.

Interim reports were written on all these tools and, with the exception of the SUSPENS tool, are included as an addendum to the "Trade-Off Tool Recommendations Report", CLIN 0002AE.

2.1.1.2 Evaluation Domains

Each of the tools were evaluated in the following domains:

- User Interfaces
- Interfaces to Detailed Simulation Tools

- Trade-off Tool Performance and Accuracy
- Cost
- Turn Around Time and Availability
- Electrical
 - Delay
 - Signal Integrity
 - DC Drop Analysis
 - Electromagnetic Radiation Compatibility (EMC)
- Thermal Analysis
- Package / Physical Analysis
 - Package Size
 - Partitioning
 - Routing
- Test
- Mechanical/Environmental
- Reliability

2.1.1.3 Evaluation Criteria

In evaluating design advisors the following criteria was used:

1. Cost Savings
2. Time To Market Savings
3. Critical Technical Requirements and Benefits

Note: Based on preliminary evaluations, available information and trade-off tool offerings it was decided to substitute Cadence for Mentor Graphics. Cadence offers both a thermal advisor and a reliability advisor that is tightly integrated with the their layout and placement tool. As there is a strong interrelationship between thermal characteristics and reliability it was important to have these two tools together so that they could be traded off against each other. Mentor Graphics does not currently offer a reliability analysis tool.

2.1.2 Trade-Off Tool Requirements

The MCM Design Advisor Requirements document that is attached to "Trade-Off Tool Recommendations Report", CLIN 0002AE, details the requirements for an MCM trade-off tool based on both customer and tool developers feedback. These requirements are summarized in **Figure 2.1-1**. The requirements break down into technical requirements and business requirements.

Figure 2.1-2 shows the decision process for trade-off analysis. The customer works interactively with the design advisor and generates a set of customer requirements which are then fed into the design and build phases of the process. Ideally, the tool generates estimates for cost, turnaround time, and performance. It can also provide package alternatives and electronic design automation (EDA) vendor options.

The trade-off tools evaluated in this report were measured against the requirements detailed in the MCM Design Advisor Requirements document attached to the "Trade-Off Tool Recommendations Report", CLIN 0002AE.

MCM Design Advisor Features

Electrical	Thermal	Package/ Physical	Mechanical/ Environmental	Reliability	Manufacturing	Test
Delay	Thermal Resistance	Placement	Chip Attach	SPQL	MCM Prototype Costs, Recurring & Non-Recurring	Burn In
Cross Talk	Power Dissipation	Wireability	Hermeticity	Mean Time To Failure	Manufacturing Costs (Yields, Equipment Costs, Overhead, Labor Costs, Component Costs)	Test Time
Signal Attenuation	Junction Temperature	Wiring Density	Temperature Cycling	Error Coverage		
Simultaneous Switching Noise	Heat Sinking	# of Wiring Layers	Shielding	Die Attach Options	Parts Availability	
EMC	Cooling Fluid	Wiring Pitch	Rework	Package Options	Learning Curve	Test Costs
Power Supply Distribution	Thermal Paste	Package Size	Module Field Replaceability (Hot Insertion)	Technology Options	Maintainability	
		Package I/O	Connector Options	Connector Options	Known Good Die	Test Coverage
		Weight / Volume	Shock Resistance	Module Attachment Options System Availability	Turn Around Time	

Figure 2.1-1: Trade-off tool features

MCM Design Advisor Decision Process

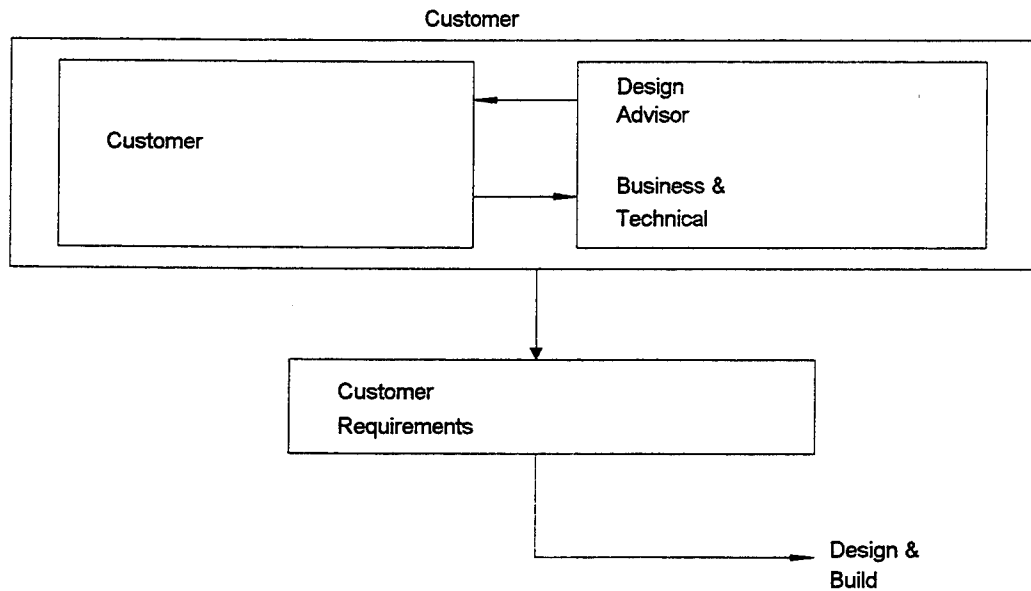


Figure 2.1-2: Trade-off tool process

2.1.3 Evaluation Domain Overview

2.1.3.1 Platforms And Operating Systems

All the tools evaluated, with the exception of SUSPENS, run on one or more of the commercial workstations. They all use UNIX or AIX operating systems. This means that it is straight forward to port the trade-off tool to anyone of the commercial workstations. No trade-off tool has been run on a personal computer. Whilst, it would not be feasible for all the features of a trade-off tool to run on a personal computer, some tools such as a cost advisor could readily be ported to a personal computer.

2.1.3.2 User Interfaces

In general the trade-off tools evaluated had good user interfaces with multiple windowing capabilities. MCC's user interface has an added attractive feature that incorporates the process flow as part of the user interface. This enables the user to access any part of the process rapidly.

2.1.3.3 Interfaces To Detailed Simulation Tools

In general interfaces to other detailed simulators have not been developed. The PEPPER tool has developed interfaces to the IBM internal downstream simulators and can accept netlist input. However, interfaces to outside commercial EDA tools have not been developed. MCC's MSDA has links developed to Cadences VIABLE reliability tool and to both OEA International's Simulator and SPICE. As an interim step procedural interfaces can be easily build for linking to EDA tools. For the long term, standard interfaces such as EDIF need to be developed.

2.1.3.4 Component Libraries

With the exception of Cadence's VIABLE and Thermax, component libraries are a major deficiency of the trade-off tools evaluated. The PEPPER tool has adequate libraries for IBM internal components. However, the developers of the tool need to address libraries for outside commercial components.

2.1.3.5 Trade-off Tool Performance and Accuracy

For a trade-off tool to meet customer requirements the turn around time needs to be fast so that a large number of iterations can be processed in a short time. All of the tools evaluated met this requirement. The accuracy of the tools varies and is detailed in the interim reports. For electrical analysis PEPPER yielded the most accurate results. For thermal analysis good accuracy is to be expected because of the 3 dimensional algorithms used to calculate thermal characteristics. Cadence's reliability tool is backed by the MIL-HDBK-217F handbook. It is difficult to assess the accuracy of the MSDA and AUDiT tools because they have not been used to develop products.

2.1.3.6 Cost

Three cost tools were evaluated; Cognition's Cost and Manufacturability Guide, MCC's MSDA cost advisor and MCC's High Level Test Economics Advisor, (HI-TEA). Comments on these tools are as follows:

1. Cognition's Cost and Manufacturing Guide provides a software shell for capturing process costs. However, no cost model exists for MCM manufacturing and assembly. If a model for MCM manufacturing is developed it will significantly improve the cost estimation process in both time and cost consistency.
2. MCC's MSDA cost advisor is specific to MCM module assembly. However, cost data is hard coded currently and cannot be altered by the user. MCC is planning to correct this deficiency in the near future.

3. MCC's High Level Test Economics provides for user cost inputs. The focus of this tool is on test costs. MCC is planning to combine this tool with the MSDA tool.

As manufacturing costs are very foundry dependent, it is recommended that direct electronic links be established between the foundry and the cost trade-off tool so that the database can be updated rapidly and in real time.

2.1.3.7 Turn Around Time and Availability

None of the tools evaluated calculates turn around time. As turn around time is very foundry dependent, it is recommended that details of factory throughput and availability be provided as a lookup table and that electronic links be established between the foundry and the trade-off tool so that the database can be updated rapidly and in real time.

2.1.3.8 Electrical

Delay

The following tools estimate delay:

1. Cornell University's AUDiT Trade-off Tool
2. IBM Corporation's PEPPER Trade-off Tool
3. MCC's MSDA Trade-off tool

The AUDiT tool analyses both chip delay and module delay. MSDA estimates package delay only. The PEPPER tool factors in both chip and package delay. Because the PEPPER tool uses 3 dimensional analysis of parametrics, coupled with a detailed simulation of net segments, this tool is rated the best for delay estimations.

Signal Integrity

Both Cornell University's AUDiT Trade-off Tool and IBM Corporation's PEPPER Trade-off Tool analyze for cross-talk and signal attenuation. Because of the use of 3 dimensional analysis techniques the PEPPER tool is rated the best for cross-talk. MCC's MSDA trade-off tool analyzes signal attenuation. However, again because of the use of 3 dimensional analysis techniques the PEPPER tool is rated the best for signal attenuation analysis.

DC Drop Analysis

MCC's MSDA trade-off tool estimates inter-planar DC drops. This is a valuable feature with sufficient accuracy for early estimations.

Electromagnetic Radiation Compatibility (EMC)

None of the trade-off tools evaluated does EMC trade-off analysis. As the frequency requirements increase EMC will become critically important. At the 1993 Design Automation Conference Racal Redac announced the development of an EMC Advisor.

2.1.3.9 Thermal Analysis

The following trade-off tools perform thermal analysis.

1. Cornell University's AUDiT Trade-off Tool
2. MCC's MSDA Trade-off tool
3. Cadence Corporation's Thermax Advisor

The use of Cornell University's AUDiT Trade-off tool is too limited to be useful. (It should be noted that Cornell has recently announced an upgrade of the thermal tool). MCC's MSDA thermal analysis tool is comprehensive. However, Cadence Corporation's Thermax Advisor has the advantage that it is based on 3 dimensional thermal analysis and has an attractive graphics output.

2.1.3.10 Package / Physical Analysis

Package Size

The following tools perform package trade-off analysis

1. Cornell University's AUDiT Trade-off Tool
2. IBM Corporation's PEPPER Trade-off Tool
3. MCC's MSDA Trade-off tool

Each of these tools use a similar theoretical approach for estimation of package sizes. There is a reasonable correlation between theory and experimental results for early estimations of package sizes.

Partitioning

The following tools perform partitioning

1. Cornell University's AUDiT Trade-off Tool
2. IBM Corporation's PEPPER Trade-off Tool
3. MCC's MSDA Trade-off tool

Both MSDA and PEPPER have interactive floor planning capability. The PEPPER tool features congestion driven floor planning. Neither the PEPPER or MSDA tools have chip partitioning capability. The AUDiT tool has both chip and module level partitioning capabilities.

Routing

The following tools have routing capabilities

1. IBM Corporation's PEPPER Trade-off Tool
2. MCC's MSDA Trade-off tool

Both tools have acceptable routing performance capabilities.

2.1.3.11 Test

MCC's High Level Test Economics Advisor estimates test costs based on user inputs for both costs and test coverage. However, the tool does not breakdown costs of different test strategies such as Level Sensitive Scan Designs, (LSSD) and Built In Self Test, (BIST). These cost figures should be generated by the MCM foundry.

2.1.3.12 Mechanical/Environmental

None of the tools evaluated does trade-off analysis for mechanical performance.

2.1.3.13 Reliability

Cadence Corporation's VIABLE is the only tool evaluated that performs reliability analysis. The tool uses MIL-HDBK-217F handbook as the main source of component reliability. No provisions are made in the tool for the contributions of die attach methods to reliability.

2.1.4 Tool Evaluation Summary

The table below summarized the evaluation results.

Trade-Off Tool	Trade-off Function	Interface to other EDA Tools	Extent of Libraries, Databases	Performance Rating	Comments
Cornell AUDiT	Package	No	Limited	Acceptable	Tool needs to develop interfaces to other EDA tools. Commercial level databases need to be established. Thermal tool needs to be enhanced to model typical thermal conditions.
	Thermal			Not Acceptable	
	System Partition			Acceptable	
	Delay			Acceptable	
	Signal Integrity			Acceptable	
IBM Pepper	Package	IBM Tools	IBM Only	Best of Breed	Good performance. Interfaces need to be developed to commercial EDA tools. Commercial databases need to be established.
	Routing & Congestion			Best of Breed	
	Floor-Planning			Good	
	Delay			Best of Breed	
	Signal Integrity			Best of Breed	
Cognition CMG	Manufacturing Costs	ASCII File Transfer	MCM Cost Models Needed	Not Acceptable at this time	Good user interface. Fast cost analysis. Standard interfaces need to be developed to mechanical design tools. Tool needs graphical capabilities. Cost models need to be developed for MCM processes

Trade-Off Tool	Trade-off Function	Interface to other EDA Tools	Extent of Libraries, Databases	Performance Rating	Comments
MCC MSDA	Package Size	No	Limited	Acceptable	Most comprehensive offering of trade-off tools. Good user interfaces. Assembly cost tool needs major rework. Libraries are limited.
	Module & System Partitions	No		Acceptable	
	Thermal	No		Acceptable	
	Routing	No		Acceptable	
	Delay	Linked to OEA & Spice Simulators		Acceptable	
	Signal Attenuation	No		Acceptable	
	DC drop analysis	No		Best of Breed	
	Reliability	Linked to Cadence's Viable Tool		See Below	
	Assembly Cost	No		Not Acceptable	
Cadence	Test Costs	No	Extensive but not for MCMs	Acceptable	Database with thermal characteristics needed for MCM components standard. Interfaces to other EDA tools required. Database with MTF data required for MCM parts . Standard interface to EDA tools required.
	Thermax	Linked to Allegro		Best of Breed	
	Viable (Reliability)	Linked to Allegro	Extensive but not for MCMs	Best of Breed	

2.1.5 Tool Effectiveness Results

As most of the trade-off tools that were evaluated have not been used in a production environment it was difficult to make an assessment of the benefits of these tools. However, the following can be concluded from customer feedback and an assessment of design advisor capabilities:

1. PEPPER (IBM) This tool is unique among the trade-off tools evaluated because it has been used in the development of a significant number of key IBM products. The feedback from the users of this tool is very positive. The following are the benefits that have been identified for this tool:
 - a) The run times are fast, approximately 3 minutes, permitting a large number of iterations in a short time. A typical number of iterations would be approximately 50. If the PEPPER tool did not exist it is estimated that an iteration would take about 3 days and quality of the analysis would be degraded significantly. This would add about 5 months to the cycle time of the product. As this would be prohibitive, the designer would end up doing fewer iterations with a resultant degradation on quality and a decrease in the likelihood of first pass success.
 - b) Users of the PEPPER tool reported that the tool helped them to quickly eliminate options that would not have worked. Furthermore, they regarded the tool as a major factor in achieving first pass success.
 - c) Because PEPPER has been used in a production environment it is possible to check the accuracy of the tool. Actual results have been reported to be within 10% of prediction, which for an early analysis tool is very acceptable.
2. Thermax (CADENCE) As component temperature is a major concern in a large number of applications, Thermax fills a critical technical requirement. The feedback on this tool is positive. The correlation between predicted case temperatures and actual measured temperature has been reported to be within 4 degrees Celsius. This is excellent.
3. Cost and Manufacturing Guide (COGNITION CORP.) Major cost savings and time savings have been reported for the use of this tool.

The following tools have not been used for a manufactured application:

1. Cornell University's AUDiT Trade-off Tool
2. MCC's MSDA Trade-off tool

Therefore, their benefits cannot be accurately assessed at this time. From the data reported above it can be expected that major savings in time and costs can be achieved by the use of design advisors. In addition, the chances of first pass success are significantly improved.

2.1.6 Conclusions

Investigations were completed and reports have been submitted to satisfy contract requirements.

2.1.6.1 Principle Recommendation

At this time MCC is the closest to a total MCM trade-off advisor. However, there are some major shortcomings in capabilities. The following is a list of these deficiencies:

1. The most notable is the lack of comprehensive component libraries. It is recommended that MCC form a partnership with a major EDA vendor who will have the resources to build up the component libraries.
2. The MCC tools need to be ported to the IBM RISC and HP workstations for universal acceptance of MCC's trade-off tools. In addition, the MCC software needs to be ported to personal computers for specialized tasks such as cost analysis.
3. The links to other EDA tools are limited. On an interim basis procedural interfaces will be a temporary solution. For the longer term, standard interfaces will be required.
4. MCC's Assembly Cost Analysis tool needs major work. Process cost variables need to be made user definable. Ideally, cost figures should originate from the MCM foundries and be updated electronically. Graphical output capability needs to be added.
5. Chip partitioning capability needs to be added to the tool.

A major advantage of the MSDA tools is that all the design advisors have been integrated under the same operating system. This results in a common look and feel in the user interface. MCC's strategy for linking to the Cadence Viable tool is a good one. It still provides the concept of "one stop shopping" without having to develop a new tool.

2.1.6.2 Point Solution Tools

PEPPER is an excellent trade-off tool. IBM has indicated an interest in offering a broad based trade-off tool capability. PEPPER would be an excellent foundation tool for this purpose. For general acceptance it will need to be ported to the SUN, HP and DEC workstations. Also, the library capabilities will need to be extended.

The AUDiT tool has a number of features that should be incorporated, if possible, in an integrated trade-off tool. These include (a) chip, module and system partitioning and (b) statistical optimization.

An offering for a mechanical trade-off advisor was not identified. This requirement needs to be addressed in the future. The need for an EMC advisor was identified. Racal Redac has announced an EMC trade-off tool. This tool needs to be evaluated.

2.1.6.3 Future Work

It is clear that major work has to be done before a fully integrated and a fully tested trade-off tool is in place. The focus of this work should address the following issues:

1. Establish a "Best of Breed" tool set of trade-off advisors that function under a single operating environment that is ported to the common workstations and in certain special applications ported to personal computers.
2. Develop standard interfaces between the trade-off tool and the major EDA vendors software.
3. It is recommended that a test vehicle be identified and used to evaluate the following:

- a) A "Best of Breed" set of design advisors
- b) The performance and accuracy of an integrated trade-off tool
- c) A comprehensive component library system
- d) Standard interfaces to detailed EDA design tools

There is no current tool that sufficiently addresses the needs of the industry, either because of lack of supporting data/libraries or due to the limited capabilities. Follow on activity will require funding to develop solutions that are widely accepted.

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2.2 Design Kits

Design kits have been developed for IBM's MCM-D technology for the Cadence and Mentor Graphics tool sets. These kits were developed through a prototyping process where test case designs were mapped into the design systems. The kits include hard-copy documentation and a tape, or other magnetic media, which contains design tool specific information, soft-copy documentation, and custom software to initialize a design environment.

In the process of creating these kits a number of documents were created. These documents are:

“ASEM Design System Requirements Report (Design Tools supported by MCM-D Design Kits)”, CLIN 0002AD, which defines tool sets that were considered in putting the design kits together as well as defines the components of a general design system.

“ASEM Design Kit Specification”, CLIN 0002AF, which generalizes design kit entities and formats that provides a basis for consistency among many kits.

“MCM-D Design Kit (1 of 2), Using the Cadence Allegro Design System” CLIN 0002AC, the design kit that describes MCM-D technology design using Cadence tools.[1]

“MCM-D Design Kit (2 of 2), Using the Mentor Graphics MCM Station Design System” CLIN 0002AC, the design kit that describes MCM-D technology design using Mentor Graphics tools.[2]

The purpose of Design kits is to facilitate quicker, cheaper, error free designs. They do this first, through a process of describing technology requirements, capabilities, and standard offerings. Secondly, the kits establish, within the design system capabilities, a set of tool parameters that maximizes the possibility of conformance to technology preferences. This does not imply that either design tool set is currently sufficient within itself to insure technology conformance, but that through a combination of tool capabilities and methodology control conformance is possible.

To say this another way, design kits provide both information to guide design system users and data that controls or is used by the tools. The tool data consists of:

- Control parameters to insure design rules are met
- Partially complete design elements
- Process automation routines.

Design kits are aimed at helping users achieve solutions with reduced cycle time and-or reduced non-recurring engineering costs.

The organization of this section is as follows:

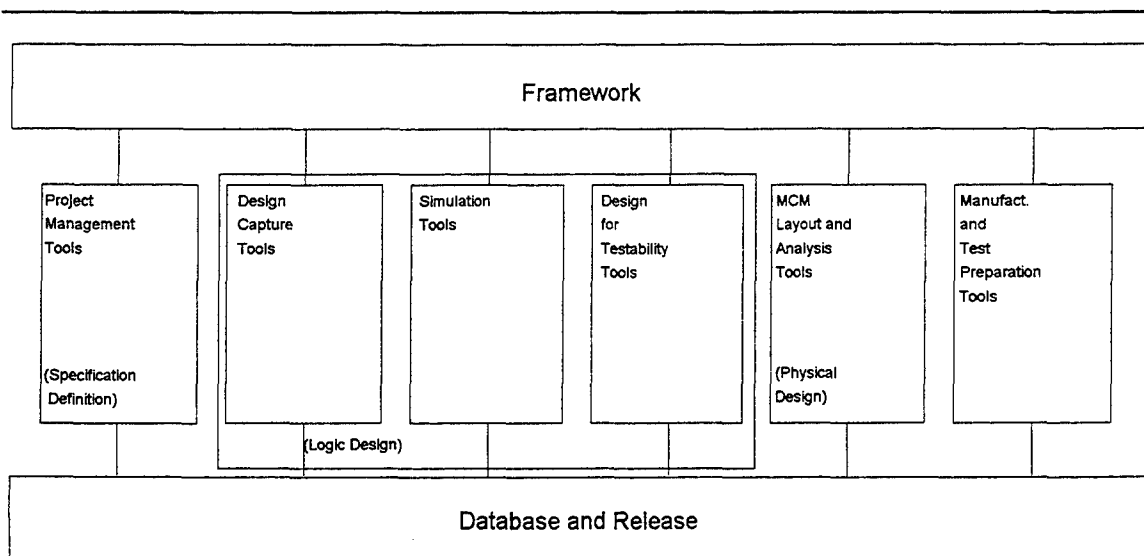
- Design System Requirements - describes the design tool sets for which the kits were developed
- Design Kit Specification - outlines the generalized information that is found in design kits
- Cadence MCM-D Design Kit - describes specifics of the Cadence Kit and use experience
- Mentor Graphics MCM-D Design Kit - describes specifics of the Mentor Graphics kit and use experience
- Conclusion - a summary of conclusions that result from the design kit development efforts

2.2.1 Design System Requirements

Design systems must provide certain capabilities to support Multichip Module (MCM) design. A detailed description of these requirements is defined in the contract deliverable "ASEM Design System Requirements Report (Design Tools supported by MCM-D Design Kits)", CLIN 0002AD. This section will not go into the full detail but will touch on the highlights of that report. It will briefly describe a general design system, then specifically define the Cadence and Mentor Graphics design tools that were selected for support in their respective design kits.

2.2.1.1 General Design System

A general design system has the capability to support specification development, logic design, physical design, and manufacturing release. As shown in **Figure 2.2-1**, adapted from the Design System Architecture described in the referenced SWAP final report [3], design system components generally can be encompassed in a framework that works out of a database structure.



Adapted from Design System Arch. from referenced SWAP Report (figure 8)

Figure 2.2-1. MCM Design System

Typically, two levels of tools are used in the design process, detailed design tools and trade-off tools. Detailed design tools are used for full implementation or evaluation of specific objectives. Trade-off tools assist at specific design levels by helping to clarify benefits and drawbacks of potential alternatives. These tools do not require full detailed design at the current design level in order to provide guidance for decisions that need to occur. Trade-off tools provide quick turn around time for responses to various design alternative questions.

2.2.1.1.1 Specification Level Tools

Specification tools capture specifications related to function, cost, performance, form factors, reliability objectives, and other product requirements. Specification definition is accomplished conceptually with the help of trade-off tools or advisor type tools. Actual specifications currently are not captured or enforced in a computer sensible manner for use by design tools.

This is demonstrated by the fact that specification information, outside of logic specification, is often conveyed by ASCII text, postscript, or hard-copy forms.

2.2.1.1.2 Logic Design Level Tools

The logic design level tools encompass the following functions:

- Design capture to establish the expression of the detailed logic as a schematic, including the generation of required schematic symbols used for graphically representing circuits and chips on the schematic. The interconnections between chip boundaries are defined in netlists within the capture tool. Performance constraints are also captured for individual nets for transfer to the physical design tools.
- Simulation to verify the function of the logic, including the generation of test cases and simulation models used in the simulation.
- Timing to verify that electrical performance of the logic meets timing requirements. This includes the expression of physical constraints which must be followed during layout of the logic in order to stay within the performance requirements.
- Fault analysis to allow fault simulation that quantifies the coverage of design verification tests and manufacturing tests.

2.2.1.1.3 Physical Design Level Tools

Physical design includes layout and analysis tools that verify functional objectives are achieved within a specific implementation. This includes:

- Placement, routing and design rule checking insure logical to physical requirements are met
- Thermal analysis insures that placement and cooling technology can support semiconductor operating requirements and data is passed to reliability tools to insure those objectives are met
- Electrical analysis in conjunction with electrical design rules insure that signal performance objectives are met and back annotation of actual route delay information is available for logic level timing tools
- Manufacturability of the design.

2.2.1.1.4 Manufacturing Release Tools

Manufacturing release tools are ones that create information in the proper formats to support documentation, tooling, and release needs of the manufacturing process. These are foundry specific files that are needed for manufacturing and are generally created by the foundry.

2.2.1.1.5 Further Information

Additional design system description can be found in the 'Silicon Wafer Advanced Packaging (SWAP) Final Report'. ARPA order number 7549/1 under contract MDA972-90-C-0064.[3]

2.2.1.2 Cadence Tool Set

Figure 2.2-2 shows the Cadence tool relationships. Tools in dashed boxes are supported primarily through text assistance rather than control or data initialization. The software version is intended to be the latest version available as of June 1993 unless otherwise noted.

2.2.1.2.1 Physical Design Level Tool List

The tools defined at this level are:

Allegro 7.0

Design for Thermal Integrity /Thermax/

Design for Signal Integrity /SigNoise/

Design for Reliability /Viable/

Design for Assembly

SPICE

DRACULA

2.2.1.2.2 Logic Design Level Tool List

The tools defined at this level are:

Concept

Composer

LeapFrog

Verilog-XL

Veritime

Verifault-XL

EDIF Interface

ValidPACKAGER

2.2.1.2.3 Specification Level Tool List

Specific tools are not available which define specifications such as cost, reliability, or performance objectives.

Some of the tools listed in the physical design section can be worked in a trade-off tool fashion. The results of such a comparative analysis can assist in directing users to appropriate solutions leading to specifications. Trade-off capabilities of the tools are described in the appropriate appendix of reference [14].

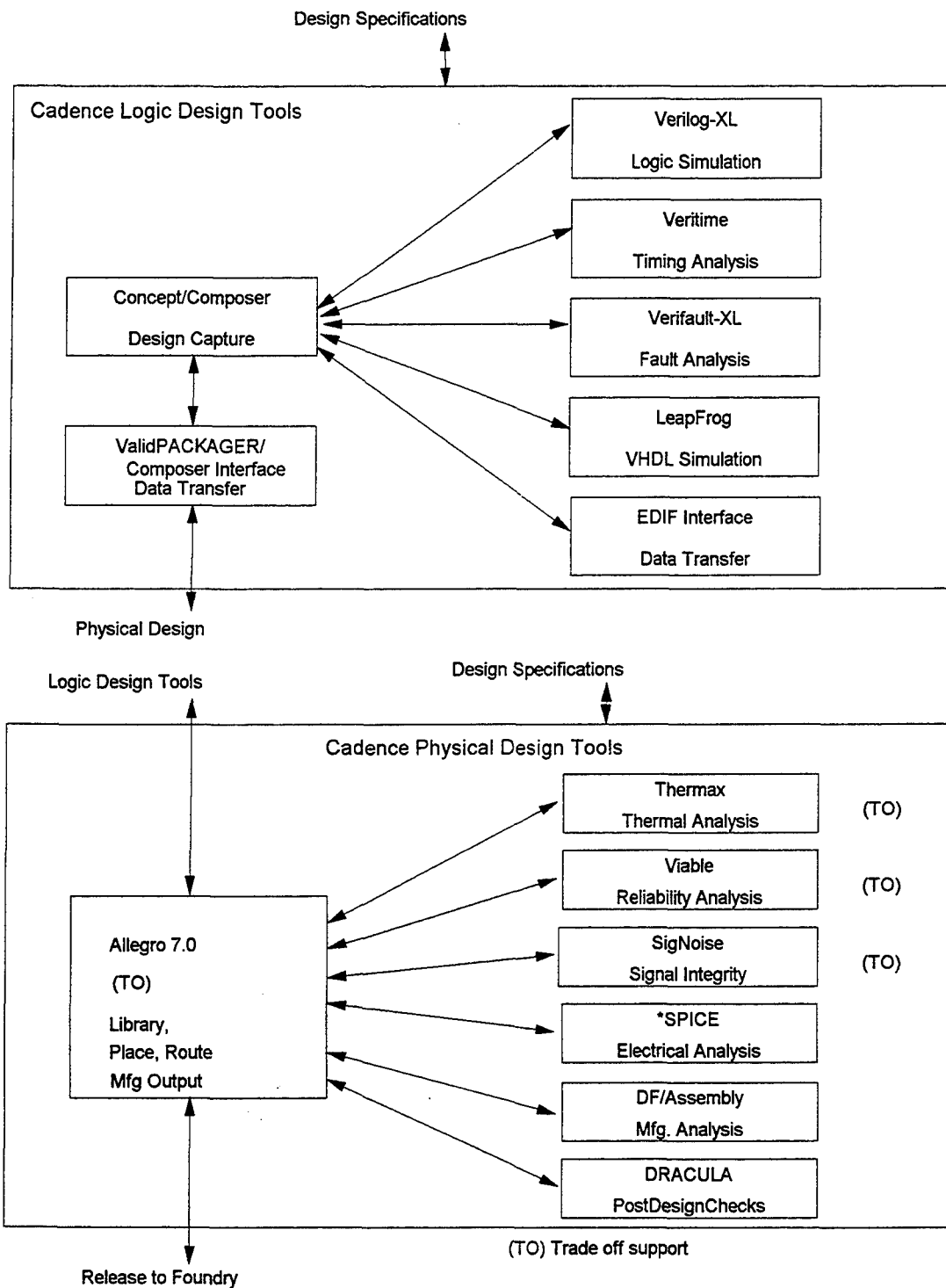


Figure 2.2-2. Cadence Tool Set

2.2.1.3 Mentor Graphics Tool Set

Figure 2.2-3 shows the Mentor Graphics tool relationships. Tools in dashed boxes are supported primarily through text assistance rather than control or data initialization. The software version is intended to be the latest version available as of June 1993 unless otherwise noted.

2.2.1.3.1 Physical Design Level Tool List

The tools defined at this level are:

LIBRARIAN

LAYOUT 500

AutoTherm

SMARTROUTERS

Quad Design XTK(XFX/XNS) PDQ

FabLink

CheckMate

2.2.1.3.2 Logic Design Level Tool List

The tools defined at this level are:

Design Architect

PACKAGE

EDIF Interface

SimView

System 1076

QuickSim II

QuickPath

QuickFault II

QuickGrade

FlexTest

FastScan

QuickCheck

2.2.1.3.3 Specification Level Tool List

Specific tools are not available which define specifications such as cost, reliability, or performance objectives.

Some of the tools listed in the physical design section can be worked in a trade-off tool fashion. The results of such a comparative analysis can assist in directing users to appropriate solutions leading to specifications. Trade-off capabilities of the tools are described in the appropriate appendix of reference [14].

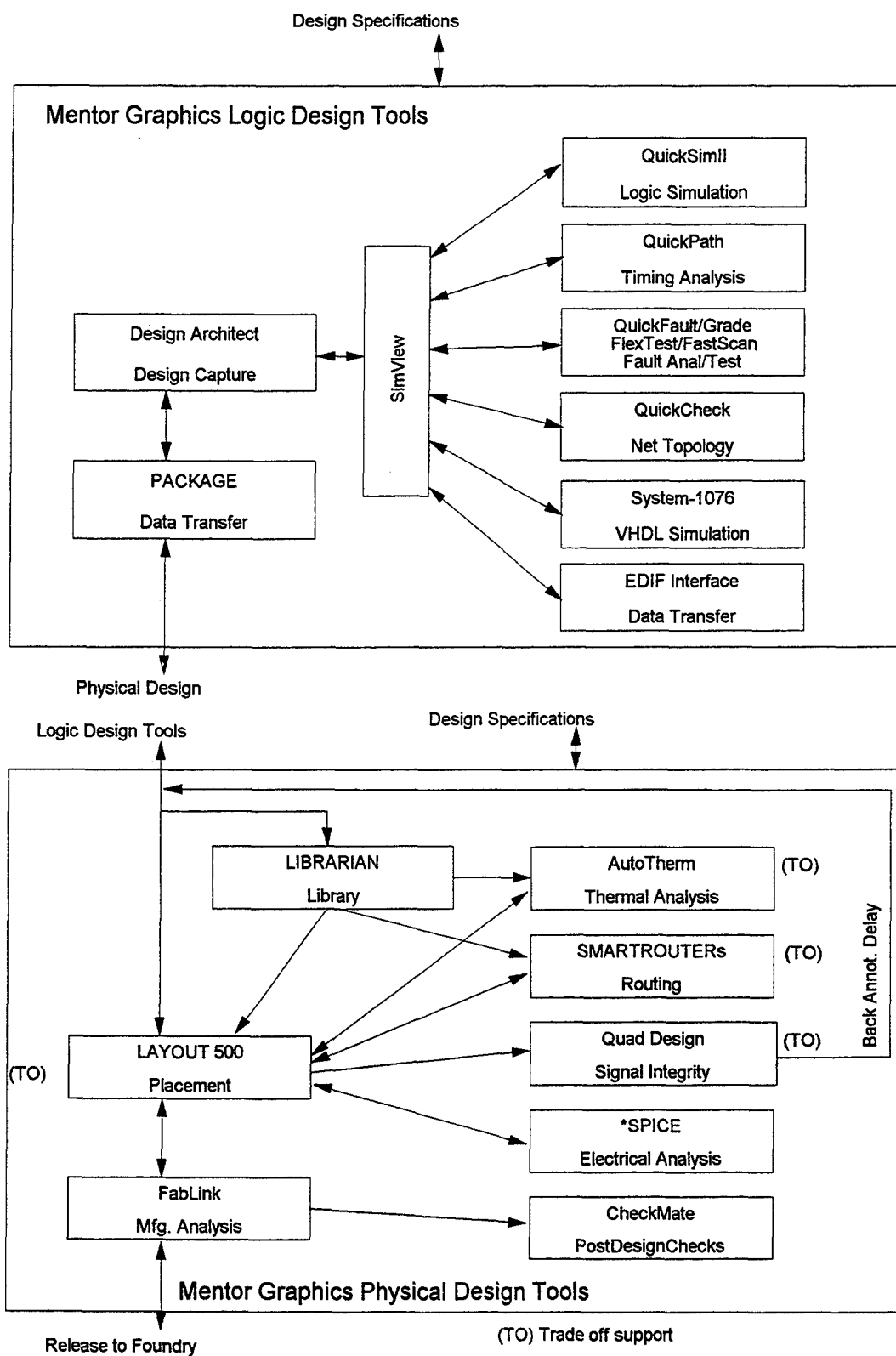


Figure 3. Mentor Graphics Tool Set

2.2.2 MCM-D Design Kit Specification

The latest version of the complete design kit specification entitled "ASEM Design Kit Specification", CLIN 0002AF, is dated June 3, 1994. This section will cover the general ideas of the specification and how it can be used in generating and reviewing to design kits. While the "ASEM Design Kit Specification" describes the many types of support possible, within the tool sets described, a foundry may choose not to support all these types. However, even with only partial support, a design kit can be useful since it clarifies aspects of design within a supported tool set.

2.2.2.1 Introduction

In compiling design kits for the Mentor Graphics and Cadence design tools, the required kit information was determined to be equivalent in nature but needed to be fitted uniquely to the tools and algorithms incorporated in the tools (e.g. routing parameters for routers that enforce design rule requirements). The specification, therefore, tries to describe the information content of a design kit.

To create a design kit, a foundry has to map the technology information described in this specification into the specific CAD tool (e.g. Mentor Graphics, Cadence) parameters and formats. Ideally, CAD tool formats will migrate to industry-standard formats like the DIE information format [4] to minimize foundry resources spent supporting the tools.

In addition to base CAD tool functionality, CAD tools which interact with extension languages allow additional new functions (programs) to be developed to support specific foundry requirements. This capability provides for a wide range of design kit extensions for such design tools. Examples of this type of customized software is included in this document.

There are three types of data described in a design kit. The three general types are:

- Documentation (e.g. The design process, tutorials, selections from the foundry's "customer-foundry interface specification" and "user's guide".)

- CAD rules, models, libraries, design tool parameter settings (e.g. Technology specific information)

- Specialized software (e.g. Special technology selection software, checking software)

The following section is included to aid in describing the relationship of design kit information to a design process.

2.2.2.1.1 MCM Design Flow and Tool Oriented Kit Information

This section gives an overview of how the tool specific information supports the design process. Figure 2.2-4 'MCM Design Flow' illustrates the customer-foundry process used to design and deliver customer requirements for an MCM. This flow will be used to illustrate the relationship of the design kit information to the design process.

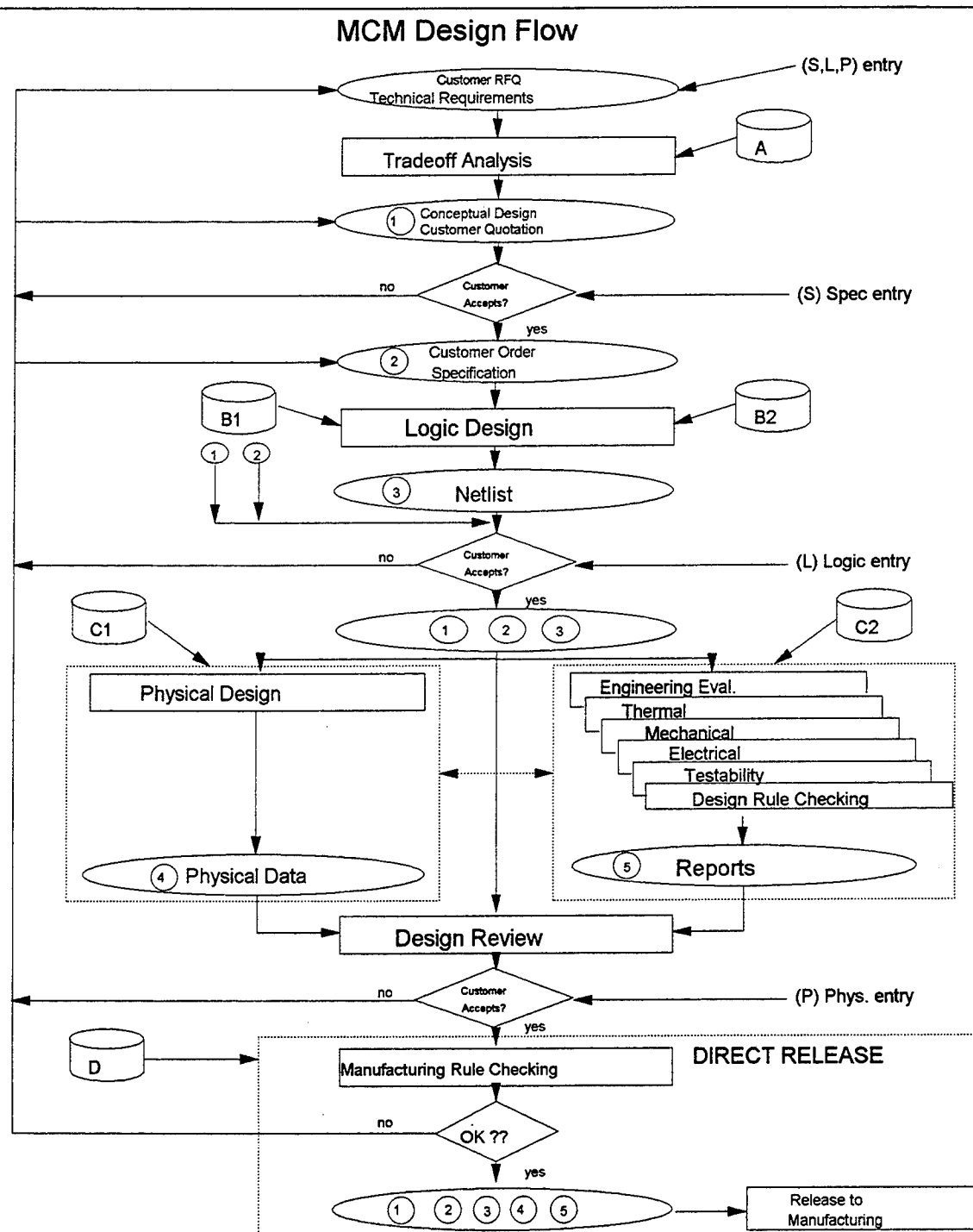


Figure 4. MCM Design Flow

2.2.2.1.2 Design Kit Information Element Definitions

Referencing Figure 2.2-4, Table 2.2-1 describes technology information that is needed to support the design process. Each element is supported with documentation, CAD rules etc., and specialized software.

ITEM	DESIGN KIT INFORMATION ELEMENTS
A	Technology data needed for trade-off analysis
B1	Rules and models for logic design (netlist creation)
B2	Rules and models for engineering analysis at the logical level
C1	Rules and models for physical design (placement and routing)
C2	Rules and models for engineering analysis at the physical level
D	Technology rules needed for "final" manufacturing rules checking(Described in a Design Ground Rules document)

Table 2.2-1. Design Kit Information Element Definitions

Each major process, Trade-off Analysis, Logic Design, and Physical Design, has both a design component and an analysis component as illustrated by the break out of the design and analysis activity in the physical design section. In Figure 2.2-4; B1, B2, C1, and C2 are broken out to illustrate this point.

2.2.2.1.3 Design Entry Definitions

All levels of entry into the foundry pass through the Request for Quotation (RFQ) and Trade-off analysis phase. This allows:

- Technical assumptions to be established in a conceptual design document
- Business assumptions to be defined such as schedules and responsibilities
- A quote to be returned to the customer for their decision and approval.

Table 2.2-2 describes design entry definitions relative to Figure 2.2-4.

The documentation needed to support these levels is described in the following section.

2.2.2.2 Documentation

The documentation that accompanies a design kit is standardized so that users can quickly and consistently find kit information regardless of the tool set or the technology the kit was created to support. To accomplish the standardization a common documentation outline was defined and is described below. Also described are documents that the foundry can provide that contribute to the content of the design kit documentation. These are described after the Kit Documentation Outline.

2.2.2.2.1 Design Kit Documentation Outline.

The Design Kit documentation describes information that comes from a variety of foundry documents. Some of the information can come from a "Foundry User's Guide". Kit documentation includes design tool specific information about the design process, CAD sensible design data, and custom software developed to support the design process within the particular tool set for the technology defined in "Design Ground Rules". It also picks from the "IBM MCM Foundry Interface Specification"[5] the applicable data paths that are available for the supported tool sets. The information is organized as shown in Table 2.2-3.

ENTRY	DESCRIPTION
S	Specification level design entry At the specification level design entry, there is a conceptual design in a particular MCM technology, a customer quotation, and the agreed to assumptions between the foundry and the customer which might include a test plan, a design schedule, and a list of responsibilities. Using the flow in Figure 2.2-4, a customer (alone or with foundry help) has used information from 'A' in order to develop requirements and supplies the foundry information as illustrated with the circled numbers 1 and 2.
L	Logical level design entry At the logic design level, the MCM customer has performed requirements analysis, schematic capture, and simulation in their MCM design environment. The customer supplies the MCM logic design as a netlist to the MCM foundry, along with acceptance tests and the information required at the specification level design entry, i.e., the conceptual design, the customer quotation, and the agreed to assumptions. Using the flow in Figure 2.2-4, a customer has used information from 'A', 'B1', and 'B2' in order to develop the design and requirements, and supplies the foundry information as illustrated with the circled numbers 1, 2, and 3.
P	Physical level design entry At the completed physical design level, the MCM customer has performed requirements analysis, schematic capture, simulation, physical design, and engineering evaluation in their MCM design environment. The customer supplies the MCM physical design, engineering evaluation reports, and the information described under logical level design entry. Using the flow in Figure 2.2-4, a customer has used information from 'A', 'B1', 'B2', 'C1', and 'C2' in order to develop the design and requirements, and supplies the foundry information as illustrated with the circled numbers 1, 2, 3, 4, and 5.

Table 2.2-2. Design Entry Definitions

Table 2.2-3. Design Kit Documentation Outline

Design Kit Documentation Outline

1.0 Overview.

- 1.1 Sections of interest (based on customer selections)
- 1.2 User guide section descriptions

2.0 MCM Technology Description

- 2.1 Substrates
- 2.2 MCM to Card interconnect options
- 2.3 Component attach
- 2.4 Module description
- 2.5 Standard module offerings
- 2.6 Quality and reliability

3.0 MCM Foundry Services

4.0 Other Services

5.0 Design process overview

- 5.1 Description of design tools
- 5.2 Description of tool specific process flows
- 5.3 Description of data required for tools

6.0 Conceptual design

- 6.1 Detailed design and analysis process
(including system concerns)
 - 6.1.1 Description of design tools
 - 6.1.2 Description of tool specific process flows
 - 6.1.3 Design kit description
 - 1. Design kit usage
 - 2. Design kit installation procedure
- 6.2 Tutorial
 - 6.2.1 Sample designs
 - 6.2.2 Sample analysis
- 6.3 Customer-foundry interface specifications
 - 6.3.1 Customer to foundry
 - 1. Conceptual design-customer quotation
 - 2. Customer order-specification
 - 3. Reports
 - 6.3.2 Foundry to customer
 - 1. Design guidelines
 - 2. Reports

7.0 Logic design

- 7.1 Detailed design and analysis process
 - 7.1.1 Description of design tools
 - 7.1.2 Description of tool specific process flows
 - 7.1.3 Design kit description
 - 1. Design kit usage
 - 2. Design kit installation procedure
- 7.2 Tutorial
 - 7.2.1 Sample designs
 - 7.2.2 Sample analysis
- 7.3 Customer-foundry interface specifications

- 7.3.1 Customer to foundry
 - 1. Conceptual design-customer quotation
 - 2. Customer order-specification
 - 3. Netlist-component information
 - 4. Reports
- 7.3.2 Foundry to customer
 - 1. Design rules
 - 2. Reports
- 8.0 Physical design
 - 8.1 Detailed design and analysis process
 - 8.1.1 Description of design tools
 - 8.1.2 Description of tool specific process flows
 - 8.1.3 Design kit description
 - 1. Design kit usage
 - 2. Design kit installation procedure
 - 8.2 Tutorial
 - 8.2.1 Sample designs
 - 8.2.2 Sample analysis
 - 8.3 Customer-foundry interface specifications
 - 8.3.1 Customer to foundry
 - 1. Conceptual design-customer quotation
 - 2. Customer order-specification
 - 3. Netlist-component information
 - 4. MCM substrate artwork
 - 5. Reports
 - 8.3.2 Foundry to customer
 - 1. Design rules
 - 2. Back annotation data
 - 3. Reports

Table 2.2-3 Design Kit Documentation Outline

2.2.2.2.2 Design Kit Document Relationships

Outline sections 1.0 through 4.0 are generic. These sections could reference a separate document such as a Foundry Users Guide. Outline sections 5.0 through 8.0 are specific to tool sets and are customized according to the Design Ground rules requirements. The foundry interface information for these sections (sub-item X.3 of these sections) are selected from the sections of the "Foundry Interface Specification" that best applied to the foundry and customer objectives. The Design Rules sections are determined from a "Design Ground Rules" document. These sections could reference a separate document.

Foundry User's Guide

A "Foundry User's Guide" describes the technology and service offerings and business processes required to interact with a customer. The guide also contains generic design process information and the range of ways to interact with the foundry (from the "Foundry Interface Specification"[5]).

The "Foundry User's Guide" could be the source of all globally described information. Outline sections 5.0 through 8.0, which are specifically defined in design kit documentation, would be substituted with a general superset of applicable information in order to give insight into the

capabilities and objectives of the processes. (Including a complete view of the foundry interface possibilities.)

Foundry Interface Specification

A "Foundry Interface Specification"[5] defines the information requirements of the foundry for applicable product and service offerings. This is a reference guide used within the foundry to compile all methods and formats for communicating required information and a description of the relative degree of effort needed to process different options.

The presumption is that a superset of all communication options supplied in various design kits, as well as potential stand alone paths, is described in the interface document. Since this is a foundry internal document, it also maintains data processing procedures and individual path concerns for reference purposes.

Design Ground Rules Document

A "Design Ground Rules" [6] document is the description of all technology specific manufacturing requirements. (e.g. line & vias sizes, spacings) The document is CAD-tool-independent and drives the definition of parameters and information for the tool specific design kit. Referencing Figure 2.2-4, this would be the 'D' information which a design is compared against when it is received at the foundry. Every design, whether originated from a design kit or not, is compared with the requirements of Design Ground Rules document before beginning manufacturing. The "Design Ground Rules" is used to define the latest understanding of technology requirements and as new capabilities arise will be the first to be updated.

2.2.2.3 Specification Level

Functional requirements are needed to enter the foundry at this stage. The kit specification goes into detail describing specific elements that support the specification level of entry within the broad categories of 'Rules, Models, Libraries, Design Tool Parameter Settings' and 'Specialized Software'. Since at this time software tools are not supported, support offered in the kit is the documentation of technology capabilities for reference by customers. Part of that documentation is a checklist that is provided to remind customers of various domain specifications that may be important to a customer application and should be conveyed to the foundry. Another part of the documentation describes typical business interaction contacts and the overall program process flow.

2.2.2.4 Logic Level

The kit documentation describes the requirements to enter the foundry at the logic entry level. Not only is logic information needed, a subset of system specification information is also required. The kit specification goes into detail describing specific elements that support the logic level of entry within the broad categories of 'Rules, Models, Libraries, Design Tool Parameter Settings' and 'Specialized Software'.

Generally the elements describe the following:

- Abstractions of typical package information, made available to assure that the logic design can map to a physical design solution. An example would be the provision of a typical signal time-of-flight that could be used to check acceptable chip to chip delays vs. a technology option.
- Logic symbols for standard MCM I/O configurations

- Testability issues - identified in the kit with the reference to the 'ASEM Report on Testability Strategy and Guidelines'[7]
- Guidance on information required for passage to the physical design stage
- Business interaction information - included to assist in providing customers with additional support.

2.2.2.5 Physical Level

The kit documentation describes the requirements to enter the foundry at the physical entry level. Not only is physical information needed, some elements of the specification and logic design are also required. The kit specification goes into detail describing specific elements that support the physical level of entry within the broad categories of 'Rules, Models, Libraries, Design Tool Parameter Settings' and 'Specialized Software'.

Generally the elements describe the following:

- Library support for template MCM's (board), I/O footprints, standard padstacks, and sample die footprints, common automation scripts and environment controls, and on-line documentation for methodology support, technology descriptions, and customer support
- MCM Templates include information about the substrates and assembly items such as; design rules, material descriptions (electrical, thermal, geometrical), package size & initial cross section, module features (cap seal band, fiducials), and device placement region
- Automated Design Flows to guide design personnel, as available
- Release information needed for the manufacturing environment

2.2.2.6 Summary Per Design Phase

Given the types of data, documentation, tool specific data, and custom software, this section of the report provides an example of kit content relative to the conceptual, logic, and physical design phases.

During the conceptual design phase, product characteristics are defined. Definitions include size, weight, testability, reliability, environment, cost, and a host of other potential product characteristics. Product characteristics are described in the documentation that accompanies the kit. The documentation also includes a design checklist that summarizes this information for shipment to the a foundry in a defined format. When commercial tools (trade-off tools) become sufficiently utilized to support decisions at the conceptual design level, the technology characteristic data can be migrated to the tool data formats. In the future, custom software may also be written to assist in product definition. A more complete view of Conceptual design can be found in reference [8].

During the logic design phase, custom chips may be designed or standard chips may be interconnected and simulated to verify the intended function. At this stage, the logic must be partitioned into blocks that are supportable by the MCM technology that is selected. Included in the kit is documentation that describes the I/O capacity of standard MCMs, typical package delay characteristics, the standard information and netlist interfaces to the physical design phase, and a format for conveying die information (the ARPA sponsored DIE format [4]). With regards to tool specific data, connector symbols that are used to define the MCM I/O are included as available, as

well as an example of a die in the DIE format. Future custom software could potentially include customer-foundry communication software.

During the physical design phase, all the requirements defined in both the conceptual design phase and logic design phase must be implemented. The design kit supports these requirements by providing documentation describing design methodology, technology ground rules, and foundry interface information such as the information needed to build the MCM at the foundry, and data transfer preferences. Tool specific data is provided in the form of library elements of standard MCM offerings (templates) and design tool parameter information for tool controlled design rule checking and functions (e.g. Router). Custom software is provided for special functions deemed by the foundry to aid in the design of an MCM which is consistent with the technology requirements (e.g. custom checks, enhanced power plane creation utilities, custom process flow automation).

Since the kit originates in the foundry, the information supplied to help the customer is based on the foundry's customer set experience, which is continually being updated as more information is requested.

2.2.3 Cadence MCM-D Design Kit

The design kit for the IBM MCM-D process was assembled around the previously described tools and reviewed with the kit specification in mind. The kit that supports the Cadence tools is titled 'MCM-D Design Kit (1 of 2), Using the Cadence Allegro Design System' dated August 29, 1994 [1]. The documentation follows that of the outline described in the specification though section titles do not exactly match. The difference is due to the kit specification describing levels of support that are not provided at this time.

Information in the Overview, Technology Description, MCM Foundry Design Services, Additional MCM Foundry Services, and Conceptual Design Phases are common to all the design kits for the MCM-D technology regardless of the tool set. This pattern is useful because as new tool sets are supported, these sections are directly copied into the new document.

2.2.3.1 Design Overview

This is the first tool set specific section. Here specific hardware and software requirements of the specific tool set are described. Tool specific setup information is provided along with a design flow that is basically tool independent.

2.2.3.2 Logic Design Support

This section is very similar between design kits since the difference at the tool level is the design capture tool that is used to convey the netlist and netlist performance constraints. MCM I/O symbols are provided for Concept. The standard output files from Concept/PACKAGER to Allegro are described. Technology characteristics such as I/O capacity, physical size, and propagation delay, that can be used as first order determinators of whether a logic design will map to a specific MCM implementation, are described in the Technology Description section of the kit.

2.2.3.3 Physical Design Support

As identified earlier, physical design support is the design phase that is most tool specific.

2.2.3.3.1 Design Process Flow

A general flow chart is provided describing the preferred methodology within the tool set and is depicted in Figure 2.2-5.

stacks for the given cross section. The only pads which will need to be created will be those required for specific components.

The pad stack Layer Type should be Blind/Buried for all pad stacks and the Inner Layer is always set to Optional. All outer surface pads, including top and bottom surface features, are defined as having a pin location of Top or Bottom, respectively.

Wire bond and tab chip pads are generally shape based pads where the shape is offset to move the via to the edge of the pad to allow more room for interconnections, see Figure 6 on page 32, Figure 7 on page 33, and pad examples in the ./pads directory.

As can be seen, the kit defines that the only padstacks that should need to be created are those which support new component interconnection requirements. Details of how to create Wire Bond and TAB chip pads are described and specific design kit documentation figures are referenced.

Specifics of design rules controlled within the tool set are described and rules that are not controlled are also described. The rules that cannot be automatically insured within the tool sets are managed with methodology steps that request foundry reviews of the outcome of the steps (e.g. new symbols, padstacks, and top surface placement information).

2.2.3.3.2 Sample Design

Another key aspect of physical design support is the provided 'Sample Design'. Instructions are included to assist designers in the completion of the sample design within the tool set using the defined parameters and rules. From the kit documentation:

The sample design provided in the kit is intended to allow practicing with the design kit in the layout and routing of MCM-D substrates to be fabricated by IBM Micro-electronics. The demo design includes the required padstacks, symbols, programs and text files used in the design of the 40 mm demo substrate. See "Example Substrate Design" on page 37 for instructions on creating the example design.

2.2.3.3.3 Design Output Required by IBM Microelectronics

The last aspect of physical design that is specifically defined by the tool set is the format of the data to be used at the physical design entry level into the foundry. The text below was extracted from the kit documentation:

The output required for IBM Microelectronics to manufacture a design created with this design kit is as follows:

- Completed Substrate File: The *.brd file will be used to create the necessary manufacturing data.
- Pad and Symbol Files: The *.ssm, *.pad, and *.dra files will be used to verify the manufacturability of the components of the design.
- Design Checklist: An ASCII file, design_checklist, is located in the directory, /ibm-lib/mcmd/verXX/text. This file contains a checklist template, which prompts the customer for product characteristic information requested by IBM Microelectronics. A completed checklist is to be provided to IBM Microelectronics.
- Any required module test data (e.g. BIST, patterns).

The design output may be sent to IBM Microelectronics via 0.25" tape, 8mm tape, or e-mail to the Design Kit Support Contact; refer to "Technical Contacts" on page 1 for the e-mail address.

The pad and symbol files are requested only to aid in foundry library development efforts.

2.2.3.4 Design Results

Two aspects of design kit usage are described. One being cycle time measurements of various design steps and the other being process learning that is captured in design methodology and tool set up improvements. The cycle time and process learning results shown are the results from controlled experiments conducted within the foundry using the design kits. Although, kit usage by three outside organizations has resulted in designs being manufactured that met customer requirements, specific cycle time and process learning data is not available.

2.2.3.4.1 Cycle Time Comparisons

The following outlines the cycle time learning for a designer new to using the Allegro design tool for each of the process steps involved in a typical design. For detailed instructions on each of the processes see the Allegro Design Manual.[9]

Padstacks:

The creation of regular padstacks using the Allegro padstack editor is straight forward and does not require a large investment in time. The overall time involved will depend on the number of unique padstacks required for the design. Shape padstacks will require slightly longer since additional process steps are required.

Symbols:

Symbols are created using the Allegro symbol editor. The time required to create a symbol will depend on the number of I/O, the regularity of the pattern and the format in which the pad placement data is provided. If DIE format, or ASCII, data is available, it can be used to create a script for automatic pin placement which decreases the cycle time.

Logic Input:

If the logical data is supplied in the form of Concept output or as a third party netlist in the proper ASCII format, the logic input process takes minutes. If there are inconsistencies between the logic

and the symbols, several attempts may be required before a clean logic input is achieved. If the data is provided in another format which requires translation or reformatting, the time for logic input can become a significant contributor to the overall cycle time.

Blind/Buried Via Generation:

The bbvia command creates the necessary level-to-level connection options quickly. The process does not add appreciably to the time required for design.

Symbol Placement:

Through the use of the plctx command the symbol placement is nearly automatic. The application engineer provides a proposed outline for component placement which is used to create the placement text file. This allows placement of the components to occur in seconds. If further trade-off research is required to determine the correct placement, the placement time will be extended.

Manual Redistribution:

Pad locations must be moved from off-grid to on-grid positions. There is now an automated SKILL routine to assist in MCM-D pin redistribution, and this can be completed in minutes. In some cases, though, redistribution is still a manual process and can be quite time consuming depending on the complexity and density of the chip I/O pattern and the ability to copy the redistribution between identical chips.

Z-Router:

For multilayer ceramic designs, the z-router command provides a means to quickly add vias connecting the I/O pads to the internal mesh and personality layers. Total time to complete this process is not significant.

Auto Router:

The automatic router quickly provides the connectivity required by the design logic. Several attempts at automatic routing, requesting specific regions or nets be connected first, may improve the completion percentage and channel utilization provided by the automatic router. This process is one of the significant contributors to overall design time. While the computing time is significant, the designer can typically multi-task while the design tool accomplishes the routing.

Overflow Routing:

If the automatic router cannot complete all connections required, the additional nets may require routing manually. For all but the simplest designs there is typically some overflow routing which must be added. Depending on the density of the routing already in place this process can add appreciably to the design cycle time. Total time involved will depend on the number of nets requiring hand routing and the complexity of the design.

Mesh Plane Generation:

The Autovoid and Shape features of the Allegro Design tool make mesh plane generation and connectivity simple. The shape based process does not add significantly to the design cycle time. For mixed redistribution and mesh planes, the shape based process could not create a plane that was processable in the foundry so a SKILL routine was written to automatically create the plane correctly. Cycle time using the SKILL program is dependent on the size of the module and the mesh grid and can usually complete within a couple of hours.

GL1 Out Process:

The GL1 out facility provides a quick means of translating the Allegro design data into the format required for IBM checking and conversion to manufacturing data format. Three simple text files must be created which outline the parameters required for the design levels (cross section), shapes (features) and line end characteristics. This process can take a couple of hours.

Cycle Time:

Detailed information for the cycle times required for an inexperienced designer to complete the above process steps is given in **Table 2.2-4**. These cycle times are for various revisions of the Milpitas (Sun Microsystems) design which are defined as follows:

- Milpitas0-preliminary design to determine layout and routing parameters before all design data was available
- Milpitas1-initial design
- Milpitas2-new SRAM design
- Milpitas3-new test net requirements

Table 2.2-4. Design Cycle Time (man- + machine-hr.), Allegro Design Tool															
Process	Milpitas0				Milpitas1				Milpitas2				Milpitas3		
	hrs./ cum hr.s.	cum days	Com- plexity	hr./ cum hr.	cum days	Com- plexity	hr./ cum hr.	cum days	Com- plexity	hr./ cum hr.	cum days	Com- plexity	hr./ cum hr.	cum days	Com- plexity
Padstack Creation		1	5 pads	0.1/0	1	2 pads	0.1/0	1	2 pads	0.1/0	1	2 pads	--/-	--	--
Symbol Creation	1.5/2.5	2-5	3 sym- bols	2/2.1	-3	2 sym- bols	0.5/0	6	1 symbols	2/2.	1-	1 symbols	2/2.	1-	1 sym- bols
Logic Input	4/6.5	6-7	--	4/6.1		--	0.3/0	9	--	0.3/	2	--	0.3/	2	--
Blind/Bu Via Generator	0.1/6.6	8	--	0.1/6	2	--	0.1/1	0	--	0.1/	2	--	0.1/	2	--
Symbol Placement	0.5/7.1	8	12 com- ponents	0.3/6	5	8 com- ponents	0.1/1	1	8 com- ponents	0.1/	2	8 com- ponents	0.1/	2	1 com- ponents
Symbol Redistribution	16/23.1	9-10	872 pins	2.5/9	-6	140 pins	2/3.1		140 pins	--/2	5--		--/2	5--	--
Z-Router Process	0.1/23.2	11	--	0.1/9	1	--	0.1/3	2	--	--/2	5--	--	--/2	5--	--
Automatic - Router Process	3/26.2	11-20	4 trials	3/12.	-9	4 trials	3/6.2	-3	4 trials	3/5.	1-	4 trials	3/5.	1-	5 trials
Over-flow Routing Generation	14.5/40. 7	20-32	31 nets	11/23	-1	23 nets	10/16	-4	21 nets	3/8.	4	21 nets	3/8.	4	5 nets
Mesh Plane Generation	1/41.7	33	6 planes	1/24.	7-	86 planes	0.6/1	.8	6 planes	0.25	847	6 planes	0.25	847	6 planes
GL1 Out Process	2.5/44.2	34-35	3--	1/25.	9	--	0.5/1	.3	--	.25/	.4	--	.25/	.4	--
Design Checking	N/A	N/A	--	10/35	0-	6--	20/37	-9	--	11/2	.5-	--	11/2	.5-	--
Design Review Prep	N/A	N/A	--	N/A	N/A	--	16/53	0-	2--	9/29	08-	2--	9/29	08-	--

2.2.3.4.2 Process Learning

Through these design experiences, updates were made to most sections of the design methodology and kit documentation. Later design experiences showed fewer (and less significant) updates were needed for effective tool utilization.

2.2.3.4.3 Cadence Design Kit Conclusions

The data presented documents significant cycle time reduction capability that supports the assertion that a five day netlist-to-physical-design cycle is possible. In simple cases the netlist-to-physical-design cycle has been demonstrated in less time.

In addition to use of the design kit at IBM, products have been built with design data created by ISI, McClellan Air Force Base Air Logistics Center, and other customers who have used the design kit, further proving the kit effectiveness.

2.2.4 Mentor Graphics MCM-D Design Kit

The design kit for the IBM MCM-D process was assembled around the previously described tools and reviewed with the kit specification in mind. The kit that supports the Mentor Graphics tools is titled 'MCM-D Design Kit (2 of 2), Using the Mentor Graphics MCM Station Design System' dated August 29, 1994.[2] The documentation follows that of the outline described in the specification though section titles do not exactly match. The difference is due to the kit specification describing levels of support that are not provided at this time.

Information in the Overview, Technology Description, MCM Foundry Design Services, Additional MCM Foundry Services, and Conceptual Design Phases are common to all the design kits for the MCM-D technology regardless of the tool set. This pattern is useful because as new tool sets are supported, these sections are directly copied into the new document.

2.2.4.1 Design Overview

This is the first tool set specific section. Here specific hardware and software requirements of the specific tool set are described. Tool specific setup information is provided along with a design flow that is basically tool independent.

2.2.4.2 Logic Design Support

This section is very similar between design kits since the difference at the tool level is the design capture tool that is used to convey the netlist and netlist performance constraints. MCM I/O symbols can be provided for Design Architect. The standard output files from Design Architect/Package to MCM Station are described. Technology characteristics such as I/O capacity, physical size, and propagation delay, that can be used as first order determinators of whether a logic design will map to a specific MCM implementation, are described in the Technology Description section of the kit.

2.2.4.3 Physical Design Support

As identified earlier, physical design support is the design phase that is most tool specific.

2.2.4.3.1 Design Process Flow

A general flow chart is provided describing the preferred methodology within the tool set and is depicted in Figure 2.2-6:

FIGURE 5

Mentor Graphics MCM Design Process Flow for IBM MCM-D Technology

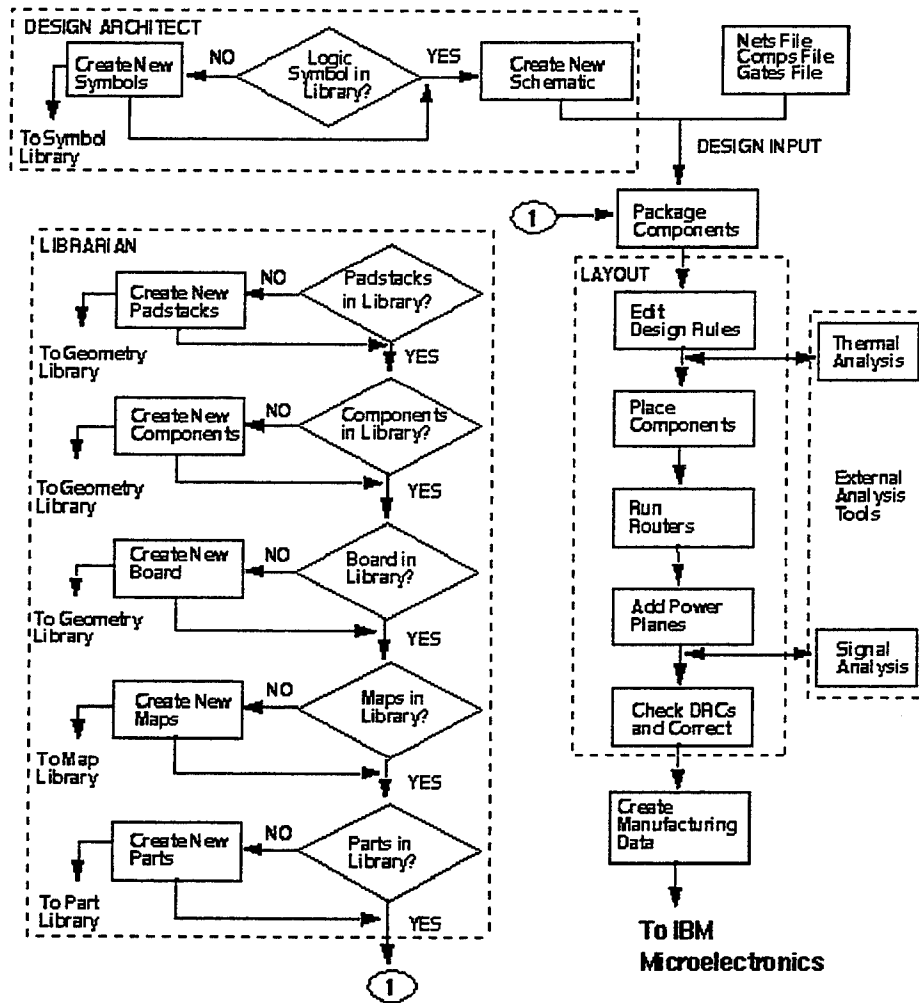


Figure 2.2-6 Mentor Graphics MCM-D physical design flow

Besides the flow chart, each design step is detailed with how the technology maps to the specific tool set and design elements. An example of this is Pin Geometries (taken directly from kit documentation):

Pin Geometries:

Pin Geometries are created in LIBRARIAN to define pin and via geometries. A separate padstack is created for each pin or via that has any variation in shape, size, or layer of build. Top and bottom surface pads, including I/O, C4, wirebond, and TAB pads, are defined as surface pins. Vias are defined as buried vias, and are created on the generic layers, signal, power, and sheet_dielectric. All vias have been defined in the pin geometry library. The only pad pins that will need to be created are ones for specific components.

Wire bond and tab chip pads are generally shape based pads where the shape is offset to move the via to the edge of the pad to allow more room for the interconnection, see Figure 7 on page 36 and Figure 8 on page 37 for pad examples.

Surface pads do not have pin rules. Buried vias have via rules that define the layers the vias may attach to single layer pads, and define the start and stop layers for the vias. A start/stop rule must be defined for each permutation of the layers that the via can span. For MCM-D technology, the start and stop layers must be adjacent signal layers. That is, vias must only span through one sheet_dielectric layer. All of the via rules necessary to design an MCM have been included in the Tech file.

To access the padstacks stored in the IBM geometry library, establish a link to the directory, `ibm_geom_lib`, using the command found in LIBRARIAN, under the geometry pull-down menu.

As can be seen, the kit defines that the only pin geometries that should need to be created are those which support new component interconnection requirements. Details of how to create Wire Bond and TAB chip pads are described and specific design kit documentation figures are referenced.

Specifics of design rules controlled within the tool set are described and rules that are not controlled are also described. The rules that cannot be automatically insured within the tool sets are managed with methodology steps that request foundry reviews of the outcome of the steps (e.g. new components, pin geometries, and top surface placement information).

2.2.4.3.2 Sample Design

Another key aspect of physical design support is the provided 'Sample Design'. Instructions are included to assist designers in the completion of the sample design within the tool set using the defined parameters and rules. From the kit documentation:

The sample design provided in the kit is intended to allow practicing with the design kit in the layout and routing of MCM-D substrates to be fabricated in the IBM East Fishkill Foundry. The demo design includes the required padstacks, components, and pcb design objects used in the design of the 40 mm demo substrate. To view the design, invoke the appropriate MCM Board or MCM Station tools on the design directory, `ibm_demo`.

For illustration purposes only, ground plane cutouts of the hatched area fill are depicted as cutouts beneath complete arrays of wirebond and TAB pads. Individual pad cutouts are also depicted on the ground plane beneath the array of wirebond pins A02-AA04 - A02-AA75, located from (15.98, -4.8875) to (15.98, -13.3475), and the array A02-AB07 - A02-AB73 located from (15.38, -5.24) to (15.38, -12.995).

2.2.4.3.3 Design Output Required by IBM Microelectronics

The last aspect of physical design that is specifically defined by the tool set is the format of the data to be used at the physical design entry level into the foundry. The text below was extracted from the kit documentation:

The output required for IBM Microelectronics to manufacture a design created with this design kit is as follows:

- Manufacturing directory: The `/pcb/mfg` directory from the completed design will contain the GERBER output for the layers, which will be submitted to IBM for processing. The `mfg` directory will also contain the neutral file, `neutral_file`, which contains board attributes data, components data, geometries and pads data, and nets data.
- Tech file: The `/pcb` directory in the design directory will contain up to the three latest versions of the tech file. The newest version of the tech file, the tech file with the greatest version number, is to be sent to IBM Microelectronics.
- Design Checklist: An ASCII file, `design_checklist`, is located in the directory, `/ibm-lib/mgc/mcmd/verXX/text`. This file contains a checklist template, which prompts the customer for product characteristics information requested by IBM Microelectronics. A completed checklist is to be inputted to IBM Microelectronics.
- Any required module test data (e.g. BIST, patterns)

The design output may be sent to IBM Microelectronics via 0.25" tape, 8mm tape, or e-mail to the Design Kit Support Contact; refer to "Technical Contacts" on page 1 for the e-mail address.

As can be seen by these preferences, Gerber output from Mentor Graphics is better suited for processing within the foundry.

2.2.4.4 Design Results

Two aspects of design kit usage are described. One being cycle time measurements of various design steps and the other being process learning that is captured in design methodology and tool set up improvements. The cycle time and process learning results shown are the results from controlled experiments conducted within the foundry using the design kits.

The IBM design kit experience using the Mentor Graphics tool set is based on three design cases. MLC-1 and 2 are test cases that were also used with the Cadence tool set to get an understanding of the base tool capabilities. The last design case was TF-1 which is a mapping of the thin film

technology that the design kit was built on. Results show the expected cycle times for designers having various levels of experience with the tools and technology.

2.2.4.4.1 Cycle Time Comparisons

The IBM MCM-C and MCM-D technologies were mapped into the Mentor Graphics MCM Board Station Design System with a 17mm substrate composed of nine chip sites and 36 signal nets. This design was also used to map IBM technology into the Allegro Design System, and therefore, provided a model for mapping the IBM technologies into Mentor Graphics. This document records the cycle times for three iterations of the design: MLC1, a first attempt to map the IBM MLC technology into Mentor Graphics; MLC2, a second pass at mapping the MLC technology after the technology was reviewed with the Mentor Graphics Benchmark team; and TF-1, a mapping of the IBM thin films technology into the Mentor Graphics MCM Board Station Design System.

The following subsections outline the cycle time learning for an inexperienced designer using the Mentor Graphics design tools for each of the process steps involved in a typical design. For detailed instructions on each of the processes refer to the Mentor Graphics Design Methodology Manual. [10]

Padstacks:

The creation of regular shaped padstacks, i.e., circle, square, rectangle, is a straight forward process in Librarian, and should not require a large investment in time. The overall time involved will depend on the number of unique padstacks required for the design. Custom shaped padstacks will require more time since some additional process steps are required to draw the shapes.

The difficulty in creating pin padstacks for the first design, MLC1, was in selecting the type of pin padstack to create: blind, surface or through pin. Padstacks in the Allegro system were created as blind pins. Initial advice was to create the pin padstacks as blind pins. The blind pins resulted in routing problems in Layout, because vias could not be added beneath blind pins. The MLC2 and TF-1 designs were created using surface pin padstacks.

Components:

Components are created in Librarian. The time required to create a component will depend on its number of padstacks, such as I/O pads, the regularity of the pattern and the format in which the pad placement data is provided. The placement data may be directly edited into the ASCII geometry file for automatic pin placement which decreases the cycle time. Similarly if data is supplied in the DIE format, or other ASCII format, this process cycle time can be significantly reduced.

Board:

The board geometry is created in Librarian within minutes and is not a significant contributor to cycle time.

Logic Input:

If the logical data has already been supplied as Design Architect output or as a third party netlist and a comps file in ASCII format, the logic input process takes minutes. If there are inconsistencies between the logic and the components, several attempts may be required before a clean logic input is achieved. If the data is provided in another format which requires translation or reformatting, the time for logic input can become a significant contributor to the overall cycle time.

Part Numbers:

Part numbers, which provide descriptions of physical devices used in the board design, are quickly created in Librarian and do not contribute significantly to the design cycle time.

Mapping Files:

Mapping files, in which physical component pins are mapped to logic symbol pins, are created in Librarian. The cycle time to create a mapping file depends on the number of component pins.

Package:

Packaging the design is a simple process that does not consume considerable cycle time. The output from Package is used by Layout.

Design Rules:

Creating the design rules entails defining the board physical layers cross section, defining via and pin padstack rules, and routing constraints. The cycle time to define the design rules will be a function of the number of physical layers, and the number of padstacks that require rules definition. Blind pins and blind vias require rules, while surface pins do not. Copying and modifying an existing ASCII tech file reduces the cycle time for defining design rules. These rules are included with the design kit so a customer does not have to perform this step, just utilize the template provided.

Component Placement:

Component placement can be done interactively, automatically, or by placing component coordinates into the comps file directly. Interactive routing is the most time consuming of the three processes.

Redistribution:

Redistribution is required to move pad locations from off-grid to on-grid positions. Redistribution can be done manually or automatically, although using the autorouter requires significant manipulation of the router through the use of autofill areas and route keepouts. In either case, the redistribution process can be quite time consuming depending on the complexity and density of the chip I/O pattern and the ability to copy redistribution layouts between identical chips.

A number of alternatives were tried before determining that the components must be partially manually routed to get the redistribution to work properly. In the future, Ample code could be written to help support this requirement.

Auto Router:

The automatic router quickly provides the connectivity required by the design logic. Several attempts at automatic routing, requesting specific regions or nets be connected first, may improve the completion percentage and channel utilization provided by the automatic router. This process is one of the significant contributors to overall design time. While the computing time is significant, the designer can typically multi-task while the design tool accomplishes the routing. The designs completed to date have been simplified, and therefore, autorouting did not consume significant cycle time.

Overflow Routing:

If the automatic router cannot complete all connections required, the additional nets may require routing manually. For all but the simplest designs there is typically some overflow routing which must be added. Depending on the density of the routing already in place this process can add

appreciably to the design cycle time. Total time involved will depend on the number of nets requiring hand routing and the complexity of the design.

Mesh Plane Generation:

Mesh planes are easily generated in either the Layout or FabLink tools using the areafill command. Total time to complete this process is not significant.

Mesh planes were not generated for the MLC1 design, because the methodology to build power planes, and to generate hatched planes with orthogonal cutouts was not understood at the time the design was mapped.

Use of the FabLink option to remove partial hatch from the Gerber allowed appropriate creation of cut out around signal wiring on the redistribution-mesh plane. The partial hatch is not removable from GDS2 output and therefore causes processing difficulties at the foundry.

Gerber Output:

The FabLink application is used to create artwork in Gerber format for input into the IBM foundry. The template contains an existing artwork format file in the design directory. The aperture table is also supplied in the kit, but generating it automatically from the design information is better because the automatic generation creates apertures for new pad shapes. Once these files are created, the artwork is generated quickly.

Cycle Time:

Detailed information for the cycle times required for an inexperienced designer to complete the above process steps is given in Table 2.2-5. These cycle time are for various revisions of the 17mm demo used to debug the design methodology for IBM MCM-C and MCM-D technologies and are defined as follows:

- MLC1 - preliminary design to debug design methodology for routing the MLC technology; basic knowledge of Board Station tools, but MCM-hybrid technology mapping not fully understood since the User's Manual and technical support were geared towards PCB technology.
- MLC2 - second mapping of MLC technology into Mentor Graphics, following a meeting with the Mentor Graphics Benchmark team. Custom Ampleware programs were written to improve routability and design process, but not used for this design.
- TF-1 - preliminary mapping of thin films technology into Mentor Graphics Board Station. Design generated after meeting with Mentor Graphics Benchmark team. The cycle time for this design was shortened because elements of the MLC2 design were used for the TF1 design.

Table 2.2-5: Design Cycle Time (man + machine hrs), Mentor Graphics MCM Station tools									
Process	MLC1			MLC2			TF-1		
	hrs/cum hrs	cum days	Complexity	hrs/cum hrs	cum days	Complexity	hrs/cum hrs	cum days	Complexity
Logic Input: Netlist	1/1	1	36 nets	1/1	1	36 nets	--/--	--	--
Logic Input: Schematic	--/--	--	--	12/13	2	36 nets	--/--	--	--
Padstack Creation	3/4	1	13 pads	0.5/13.5	2	4 pads	0.5/0.5	1	4 pads
Symbol Creation	2/6	1	2 symbols	0.5/14	2	1 symbol	0.5/1	1	1 symbol
Map / Part No. Creation	0.5/6.5	1	2 maps	0.5/14.5	3	1 map	--/1	1	--
Package	0.2/6.7	1	2 components	0.1/14.6	3	2 components	--/1	1	--
Create Design Rules	2/8.7	2	23 layers	0.5/15.1	3	27 layers	0.5/1.5	1	9 layers
Symbol Placement	0.5/9.2	2	9 components	0.2/15.3	3	9 components	--/1.5	1	--
Symbol Redistribution	4/13.2	2-3	270 pins	5/20.3	3	270 pins	5/6.5	1	270 pins
Automatic Router Process	--/13.2	3	--	--/20.3	3	--	2/8.5	2	6 trials
Manual Routing	29/42.2	6	36 nets	16/26.3	5	36 nets + power	--/8.5	2	--
Mesh Plane Generation	--/42.2	6	--	1/26.3	5	4 planes	0.1/8.6	2	2 planes
Gerber Artwork	--/42.2	6	--	5/26.8	5	27 layers	0.5/9.1	2	9 layers

2.2.4.4.2 Process Learning

Through these design experiences, updates were made to most sections of the design methodology and kit documentation. Later design experiences showed fewer (and less significant) updates were needed for effective tool utilization.

2.2.4.4.3 Mentor Graphics Design Kit Conclusions

The data presented documents significant cycle time reduction capability that supports the assertion that a five day netlist-to-physical-design cycle is possible. No additional products have been built specifically from this design kit at this time.

2.2.5 Design Kit Section Conclusions

Design kits have been provided to support the IBM MCM-D technology. The use of design kits has demonstrated that the kits can effectively aid in conveying the necessary technology information required to understand and implement products in a cost and time effective manner.

2.2.5.1 General Observations

In a perfect world, only one design kit should be needed for each technology, however, because of the uniqueness of tools and their database formats, design kits currently are required to be personalized in order to support specific tool sets. Design kits can enhance the utility and applicability of design systems while also transferring foundry technology information to MCM Design engineers. The content and format of current design kits are expected to be enhanced to include additional information requests from customers. Future kit extensions will be driven by market demands.

Regular kit support requires continuing tool expertise. Kit support also requires updates reflecting current technology offerings and foundry information such as information in Design Ground Rules, Foundry Interface Specifications, and Foundry User's Guides. It also expects that foundries will continue to support new releases of tools which improve the user's capability to verify and validate design conformance to manufacturability requirements.

2.2.5.2 Design Tool Support Observations

Certain tool limitations were identified in the process of creating the first (MCM-C) design kit. These limitations were identified to the EDA companies and work began to find short and long term solutions to the problems. The limitations were mainly in two areas; Routing channel control and mesh plane generation. Routing channel control was mainly a MCM-C issue while the mesh plane requirements had to be addressed for both 'C' and 'D' technology.

Routing channel control is an issue for two reasons. Controlling line position relative to a mesh plane position reduces the variation in electrical parameters of the lines on an MCM. Secondly, for the IBM MCM-C technology, creating the X, Y routing with the 'under mesh' control maintains the impedance described in the kit. While Cadence tools did support these requirements, the Mentor Graphics tools did not.

The mesh plane limitation has to do with the way short signal line redistributions on the mesh planes are isolated from one another. Initially, the Cadence tool did not support rectangular isolation areas surrounding the signal lines but this was ultimately solved with a SKILL program. Mentor Graphics did support this capability by the elimination of stubs from the mesh plane artwork (Gerber only).

In the process of creating the MCM-D design kits, a general understanding arose as to the kind of information required for a design kit. This information is described in the 'Design Kit Specification'. Given unlimited resources, all the items discussed in the kit specification could be implemented for customers. It is also true that design systems that are supported with extension languages, such as SKILL or Ample, can overcome many of the base function limitations that may have precluded them from supporting technology requirements. Extension language capability is one of the key capabilities to look for in choosing MCM design system software.

The design kit specification outlines the type of information needed to describe MCM technology for the physical design phase, logic design phase, and specification development phase of prototype development. Three general classifications of information are necessary; documentation, tool specific data, and custom software.

- The documentation includes text and visual support information to describe the technology and business requirements of customer foundry relationships.
- Tool data relates to information specifically developed to initialize or control the design tools. Examples are minimum and maximum feature spacing, template boards, and-or router controls.
- Custom software defines special programs to support technical and business activity related to the MCM process. Examples are design automation routines and data exchange software.

MCM Design Tool capability, and IBM experience with the tools, developed to the point where MCM-D design kits were developed for both the Cadence and Mentor Graphics Corporation design tools. Copies of the MCM-D design kits were delivered as part of the contract. Cadence and Mentor Graphics kits were transferred to foundry personnel in order to continue development and extensions to the kits to incorporate extensions in the foundry standard offerings. This is best exemplified by the extension of the MCM-C kit from a single 64mm package to a product range of 18 to 64mm, solder grid array-pin grid array, hermetic-non-hermetic, and capped-cap-less modules, see reference [11].

Initial feedback on the initial design kit offering was that it needed to be more user friendly where the friendliness was determined by the ease of locating information in the documentation and the naturalness of the detailed design steps. Initial problem areas were the documentation, the number of non-standard or non-intuitive design steps, and the ease of the interface to those non-standard design steps that were required of the design engineer. This was taken into account with clarification and the restructuring of information in subsequent releases. Efforts to further automate the insertion of technology requirements into the tool specific design processes will continue to improve usability. The automation ranges from improving a tool set's ability to implement technology requirements (e.g. mesh planes, via requirements) to improving forms interfaces for the customer's use. Since this is a continuing evolution of technology and tools, the kits demonstrate improved friendliness which is expected to further improve over time.

Technical achievements are demonstrated in the releases of technology to the foundry. The current customers have been Cadence customers and there have been four releases to the foundry; Mayo and the Sacramento Air Logistics Center have released MCM-C designs; Mayo and ISI will have released MCM-D designs. IBM has used the design kits in the ASEM designs for Sun and the known good die SCMs.

2.2.6 References

- [1] "MCM-D Design Kit (1 of 2), Using the Cadence Allegro Design System" CLIN 0002AC, dated August 29, 1994.
- [2] "MCM-D Design Kit (2 of 2), Using the Mentor Graphics MCM Station Design System" CLIN 0002AC, dated August 29, 1994.
- [3] 'Silicon Wafer Advanced Packaging (SWAP) Final Report'. ARPA order number 7549/1 under contract MDA972-90-C-0064.
- [4] DIE Format information found via anonymous ftp to vhd1.org; /pub/die/die1-0
- [5] "IBM MCM Foundry Interface Specification" CLIN 0002AG
- [6] IBM's Design Ground Rules document
- [7] 'ASEM Report on Testability Strategy and Guidelines'
- [8] Peter A. Sanborn, Hector Moreno "Conceptual Design of Multichip Modules and Systems" Kluwer Academic Publishers 1994
- [9] IBM's Allegro Design Manual.
- [10] Mentor Graphics Design Methodology Manual.
- [11] "IBM SCM/MCM-C Design Kit Guide, Using the Cadence Allegro Design System"
- [12] "IBM SCM/MCM-C Design Kit Guide, Using the Mentor Graphics MCM Design System" Version 1.0
- [13] IBM MCM Foundry User's Guide (TBD)
- [14] "ASEM Design System Requirements Report (Design Tools supported by MCM-D Design Kits)", CLIN 0002AD

2.2.6.1 Trademarks

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2.3 Design System/Foundry Interfaces

The objective of the interface effort was to define a multi-level design interface to the IBM foundry from the Cadence and Mentor Graphics tool sets that would minimize interface cycle time and errors. Design interfaces are the interfaces between design phases and between tool sets used in design. They require specific sets of information to be exchanged and specific formats for the information so it can be routinely processed. The scope of the interface effort was limited to mainly support the interface between completed physical design and the foundry, but some effort was allocated to the logic to physical design phase, and minimal effort was allocated to address the specification interface to logic design. The interfaces were documented and in some cases information processors were developed to reduce the cycle time through the interface. This (Design System/Foundry Interfaces) section simply describes the interfaces, the exercising of the physical and logic interfaces is detailed in the Direct Release section to demonstrate their successful definition and corresponding cycle times. Demonstration of the specification interface is supported by IBM's historic capability to create functional products. No additional specification interface demonstration effort was deemed cost effective toward meeting contract objectives.

In documenting the Design System/Foundry Interfaces, effort was made to incorporate as many standards and pseudo-standards as possible. Standards and pseudo-standards included Gerber and GDS2 for artwork, EDIF as part of the logic interface, and VHDL for behavioral specification activity. The initial description of the interface was made with an effort to be consistent with other MCM foundries, through joint activity with the ASEM Customer Foundry Working Group associated with the MCC ASEM contract. The Design System/Foundry Interfaces effort resulted in the deliverable titled "IBM Foundry Interface Specification CLIN 0002AG". Additional details regarding the interfaces can be found in that document.

The interfaces described include:

- Completed physical design interface to the foundry
- Completed logic design interface to the foundry
- Definition of the specification interface to the foundry

Since Cadence Allegro is used for original equipment manufacturers (OEM) MCM physical design at the IBM foundry, the following combinations of tools and interfaces have been defined. The logic and physical interfaces were exercised (cases 2 through 6).

Case	Logic Design	Physical Design	Release
1	IBM(Mixed)	IBM(Cadence)	IBM(internal)
2	Customer(Cadence)	IBM(Cadence)	IBM(internal)
3	Customer(MGC)	IBM(Cadence)	IBM(internal)
4	Customer(Cadence)	Customer(Cadence)	IBM(internal)
5	Customer(MGC)	Customer(MGC-Gerber)	IBM(internal)
6	Customer(MGC)	Customer(MGC-GDS2)	IBM(internal)

2.3.1 Communication Channels

Business contacts are established through the marketing and sales organization.

Preferred paths for exchanging data are:

- Internet - mail, ftp

- Disks - 3.5 inch

Additional paths can be considered on an individual basis.

2.3.2 Specification Interface

The specification interface requires the foundry to complete detailed logic and physical design (depicted as case 1).

Case	Logic Design	Physical Design	Release
1	IBM(Mixed)	IBM(Cadence)	IBM(internal)

The information required includes:

(note that preferences are listed in order for each environment, hard-copy is an option but is not listed since it can be used to convey all the information elements)

Information	Mentor Graphics Customer	Cadence Customer
Design Documentation and Product Specifications	ASCII, Postscript	ASCII, Postscript
Schematic (with Symbols)	EDIF 2 0 0, Postscript	Cadence Files, EDIF 2 0 0, Postscript
Behavioral model	VHDL 1076	VHDL 1076
Design verification tests	WAVES, QuickSim	WAVES, Verilog, RapidSim

Optional information includes:

Information	Mentor Graphics Customer	Cadence Customer
Chip physical symbols, timing, and thermal data	DIE format, ASCII, Postscript	DIE format, ASCII, Postscript

This (specification) interface demonstration is supported by IBM's historic capability to create functional products. No specific demonstration effort was deemed cost effective toward meeting contract objectives.

2.3.3 Logic Interface

This interface was defined for the following cases:

Case	Logic Design	Physical Design	Release
2	Customer(Cadence)	IBM(Cadence)	IBM(internal)
3	Customer(MGC)	IBM(Cadence)	IBM(internal)

The following information is needed:

(note that preferences are listed in order for each environment, hard-copy is an option but is not listed since it can be used to convey all the information elements)

Information	Cadence Customer	Mentor Graphics Customer
Design Documentation and Product Specifications	ASCII, Postscript	ASCII, Postscript
Chip physical symbols, timing, thermal data	DIE format, ASCII, Postscript	DIE format, ASCII, Postscript
Netlist	Concept Native, Third Party, ASCII	Cadence Third Party, MGC Native, ASCII, EDIF 2 0 0
Layout constraints	Netlist Property, ASCII, or Schematic	Netlist Property, ASCII, or Schematic

Optional information includes:

Information	Cadence Customer	Mentor Graphics Customer
Manufacturing test (MCM functional test) vectors	Verilog VCD file, Signal def. file	QuickSim Log file, Signal def. file
Manufacturing test (Chip internal test) - JTAG ASIC	ASIC BIST Interface	ASIC BIST Interface
Manufacturing (MCM interconnect test)	BSDL (each ASIC)	BSDL (each ASIC)
Back annotation (Schematic)	Cadence Files	EDIF 2 0 0, Generic Netlist
Back Annotation (Delay)	SDF (Verilog), Generic (RapidSim)	ASCII delay b.a. file (QuickSim)

Design Documentation and Product Specifications can be free format, but a soft-copy checklist requesting this type of information is also available from the foundry and is provided with available design kits. Defining the checklist allowed easier searching and recognition of requirements at the foundry. This soft-copy document also reminds users to consider defining various characteristics that their product may want.

The development of the DIE format for conveying chip information provides a potentially standard format to enhance library development and therefore significantly reduce design cycle time. The DIE format also provides the electronic format capability that reduces opportunities for error by eliminating the need to re-enter data. Prior to the DIE format development, the recommended format was some variation of ASCII, again in an effort to reduce data entry problems and provide a somewhat processable format.

Test can be a significant cost and cycle time aspect of a product, for that reason care should be given to partition the test effort effectively between the customer and foundry. Typically the test task partitioning has resulted in the foundry only doing some level of interconnect test for prototypes but not much functional test. When test is part of the program, effort should be placed on insuring that the version of the test data really corresponds to the version being assembled. When module test information needs to be provided, test information can come through the standard formats supported by either the Cadence or Mentor Graphics logic design tools.

2.3.3.1 Cadence Customer - Logic Design

A customer using Cadence logic design tools would send the native Cadence interface files to initiate physical design since IBM uses the Cadence tools. By defining the IBM-Cadence interface as the native Cadence tool interfaces, not only does forward data transfer become simple, back-annotation is also maintained by 'standard' Cadence customer support activities.

Secondary formats can be processed, such as EDIF 2 0 0, ASCII files, but these formats are less preferable due to additional cycle time impact, hence cost. A discussion regarding the processing of EDIF can be found in the Mentor Graphics Customer - Logic Design section.

2.3.3.2 Mentor Graphics Customer - Logic Design

A customer using Mentor Graphics Corporation logic design tools would send the native files or an EDIF file to initiate physical design.

Two native file paths are preferred. First, the Cadence Third Party format is identified as the preferred format for the netlist since Mentor Graphics does support the Third Party format from Design Architect. Second, since many customers may not have purchased this option, native Mentor Graphics physical interface file formats are also supported. The native Mentor Graphics physical interface files consist of the 'NETS', 'COMPS', and 'GATES' files. These contain the information to create the Cadence Allegro 'Third Party' Interface. With the converted Mentor Graphics native physical interface scenario, back-annotation of pin numbers and reference designators is obvious (part of the file formats).

EDIF 2 0 0 is supported for the logic interface but EDIF adds significant complexity to the transfer and does not ease the back annotation issues.

When exercising the EDIF data exchange path, non-standard properties used to convey standard information had to be resolved. Significant effort was required to scope the limitations of the exchange capabilities, entities such as bus descriptions, property mapping files, and even representation size information had to be described. With the characteristics defined, the EDIF was handled through the Cadence EDIF Interface facility. After the EDIF was converted to a Cadence schematic, it still needed to be processed through PACKAGER to convey the physical design information to Allegro. Outputting data from PACKAGER involved additional library development work.

Back-annotation with EDIF requires a full schematic replacement, therefore the only way to reverify the back annotation did not change functionality is to completely reverify the schematic.

2.3.4 Physical Interface

This interface was defined for the following cases:

Case	Logic Design	Physical Design	Release
4	Customer(Cadence)	Customer(Cadence)	IBM(internal)
5	Customer(MGC)	Customer(MGC-Gerber)	IBM(internal)
6	Customer(MGC)	Customer(MGC-GDS2)	IBM(internal)

In general there are some specifications, some logic information and physical information needed to adequately support MCM build through the physical interface.

The following information is needed:

(note that preferences are listed in order for each environment, hard-copy is an option but is not listed since it can be used to convey all the information elements)

Information	Cadence Customer	Mentor Graphics Customer
Design Documentation and Product Specifications	ASCII, Postscript	ASCII, Postscript
Netlist	From Cadence .brd file, Third Party Netlist format	From Mentor Graphics 'Neutral' file, (NETS, COMPS, GATES), ASCII
Chip physical symbols	Cadence .brd file, Cadence Symbols	Converted from 'Neutral' file
Shapes (Artwork) data	From Cadence .brd file, Gerber	Gerber files, Aperture Table, Format Description, Technology File (Layer cross reference table), GDS2 files

Optional information includes:

Information	Cadence Customer	Mentor Graphics Customer
Manufacturing test (MCM functional test) vectors	Verilog VCD file, Signal def. file	QuickSim Log file, Signal def. file
Manufacturing test (Chip internal test) - JTAG ASIC	ASIC BIST Interface	ASIC BIST Interface
Manufacturing (MCM interconnect test)	BSDL (each ASIC)	BSDL (each ASIC)
Back annotation (Schematic)	Cadence Files	EDIF 2 0 0, Generic Netlist
Back Annotation (Delay)	SDF (Verilog), Generic (RapidSim)	ASCII delay b.a. file (QuickSim)

Design Documentation and Product Specifications can be free format, but a soft-copy checklist requesting this type of information is also available from the foundry and is provided with available design kits. Defining the checklist allowed easier searching and recognition of requirements at the foundry. This soft-copy document also reminds users to consider defining various characteristics that their product may want.

Test can be a significant cost and cycle time aspect of a product, for that reason care should be given to partition the test effort effectively between the customer and foundry. Typically the test task has resulted in the foundry only doing some level of interconnect test for prototypes but not much functional test. When test is part of the program, effort should be placed on insuring that the version of the test data really corresponds to the version being assembled. When module test information needs to be provided, test information can come through the standard formats supported by either the Cadence or Mentor Graphics logic design tools.

Of the two Mentor Graphics Physical Design paths, the Gerber path is preferred. Reasons GDS2 is not preferred will be described in more detail in the Direct Release Demonstration section.

2.3.4.1 Cadence Customer - Physical Design

Early in the IBM/Cadence company relationship, a converter was written for the conversion of the Cadence internal database format to the IBM internal release format (GL1). Since the Cadence/GL1 path exists, the standard process for releasing physical designs to the foundry is by shipping the Cadence board (.brd) file.

The Cadence board file provides both the physical and logic information required. Many MCM designs have been released to the foundry from both internal IBM designers and OEM customers who use Cadence tools. In order to identify potential problems earlier in the design process, interim design reviews have been described in the design methodology recommendations such that

devices defined in Cadence symbols get reviewed with the foundry before releasing a completed design. Requests for pad stack and symbol (.dra) files have been made to aid in library development.

The Cadence Customer - Physical design interface has many of the same concerns as the logic interface relative to the data consistency issues regarding module assembly and test. However, the strict conversion of physical design data occurs rather smoothly.

2.3.4.2 Mentor Graphics Customer - Physical Design GERBER

Data included in this interface is:

Information	Mentor Graphics Customer
Netlist	From Mentor Graphics 'Neutral' file, (NETS, COMPS, GATES), ASCII
Chip physical symbols	Converted from 'Neutral' file
Shapes (Artwork) data	Gerber files, Aperture Table, Format Description, Technology File (Layer cross reference table)

The Gerber path is the preferred path for physical design entry from the Mentor Graphics tools.

The data exchange from Mentor Graphics utilizes Gerber, augmented by logic and device information in an ASCII format. The ASCII format chosen is the standard Mentor Graphics 'neutral file' from the FABLINK tool. The 'neutral file' has more information than minimally required but is easy to generate by the customers. An alternate format that could be equally effective is a 'Point file' as defined in the MCC ASEM Foundry Interface Spec. The 'Point file' format was not the primary format worked on because it was not available as a base tool output, though it could be created from available data.

Gerber is used to exchange artwork information which represents physical net location and relationships to other nets. In that sense, the exchange format, either Gerber, is not used as originally intended as a artwork tool driver, but the format is used to exchange information. The difference is that, in a pure artwork tool environment, it is not particularly a concern whether a shape is created as a single entity (e.g. a flash, or shape) or whether it is drawn and filled in with lines or shapes. For data exchange, it is important that each feature is represented as a single shape or 'flash' of an aperture. Only lines are drawn, and those lines are drawn from coordinate to coordinate and should begin at the location of a shape (e.g. pad or via). The format when used for data exchange needs to be able to represent the characteristics of the technology (e.g. only circles, rectangles and lines, or only polygon pads and circular vias etc.)

When Gerber is the transfer format, it is imported to Cadence Allegro for conversion to the IBM internal format. The internal format data is processed against manufacturability checks (using MDS) prior to release to the factory.

The 'neutral file' data is used to verify logical to physical implementation in the foundry internal data format. The data is manipulated to recreate the device information, placement information, and netlist information, all in a format that is processable at IBM. The IBM processable data format is used to create the data for substrate opens and shorts test, and supports manufacturing assembly and documentation requirements. An automated program 'MgcToCad' was created to support the 'neutral file' data conversion.

The Mentor Graphics Customer - Physical Design Gerber interface has many of the same concerns as the logic interface relative to the data consistency issues regarding module assembly and test. However, the strict conversion of physical design data occurs rather smoothly.

2.3.4.3 Mentor Graphics Customer - Physical Design GDS2

Data included in this interface is:

Information	Mentor Graphics Customer
Netlist	From Mentor Graphics 'Neutral' file, (NETS, COMPS, GATES), ASCII
Chip physical symbols	Converted from 'Neutral' file
Shapes (Artwork) data	GDS2 files, Technology File (Layer cross reference table)

With the exception of the artwork processing the GDS2 path is very similar to the Gerber path. For processing the artwork, there is a stand alone program used to convert GDS2 into the IBM internal format. The internal format data is processed against manufacturability checks prior to release to the factory. Much more editing of the data is required to process GDS2 data so it is not the recommended path.

Mentor Graphics Customer - Physical Design GDS2 interface has many of the same concerns as the logic interface relative to the data consistency issues regarding module assembly and test. The strict conversion of physical design data is generally more difficult than the Gerber path.

2.3.5 Conclusions

Interfaces have been defined to support multiple design level interfaces to the foundry.

Well defined interfaces have improved communications with OEM customers. Many are willing to provide information in requested formats. For those that have special needs that require submission of information in formats other than those described, it is known at the beginning of the relationship that additional processing effort will be required. Continued foundry maintenance of these interfaces is necessary as industry and technology changes occur.

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2.4 Direct Release

IBM had developed a release system strongly directed towards the standard module families used by many of the internal IBM product lines that the foundry traditionally supported. The IBM internal release process focused on quick release of routing interconnect layers that were compatible with pre-designed redistribution and power layers for a given chip set and package definition.

This existing release system was not suited to handle the custom MCM's typically required in the merchant market. Custom MCM's require that all layers of an MCM be designed and released concurrently. In addition, specifications and drawings are generated concurrently with the design so traditional work sequencing that was incorporated into the standard module family release process appeared as product delays and bureaucracy in the custom MCM environment. For this reason contract activity was defined to enhance the release process to meet the ASEM goals of providing low volume access to a high volume foundry, reducing cycle times and NRE, and routinely achieving first pass success on designs.

2.4.1 Introduction

Some common terminology will be described since it will be used throughout this report.

Multichip Module (MCM) layers can be categorized into three types; redistribution (chip to substrate grid translations), power-and-reference, and personality (signal netlist interconnections). Redistribution and power-and-reference layers can be referred to as "fixed" layers because they don't have to change if the netlist changes. Personality layers contain signal interconnections, which represent the 'personality' of a module, hence its name. Any layer that interconnects net terminals is called a personality layer, regardless of any power or redistribution functions also occurring there.

Standard-module-families versus custom MCMs also needs to be defined. Custom MCMs are defined to be MCMs that are unique to a single application. A standard-module-family (MCM-family) is group of applications that utilize a common chip set. Some other features of a MCM-family are a common device placement, common power I/O assignment, and common signal I/O availability (I/O to chip set connections are not predefined just the number and locations of signal I/O). Note that if the chip set included a number of ASICs or FPGAs, the foot prints can be the same even when the function is vastly different. Within a MCM-family, the module 'personality' layers are the layers that make a module unique to a specific application. IBM has used MCM-families to support many internal product development efforts. The IBM OEM business tends to be custom in nature because of the variation in customer requirements and design philosophies.

Since single chip modules (SCMs) are a special case of custom MCMs, their release will also be described in this document.

Prototypes are built for product verification activities, are limited in number, and are not generally end-user shippable. Production modules are made in quantity for end-user deliveries. This distinction is made to allow different release criteria for prototype versus production modules, which intentionally reduces the cycle time for development of prototypes.

In this report, the term manufacturing represents substrate build, substrate test, module assembly, and module test. A customer can request products with any or all of these items.

The release process is the interface between development (design) and manufacturing. Therefore the major objective of a release system is to support:

Documentation development and management

Data verification

Data transformation to manufacturing tools/data (masks, etc.)

2.4.2 Architecture and Objectives

The Corporate Release Processing System (CRPS) developed for IBM's internal standard module family release requirements had been very effective at helping IBM achieve its world class product delivery capabilities. For that reason it was seen as a proper starting point for defining typical capabilities and objectives.

When initiating release of a new member of an MCM family in IBM, functional requirements are defined in a single data container called a Release Interface Transmittal (RIT). By definition, the ideal of a single container allows management of data integrity because all needed information resides or is referenced from the single data container. With a single data container, various checks can also be run to verify that all expected information was available and to some extent proper (e.g. a correct format). More information was needed to describe a custom MCM than what was currently supported with a RIT. For this reason an eXtended Release Interface Transmittal (XRIT) definition was to be used.¹ The ASEM defined XRIT was to be much more complete. This type of a single repository system was defined in the "ASEM Report on Architecture"; Direct Release Architecture Document, CLIN 0002AJ.

XRIT expansion came from defining and adding parameters beyond existing XRIT and RIT parameters to handle requirements for the redistribution, power/reference layers, and the increasing number of mixed layer types. Effort was also placed on defining improved user interfaces to existing parameters needed for personality layers. Included, also, was definition of manufacturing documentation automation (part number assignment, bill of material generation, etc.)

Studies were made on what types of data integrity checks could be possible. This included logical to physical re-verification, data format and syntax checking, time-date stamp items.

2.4.3 Implementation

The results of these studies showed what needed to be done, the next problem was to determine how to implement the requirements into an effective system. Two approaches were available, extend the existing release system to cover the new requirements or incrementally integrating the manual paths in a way that prototype capabilities could be tested, then utilized as they were developed.

2.4.3.1 Strategy

The approach taken was to insure success of the implementation by incrementally prototyping the integration and automation efforts. This turned out to be very successful, the team that implemented this was a combination of users and programmers that worked out operational issues

¹ Original IBM XRITs focused on improving standard module family rule generation and data integrity verification, the ASEM use of XRITs for custom MCMs was to eliminate rule generation since processing would be 'one shot' only

and tested individual features as early as possible. Along with the prototyping efforts, a concurrent look at errors was continued in weekly meetings. The weekly meetings gave focus to the most critical aspects of release and insured that efforts were directed to solving the worst problems first.

2.4.3.2 Methods and processes within the System

This section summarizes the information described in deliverable "ASEM Report on Methodology & Process within the Release System" Document Number CLIN 0002AK.

2.4.3.2.1 IBM Module Release Overview

In the packaged electronics development environment, a typical process to build an MCM product consists of three phases which can overlap: design, release, and manufacturing. In the ISO9001 registered IBM Foundry, these phases are part of the overall 'E.Fishkill Packaging Development Checkpoint Process' that has been developed to assure timely and systematic execution of new product development activity. This Checkpoint Process requires each new product to have a unique 'Document of Execution (DOE)' written to describe what aspects of the general process are needed for this specific customer. The DOE also identifies responsible organizations that will generate the release information, line control requirements, key dates, and other program information. This report will describe the release methodology and processes that are used to satisfy the product requirements defined in the DOE.

Organizational Responsibility

Per the 'E.Fishkill Packaging Development Checkpoint Process', Product Engineering is responsible for most release activity however Design Engineering has a large supporting role.

Design Engineering is responsible for creating and preparing for review all computer aided design (CAD) data, whether submitted by the customer or generated by the design organization. In the preparation for review, manufacturability verification (e.g. Design Rule Checking) and any additions or modifications (e.g. mask support mesh) is done to support manufacturing. The verification also insures that data needed to support substrate build and test are in acceptable formats for processing. Any changes required to the customers data are, of course, reviewed with them first. Documentation is created describing the design data and a review is held. Given completion of the review, Design Engineering stores all its data on a secure database and provides Product Engineering with the data, thus completing its responsibilities. An additional special function of Design Engineering is to create rules for customers designing members of MCM-families in the IBM Engineering Design System (EDS) and to release them through the automated release process described later.

Documentation development, data transformation, and rest of the data verification (e.g. module assembly and test) responsibilities belong to Product Engineering. This will be described more completely below. Except where noted, Product Engineering will be performing the items described.

Release System Functions And Cycle

Release activities overlap design and manufacturing processes to minimize product cycle times by beginning the manufacturing phase as soon as information is available for the initial build steps. The critical path consists of design, some elements of release, and manufacturing. In the Custom MCM/SCM and MCM-family release sections, these critical path items will be highlighted.

Release functions will be generally described next and are identified globally as:

Documentation development and management

Data verification

Data transformation to manufacturing tools/data

Documentation development and management

The objective of documentation development and management is to assure that data is available, distributable, and properly stored. This includes data backup and recovery requirements.

Product documentation, which consists of business data, bills of materials (BOMs), specifications (including process definition and routings), and mechanical drawings that describe the product, is managed based on the program requirements defined in the DOE.

In the Release process, unique identifiers (e.g. part numbers) get added to sets of product information and manufacturing process information to create the product documentation which is the recipe to build what the customer needs. Product Engineering is responsible to compile the documentation requirements from information created by Applications Engineering (with the Customer) and Design Engineering. Product Engineering makes sure that this data satisfies the product and manufacturing requirements.

For production modules the DOE will define completion of all phases of the checkpoint process. Part of that completion is that documentation must conform to format and review requirements as described in 'Pre-Analysis/Implementation of Engineering Changes Process (OP45)'. OP45 is a site operating procedure used to insure EC control of manufacturing product data. Product documentation is originally compiled on 'Product Engineering Worksheets' and then transferred to formal documentation formats. Manufacturing Work requests (MWR)s are used to describe processes for manufacturing products. These are created manually for new MCM-families and custom production MCMs. Routings are also manually established in the Factory Integrated Routing System (FIRS) system which directs operation on the manufacturing floor. All data is reviewed and approved within the formal OP45 process. Production module documentation is stored with the product engineer until OP45 is complete. When OP45 is complete, all the product documentation can be found via the Development & Production Records System (DPRS). While referenced from DPRS, drawing information is kept in the CATIA Data Manager (CDM) data base. CDM and DPRS have the necessary controls for data management and recovery.

For prototypes, the DOE does not generally require completion of all the phases of the checkpoint process. Therefore documentation does not have to conform to OP45 requirements like production modules. Engineering Work requests (EWR)s are used for process definition and routing of prototypes and engineering projects. Memos and product descriptions are used for specifications and bills of materials (BOMs). The EWRs and BOMs are manually created by product engineers as the data becomes available from Applications and Design Engineering. Prototype documentation is stored by the product engineer or program manager per DOE requirements.

The Prototype and Production Module documentation approach is summarized in **Figure 2.4-1**. Product documentation is distributed to the appropriate members of the product management team, defined in the DOE, and design review meeting members.

RELEASE DOCUMENTATION			
	PROTOTYPES (ENGR. FILES)	VOLUME PRODUCTS (OP45, DPRS, etc.)	
ORGANIZATIONAL RESPONSIBILITIES	DOE	DOE	
BUSINESS INFORMATION	DOE	DOE	
NETLIST / DIE DOCUMENTATION	CUST. SUPPLY	PE DATA SHEET	/SPECS,DWG
MODULE/SUBSTRATE SPECS	PROD. DESCRIPTION	PE DATA SHEET	/SPECS
MODULE BOM	PROD. DESCRIPTION	PROD. DESCRIPTION	/BOM
MODULE ROUTINGS	EWR	PE DATA SHEET	/FIRS
MODULE TEST DATA	CUST. SUPPLY	PROD. DESCRIPTION	/BOM
TOP/BOTTOM DRAWINGS	DES.REV. PKG	PE DATA SHEET	/DWG
MODULE ASSEMBLY/TEST DETAIL	DES.REV. PKG	PE DATA SHEET	/DWG
SUBSTRATE BOM (X-SECT. DEPEND.)	DES.REV. PKG	PE DATA SHEET	/BOM
SUBSTRATE DRAWINGS	DES.REV. PKG	PE DATA SHEET	/DWG
SUBSTRATE ROUTINGS	EWR	PE DATA SHEET	/FIRS
POST PROCESSOR PARAMETERS	GLP SHEETS	GLP SHEETS	/BOM
LAYER/MASK BOM	EWR	PE DATA SHEET	/BOM
SUBSTRATE TEST DATA	OS TEST DATA	OS TEST DATA	/BOM

Figure 2.4-1: Release Documentation Approach

CAD data (not mechanical drawings), though not treated the same as plain documentation, also needs handling for storage and availability. It is created as part of the design process either at the foundry or at the customer location. CAD data is released to manufacturing and made available to the Data Transformation functions. CAD Data is stored in its processable data format, Graphics or Network Language One (GL1 or NL1), in a database used by manufacturing called Integrated Storage Management (ISM). This is a responsibility of the Design Engineering organization. Data conversion controls (e.g. to masks, vias) and the converted data, created by Product Engineering, is also stored there. A detailed list of files on ISM is described later. ISM has all the necessary controls for data management and recovery.

Data verification

The objective of data verification activities is to verify consistency of data to manufacturing requirements (e.g. design rules), to verify the consistency of data within itself (e.g. design data and test data), and to verify the consistency of data formats to processing requirements.

Data verification for both custom MCMs and new MCM-families is done by processing CAD data through the 'Module Design System (MDS)', through checklist completion, and through design/product reviews.

Design Engineering is responsible for substrate (including thin films) CAD data verification. Regardless of the design data format received (Gerber, GDS2, ASCII, etc.), design data is converted to the IBM format NL1 and is verified against manufacturability requirements. MDS is used to check the design rules, verify logical/physical equivalency, and assure data is properly formatted for the post processors. Design rules (spacing, width, and grid verification) are checked on individual layers and 'Z' direction ground rules are checked from layer to layer. A continuity check is done by establishing nets out of features that touch according to data convention rules

(layer and adjacent layer rules). The resulting netlist can be compared with a user supplied netlist to assure that processed data is logically equivalent to the customers original intent. In doing these checks, design data format (NL1) conventions are verified to insure the data will be post processable. MDS creates a Module Control File (MCF) which is used in opens/shorts test data creation and rules generation for MCM-families.

Substrate build and test information is generated from this verified design data thus insuring that data is consistent with the design intent. The data flow is shown in Figure 2.4-2.

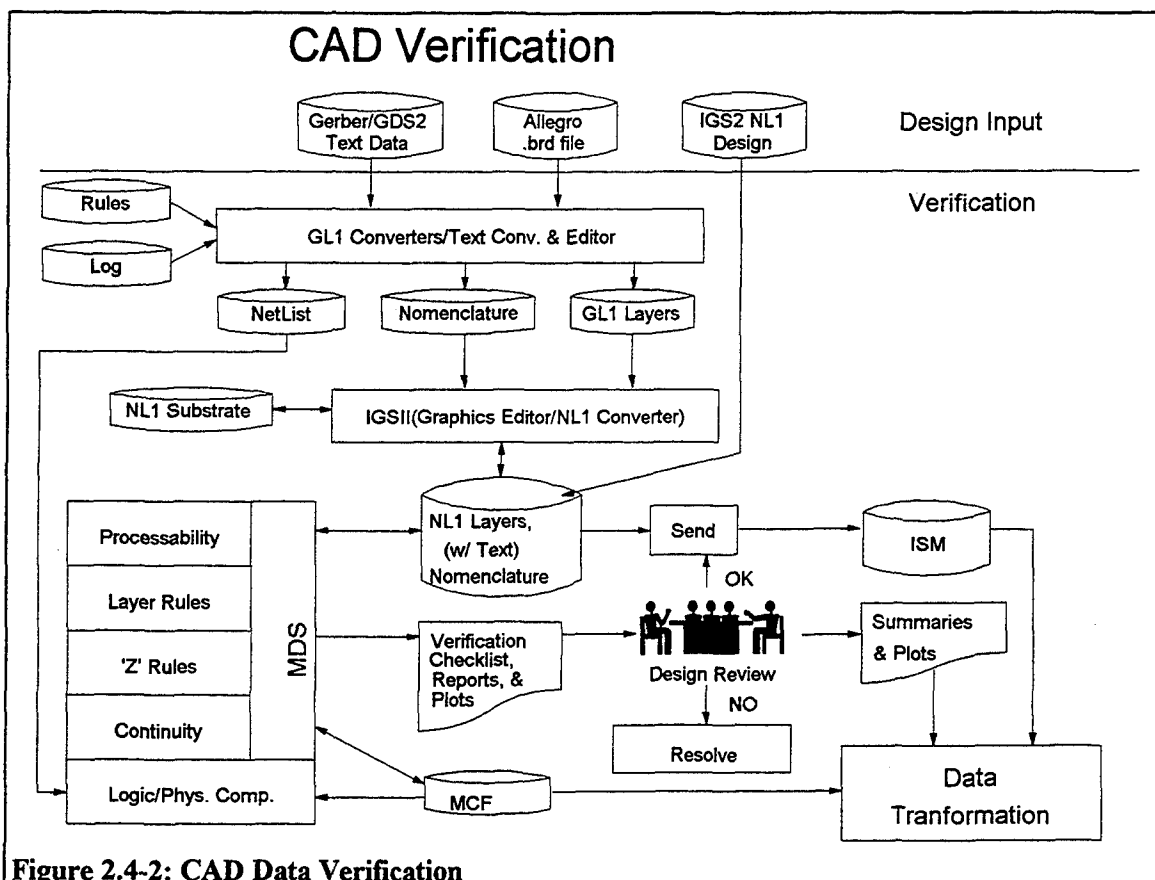


Figure 2.4-2: CAD Data Verification

Checklists and reviews are used to verify data consistency when tool data is not generated from the design database (e.g. MCM assembly and test). Additionally, checklists (also known as worksheets) are used in the review process to insure that all the necessary checking and documentation of the design data has been done thereby ensuring that each function will have the data needed to support the customer's product requirements.

Finally, after CAD data verification and the checklists are complete, design reviews are held so all key people can review the findings and approve release of the design to manufacturing. Function approvals (sign off) at the reviews and meeting minutes describe the findings of these reviews. Any issues discovered in the verification process are discussed with the customer or the appropriate IBM personnel such that answers are available during the final review meeting. All information required for build is reviewed with the proper organizations.

Data verification for new members of existing MCM-families is handled completely within the release tool described in the MCM-family section later in this report.

Data transformation to manufacturing tools/data (masks, etc.)

The objective of data transformations is to convert stored design data (GL1 or NL1) into data that allows required tools (masks etc.) to be built and into data that will direct the tools (numerical control 'NC' data). Figure 2.4-3 shows the technology/tool requirements for feature definition.

	Manufacturing Process		
	MCM-D	MCM-C	
Design Feature	Standard/Prototype	Standard	Prototype
Pattern	Expose Mask	Metal Mask	E-BEAM Data
Vias	Laser Mask	Punch Data	E-BEAM Data

Figure 2.4-3: Technology feature definition approach

Design data transformation occurs through Post Processors used in automatic and/or manual mode. The post processors require parameter definition to convert the GL1 or NL1 data into data for the appropriate tool set. As part of this process, part numbers are assigned so that converted data can be referenced from the EWR/MWR/Routing documents previously described. Most custom MCMs and first MCM-family members are processed in manual mode because the parameters have not been previously established as is necessary for an automatic run. Therefore it is more convenient, more versatile, and faster to run the post processors as the parameters are defined. Cycle time and error reduction activity is focused on improving the user interfaces to ease design data and parameter entry and to assist in run verification activity. The only true automatic release runs are for additional members of existing MCM-families where the parameters have been predefined and verified. Detailed flows will be shown at appropriate places later in this report.

In automatic release runs, for production MCM-family members, the post processors and test data are automatically initiated, part numbers are automatically assigned as necessary, bills of materials are created and loaded to DPRS, and routings are automatically loaded to FIRS.

Custom MCM/SCM Release Paths

This section will show specific data flows and tools used for custom MCM releases given the prototype and production scenarios described in the previous overview section. Critical path items will be identified and described along with other details unique to the scenario being described.

As previously stated, SCMs are processed as defined in this section, so wherever MCM is mentioned it can be interpreted by the reader to also mean SCM.

The documentation process is the same for MCM-C and MCM-D custom MCMs. Module level data verification is the same for MCM-C and MCM-D. Substrate data verification is unique due to the MCM-C versus MCM-D mask differences and will be described. Data transformation is unique, again due to tool choices (reference Figure 2.4-3).

MCM-D Release

MCM-D critical path items are design, CAD data verification including mask data preparation, mask data transformation, and mask availability.

Documentation is developed as described in the overview section.

Critical path documentation includes the NL1 summary sheets, plots, Mask order information, and Laser Mask control cards as is shown in Figure 2.4-4.

Errors are minimized by clear ownership of the current documentation.

Data verification

MDS is used for CAD data verification as described earlier in the overview section. Feature widths and spacings, via stacking, large shape characteristics, and mask partitioning are critical to manufacturability. Grids, which are important in MCM-C are much less important here.

An additional MCM-D data preparation and verification activity is the partitioning of design data into mask segments. This is required for designs where the MCM is larger than the tool processing fields. Verification is achieved by reconstructing a full layer from the pieces and comparing with the original full field layer design data.

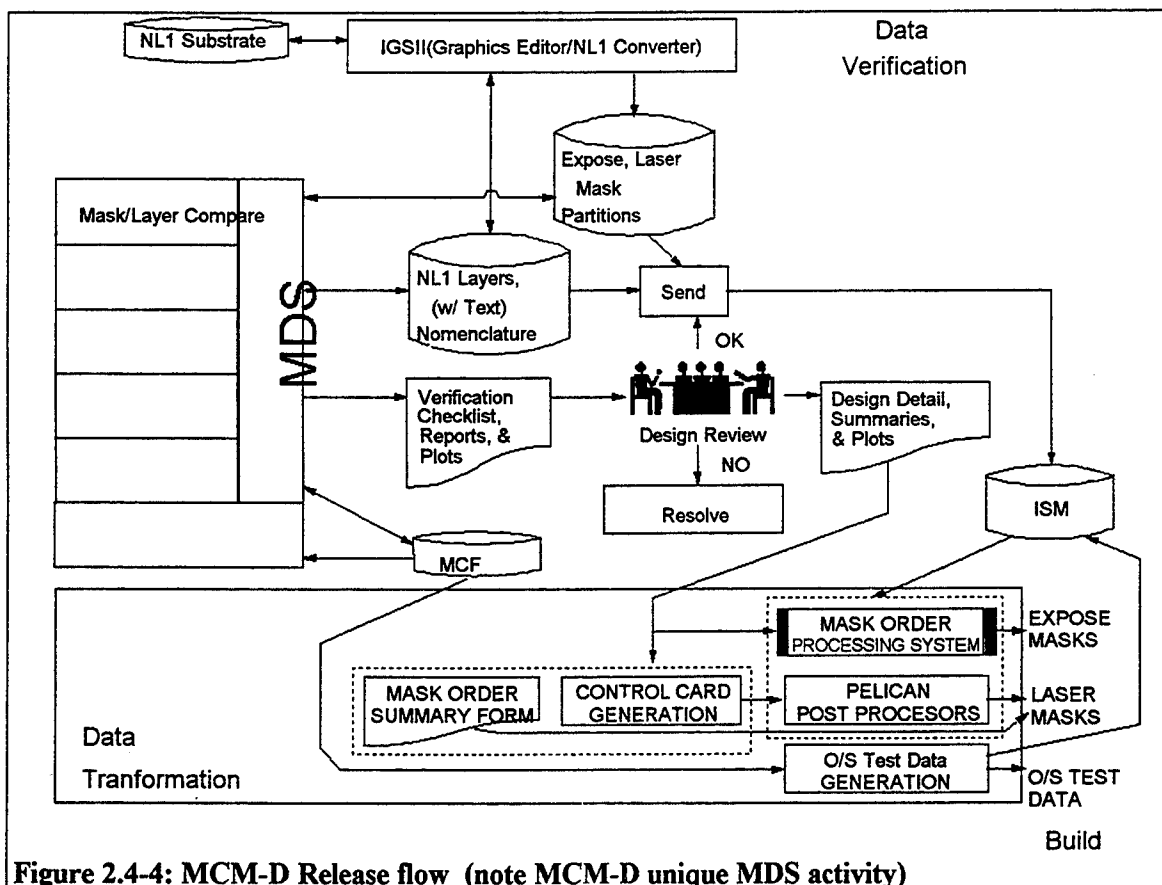
Substrate verification is part of the critical path therefore substrate verification cycle time reductions directly affect product cycle times.

Module level data verification is handled the same for both MCM-D and MCM-C, through checklist completion and product reviews.

Data transformation to manufacturing tools/data (masks, etc.)

As shown in the overview, data transformation occurs to create via masks, pattern masks, and opens/short test data. Mask data is processed with the Pelican post processor. Test data is created from the MCF created by MDS. The Mask Order Processing System is an automated interface for ordering and post processing data for expose masks. Currently laser mask release occurs through text editors and batch job submission.

Data integrity checks include return code validation and run log message verification.



MCM-C Release

MCM-C critical path items are dependent on the tooling chosen for build. The tooling choices are dependent on product requirements and business expectations. Production modules are always created with the standard MCM-C tooling. Prototypes can be created using either the standard tooling or Prototype (E-BEAM) tooling for creation of the substrate layers. Tooling choices exist at both the substrate and module assembly levels. Typically prototypes tooling is chosen to expedite delivery to customers who use the prototypes in their product development activities. Critical path flows will be shown in their respective sections.

Documentation is developed as described in the overview section.

Critical path flows will be shown in the Standard and Prototype MCM-C tooling sections.

Errors are minimized by clear ownership of the current documentation.

Data verification

CAD data verification is processed through MDS as done with MCM-D, excluding the partitioning/verification for masks since MCM-C is always full field. Grid characterization of the pattern is important for Standard tooling MCMs since the grid and pattern affect mask creation choices. This information is noted on plots that proceed to the data transformation processes.

Module level data verification is also handled the same for MCM-C and MCM-D, through checklist completion and product reviews.

Data transformation: Standard Tooling MCM-C Release

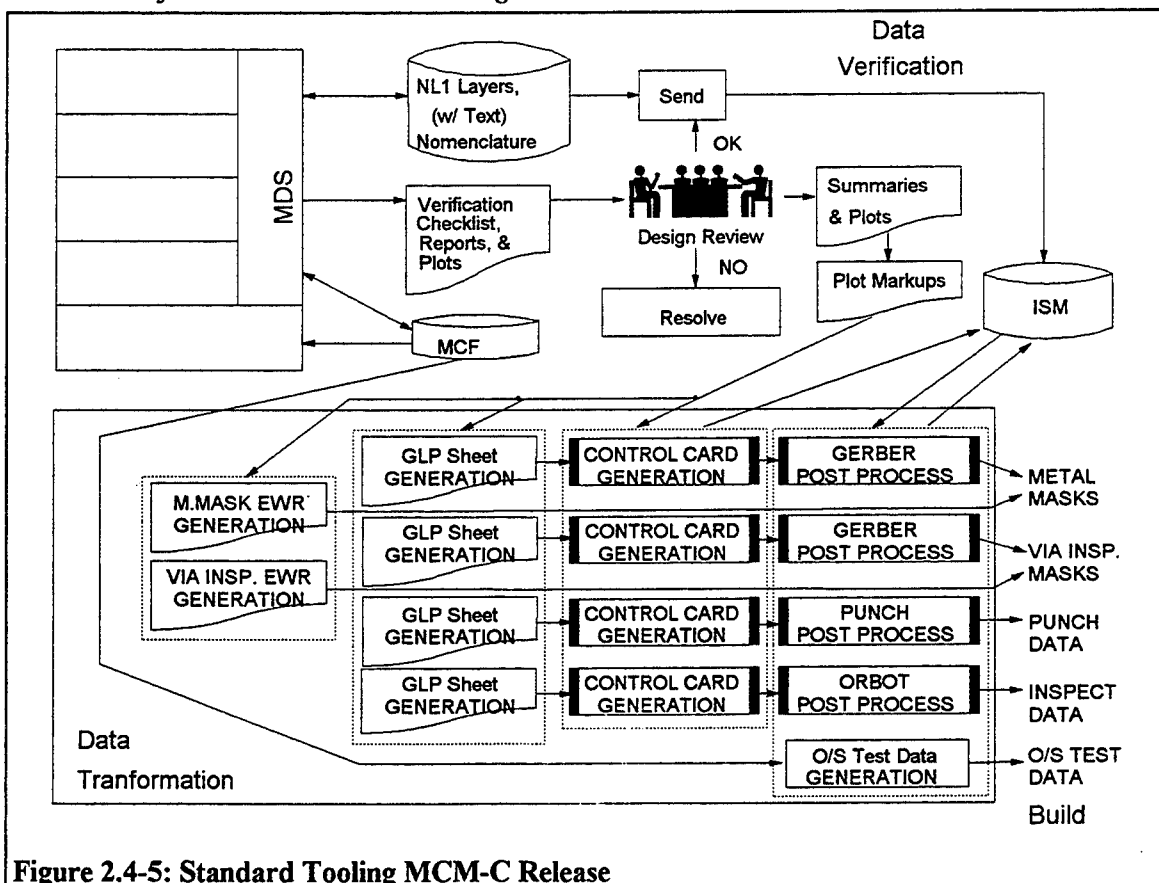


Figure 2.4-5: Standard Tooling MCM-C Release

Standard Tooling MCM-C release is shown in Figure 2.4-5 after the point of CAD data conversion to NL1. Critical path items are design, CAD Data verification, *Summary Sheets, *Marked up Plots, *GLP Sheets, Control Cards, Post Processing, *Mask Orders (EWRs), and Mask Delivery. The documentation aspects are identified with an asterisk (*).

Automated interfaces have improved data entry and processing of the design data reducing both cycle time and errors in the creation of Control Cards and Post Processing.

Data integrity checks include return code validation and run log message verification.

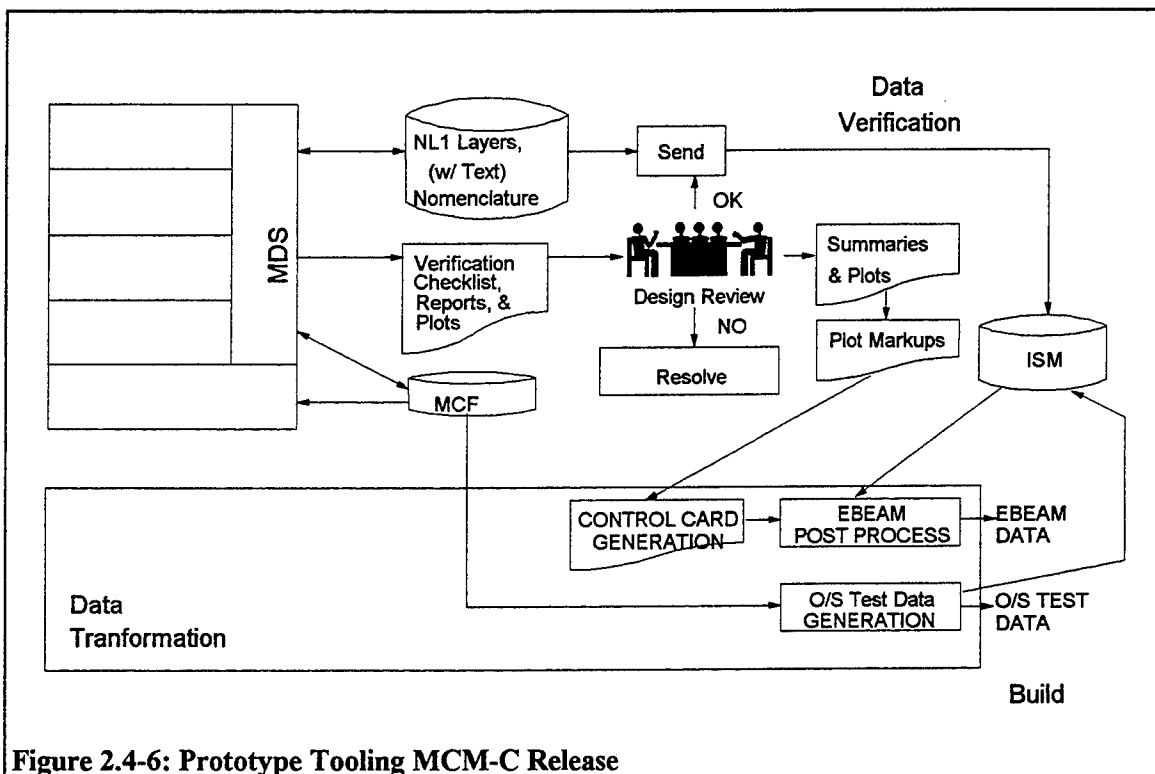


Figure 2.4-6: Prototype Tooling MCM-C Release

Data transformation: Prototype Tooling MCM-C Release

Prototype Tooling (E-BEAM) MCM-C release is shown in Figure 2.4-6 after the point of CAD data conversion to NL1. Critical path items are design, CAD Data verification, *Summary Sheets, *Marked up Plots, Control Cards, and Post Processing. The documentation aspects are identified with an asterisk (*).

Data integrity checks include return code validation and run log message verification.

Cycle time is shorter due to the elimination of mask generation.

Release for IBM MCM-Family

Release for IBM MCM-families is specific to IBM so it will not be summarized in this report. See the complete "ASEM Report on Methodology & Process within the Release System" CLIN 0002AK for those details.

ISM Data Repository Detail

As previously mentioned, manufacturing relies on the ISM Database to control and store design data and critical data created during release. The types of data managed are as follows:

Design data

- FG: GL/1 data, MCM-family personality data is stored as GL1.
FN: NL/1 data, Custom MCM/SCM layer data is stored as NL1.
XR(IT): eXtended Release Interface Transmittal which contains the design converted to a new format (Used with MCM Families)

NC data

Artwork

- FC: Fixed Layer module Graphics Language Processor for Gerber artwork (GLPG) control information
(K)AR: MCM-family (Personality) Vias Inspection artwork control cards
()AR: Other artwork data for special case masks (e.g. vias only, top surface screening)
(Q)AR: Q-levels Layer (mask pattern) artwork control cards
(T)AR: Support tabs for metal 'Q' masks

Punch tools

- QC: Fixed Layer control cards to drive programmable via punch
PV: Fixed Layer NC data for programmable via punch tool

Inspection tools

- IF: Auto inspection data associated with ORBOT
FO: ORBOT screening mask inspection data
OR: Control cards(Fixed Layer) for auto inspection (ORBOT).
OC: Control cards(Personality) for ovation data.
OS: Test data

Manufacturing rules

- MF: Fixed Layer input to post processors which create FIRS transactions
AF: FIRS data for Fixed Layer personality artwork layers

The ISM database manager controls the storage and retention of design and NC data, as well as read, write, and list access to this data.

2.4.4 Demonstration

Release of designs through the IBM foundry has been demonstrated for the logic and physical design entry paths and for both prototype and manufacturing volume product situations. This section of the report describes the demonstration. The full report is contract deliverable "Report on Release System Demonstration" CLIN 0002AL.

This section is further subdivided into sections on:

- Foundry Interfaces and Validation - This sub-section describes release of designs through the logic and physical design entry interfaces described in the Design System/Foundry Interface section (section 2.3) of this report. The details in this section describe the processing of design data to create and validate physical design data, and to release documentation and test requirements. The general methodology and process of release have previously been defined in the deliverable "ASEM Report on Methodology & Process within the Release System" CLIN 0002AK.

Design data transformation will be specifically addressed in the second sub-section on Manufacturing Tools Release Paths and Validation.

- Manufacturing Tools Release Paths and Validation - This section refers to release activities that are a function of the manufacturing tooling used to fabricate the MCM. It specifically covers transformation of design data into tool data.
- Conclusions - This section nets out conclusions gained in demonstrating the Release capabilities.

2.4.4.1 Foundry Interfaces and Validation

The interfaces that have been demonstrated are:

Case	Logic Design	Physical Design	Release
2	Customer(Cadence)	IBM(Cadence)	IBM(Internal)
3	Customer(MGC)	IBM(Cadence)	IBM(Internal)
4	Customer(Cadence)	Customer(Cadence)	IBM(Internal)
5	Customer(MGC)	Customer(MGC-Gerber)	IBM(Internal)
6	Customer(MGC)	Customer(MGC-GDS2)	IBM(Internal)

Regardless of the path taken, a Document of Execution is written describing the activities required for releasing a new product through the ISO9001 "E. Fishkill Packaging Development Checkpoint Process". This Checkpoint Process requires each new product to have a unique 'Document of Execution (DOE)' written to describe what aspects of the general process are needed for this specific customer. The DOE also identifies responsible organizations that will generate the release information, line control requirements, key dates, and other program information as described in the "ASEM Report on Methodology & Process within the Release System" CLIN 0002AK.

The DOE gets developed through a series of iterations with the customer as their requirements are described and solutions proposed. These requirements get converted into appropriate documentation to drive manufacturing to provide hardware that will meet customer needs.

Logic entry into the foundry requires the foundry to complete the physical design. In the physical entry paths, the customer has completed the physical design. Between the two paths, the equivalent

data needs to be generated, verified, reviewed, and released. Therefore there are many similarities in the data that is required and processed. Differences are generally the result of formats available from specific tool sets and process differences to accommodate different source tool capabilities.

In both logic and physical entry paths, improvements in the data conversion paths from the commercial design systems into the IBM internal design data formats have significantly reduced cycle time. The data conversion processes are optimized by using design kit recommended conventions. The conventions include for example instantiation of I/O pads within a separate symbol or component and definition of apertures for each pad type so that features in Gerber (other than lines) are flashed and not drawn. Experience with the Cadence tools has minimized the creation of duplicate features in the Cadence data base. Previously these duplicate features were removed after the conversion process.

Cycle time has also been reduced by optimizing the documentation requirements into informal and formal formats depending on application requirements as described in the 'E.Fishkill Packaging Development Checkpoint Process'.

Cycle time and errors have been reduced by improved manufacturability checking. The checking has improved in the areas of detecting logical/physical conversion problems by netlist comparison capabilities, minimum line segment lengths detection, more automatic nomenclature cell creation for the checking system, and improvements in the types of connectivity recognized (both point to point and overlapping connectivity).

2.4.4.1.1 Production Modules

The data required to build production modules is identical to building prototypes. However, production MCM release has a more rigid documentation release path and unique paths for transformation of verified design data into tool sets defined for both Ceramic and Thin-Film MCM technology. The major differences being formalized part numbers, mechanical drawing format requirements, and a more formal design review process. These can add another week into the process, though prior to the current 'E.Fishkill Packaging Development Checkpoint Process' this could take more than double the time.

2.4.4.1.2 Logic Entry

In the logic entry path scenario, a netlist with constraints, along with chip information and a package description, defines a product whose physical design, fabrication, assembly, and test is to be completed at the foundry. The interfaces defined are for cases 2 and 3.

Case	Logic Design	Physical Design	Release
2	Customer(Cadence)	IBM(Cadence)	IBM(Internal)
3	Customer(MGC)	IBM(Cadence)	IBM(Internal)

The physical design process used is the one defined in the MCM design kit created for the Cadence tool set. The basic activity blocks of time for physical design are depicted by the following list of activities:

Library Development

- Create Pad stacks
- Create Symbols
- Create (Template)

Customer Review/Netlist Preparation

- Reformat/Edit/Review Netlist

Physical Design

- Open Board Template/Verify Cross-section/Import the Netlist
- Create Blind/Buried Vias
- Place Symbols
- Run Z Router ('C' Tech)
- Run Routers
- Interactive Routers
- Power Planes
- DRC recheck

MDS (Manufacturability) Verification & Release

- Conversion to Internal Manufacturing format (NL1)
- Manufacturability verification
- Design Review
- Design Storage/Data Documentation
- Data Transformation

The product specifications and design documentation, described or referenced from the DOE, are used to fully define the product and insure that the solution meets all user requirements. Similarly when test is part of the agreed work-scope on a product being delivered, appropriate test data has to get to the right manufacturing operations.

Cadence Logic Entry Demonstration

With native information formats, the transfer of information occurs smoothly from the Cadence logic design environment to the Cadence Physical design tools used by the foundry.

Numerous designs have been processed from Cadence front end tools using the native exchange files. All have been successful.

Sun Microsystems, Inc.

Process Overview

The development of the MCM began with a preliminary hard-copy input from Sun Microsystems Inc., describing the physical aspects and power attributes of the devices to be packaged. This developed into a 'Document of Understanding' which was the precursor to the currently required 'Document of Execution'. The product requirements, proposed solution, and program responsibilities are describe in that document.

Upon receipt of the netlist from Sun Microsystems, Inc. the development of the MCM proceeded along five concurrent paths: electrical and physical design of the substrate; thermal analysis and design of encapsulation hardware; Flip Chip wafer bumping; module interconnect test; and module functional test. Each of the five paths proceeded in a concurrent engineering environment

encompassing both multiple disciplines and multiple companies (as in the case of discussions involving the inclusion of test pins in the substrate design to facilitate module debug).

Upon completion of the design, a design review meeting was held so that all manufacturing units responsible for the build of the module could review and concur with the design. Included in the design review process were representatives from the substrate build, bond, assemble, and test areas. A design review was also held between the companies at critical stages of the project, to insure the module and the functional test preparation converge.

Substrate Design & Release

Library Development

By the time the netlist for the module was complete the major library development work was done. One component footprint (the SRAM) needed modification and this took only took a couple of hours. Most of the time for this step is spent in validation of hard-copy information.

Customer Review/Netlist Preparation

A number of iterations between the customer and foundry occurred. This was for the most part due to the development of proposals to improve performance and testability. The Cadence third party ASCII netlist file format was the easiest way to communicate these updates, so this format was edited and verified in communication between the foundry and Sun Microsystems, Inc. The final iteration only took about 20 minutes, though iterations occurred over a few calendar months.

Physical Design

This whole physical design process took about 9 hours in Allegro over the course of 4 days. Details are in Table 2.4-1. Key to short cycle time was the effectiveness of the Auto-Router. A last minute change to power requirements was requested to accommodate a separate voltage for the Viking chip. Since the rest of the design was unchanged, it was decided to make the change in the IBM IGS-2 design tool that works with the NL1 format data needed for manufacturing. This choice eliminated the re-conversion and re-verification of all the layers that remained unchanged. The change took about 8 hours to implement.

MDS (Manufacturability) Verification & Release

Standard manufacturability checking was done and ran fairly uneventfully. Checks required the creation of Nomenclature information, that is semi-automatically created from Cadence ASCII reports. The checks themselves included cursory processability checks (level checks), layer checks (spacing, widths, grid characterization, minimum line segment lengths, and metal density), Z rule checks, Continuity checks, and final processability (report) runs. A comparison of the physically generated netlist is made against the original logic (Allegro) netlist, to insure proper conversion. This took about 30 hours.

Design documentation was completed outside the critical product cycle path. The top and bottom surface design drawings were imported to a CADAM tool where the substrate tolerances were placed on the drawings. A substrate layer drawing was also generated, describing the function of each of the individual substrate layers. The drawings were placed on the IBM part number list, controlled by a Product Engineer, with all changes requiring concurrence by the engineering team responsible for the project (Team consists of Manufacturing, Product, Development, and

Applications Engineers). The substrate was not built on the Manufacturing line, but on the prototype line, using an Electron Beam tool (E-BEAM), which produces substrate layers without using metal masks. Details on the E-BEAM tool processing are in the section on 'Manufacturing Tools Release Paths and Validation'.

The test data requirements were also satisfied outside the critical path. Substrate opens and shorts test data was generated from the verified design data. Module (Interconnect) test chip BSDL, SRAM functional descriptions, and netlist information was provided to module product engineers to satisfy test engineering information requirements.

Flip Chip Bumping

For this module, not only was the MCM physical design, assembly, and build performed, but the die were converted from their original wire bond format into a flip chip (C4) format. This design was also done in the Cadence Allegro system and released to the wafer bumping organization.

Table 2.4-1 Cycle time breakdown of the Design and CAD Data Verification activities for the Sun Microsystem Design

Library Development	Hours	Comments
Create Pad stacks	0	
Create Symbols	2	1 Symbols (1 chip) the rest existed
Create (Template)	0	
Customer Review/Preparation		
Reformat/Edit/Review Netlist	0.3	Third Party Format (includes inputting to Allegro)
Physical Design		
Open Board Template/Verify Cross-section	0	
Create Blind/Buried Vias	0.1	
Place Symbols	0.1	
Run Z Router ('C' Tech)	0	
Run Routers	3	(previous strategy defined)
Interactive Routers	3	5 Overflow nets
Power Planes	0.25	6 Planes
DRC recheck	0	
Total Allegro Design Days	(8.75 hours)	4 Days
Cadence Physical Design Release		
GL1 Converter	.25	gllout
IGS-2 Additional Power Plane Design	8	(New Split Mesh for Viking)
Nomenclature Cell Creation	2.5	
Read Nomenclature	0.5	
Processability/Level checks	0.16	
Layer Checks		
PD checks	1.68	
ORBOT checks.	0.16	
Metal area checks.	0.5	
Z rules checks	1	
Continuity	4	
Logical/physical Comparison	0.5	
Processability/Release (Summaries/plots)	9	
Design Review (wait)	0	
Design Review	2	
Total CAD Data Verification Days	(30.25 hours)	4 Days
Total 'SUN' Design & CAD Data Verification Days	(39 hours)	9 Days

National Semiconductor

Process Overview

The development of the MCM began with preliminary hard-copy input from National Semiconductor describing the physical aspects and power attributes of the devices to be packaged. This developed into the currently required 'Document of Execution'. The product requirements, proposed solution, and program responsibilities are described in that document.

A partial netlist was received from National Semiconductor and remaining necessary physical design activity was started.

Upon completion of the design, a design review meeting was held so that all manufacturing units responsible for the build of the module could review and concur with the design. Included in the design review process are representatives from the substrate build, bond, assemble, and test areas. A design review was also held between the companies at critical stages of the project, to insure the module and the functional test preparation converge.

Substrate Design & Release

Library Development

New padstacks, chip footprints, device files, and a module template was needed for this design. Nothing unusual was encountered and the activity took about 7 hours to complete.

Customer Review/Netlist Preparation

Since only a partial netlist was provided, the rest was added with an editor. The Cadence third party ASCII netlist file format was used to communicate and verify the updates with National Semiconductor. About 6 hours was spent making the necessary modifications.

Physical Design

The physical design had unique requirements that lead to 100% manual routing. This took roughly 4 days in the Cadence Allegro System and contributed to half the design time. Problems also occurred trying to use the plane generation SKILL routines, so they were only partially completed in Allegro, though 2 days were spent trying. Total design time in Allegro was about 8 days.

Power planes were completed in IBM's IGS-2 environment, with another day's effort.

MDS (Manufacturability) Verification & Release

Standard manufacturability checking was done and ran fairly uneventful. Nomenclature checking information was semi-automatically created from Cadence ASCII reports. The checks themselves included cursory processability checks (level checks), layer checks (spacing, widths, grid characterization, and metal density), Z rule checks, Continuity checks, and final processability report runs. A comparison of the physically generated netlist was made against the original logic (Allegro) netlist, to insure proper conversion. This took about 3 days.

There was another days effort creating design review documentation, a contingency day, then the design review. Total calendar cycle was 15 days from input through reviewed design. A rough distribution between tasks is listed in Table 2.4-2.

Design documentation was completed outside the critical product cycle path. The top and bottom surface design drawings were imported to a CADAM tool where the substrate tolerances were

placed on the drawings. A substrate layer drawing was also generated, describing the function of each of the individual substrate layers. The drawings were placed on the IBM part number list, controlled by a Product Engineer, with all changes requiring concurrence by the engineering team responsible for the project (Team consists of Manufacturing, Product, Development, and Applications Engineers). The substrate was built on the Manufacturing line, which produces substrate layers using metal masks. Details on the Ceramic Standard Tooling processing are in the section on 'Manufacturing Tools Release Paths and Validation'.

Also outside the critical path, substrate opens and shorts test data was generated.

Table 2.4-2 Approximate cycle time breakdown of the Design and CAD Data Verification activities for the National Semiconductor Design

Library Development	Hours	Comments
Create Pad stacks	1	
Create Symbols	4	2 Symbols (1 chip, 1 BSM)
Create (Template)	2	
Customer Review/Preparation		
Reformat/Edit/Review Netlist	6	Partial netlist & Reformat activity (includes inputting to Allegro)
Physical Design		
Open Board Template/Verify Cross-section	0.5	
Create Blind/Buried Vias	0	
Place Symbols	0.5	
Run Z Router ('C' Tech)	0	
Run Routers	0	
Interactive Routers	32	All manual routing
Power Planes	16	Partial Success / remainder in IGS/NL1
DRC recheck	0	
Total Allegro Design Days	(62 hours)	8 Days
Cadence Physical Design Release		
GL1 Converter	2	gl1out, level modifications
IGS-2 Additional Power Plane Design	8	
Nomenclature Cell Creation	5	
Read Nomenclature	2	
Processability/Level checks	0.5	
Layer Checks		
PD checks	2.5	
ORBOT checks.	1.5	
Metal area checks.	1.5	
Z rules checks	2	
Continuity	6	
Logical/physical Comparison	3	
Processability/Release (Summaries/plots)	8	
Design Review (wait)	8	
Design Review	8	
Total CAD Data Verification Days	(58 hours)	7 Days
Total 'National' Design & CAD Data Verification Days	(120 hours)	15 Days

TDV Subset Design

This design was processed to allow comparisons of the different paths associated with design data verification and release. Table 2.4-3 indicates cycle time. No documentation release was

processed or tooling data created.

Table 2.4-3 Cycle time breakdown of the Design and CAD Data Verification activities for the TDV Subset Design

Library Development	Hours	Comments
Create Pad stacks	0	
Create Symbols	0	
Create (Template)	0	
Customer Review/Preparation		
Reformat/Edit/Review Netlist	0	
Physical Design		
Open Board Template/Verify Cross-section	0.16	
Create Blind/Buried Vias	0	
Place Symbols	0.16	
Run Z Router ('C' Tech)	-	
Run Routers	0.92	Redist. Pgm, Autoroute, Gloss
Interactive Routers	0	
Power Planes	1.25	Mesh Pgm 2 planes
DRC recheck	0.33	line segments, & reports
Total Allegro Days	(2.82 hours)	
Cadence Physical Design Release		
GL1 Converter	1	gllout, level modifications
Nomenclature Cell Creation	1	Initial Creation
Read Nomenclature	3	Editing for wirebond pad location round-off corrections included
Processability/Level checks	0.16	
Layer Checks		
PD checks	1.35	
ORBOT checks	0.16	
Metal area checks	0.5	
Min Line Segment checks	0.16	
Z rules checks	1	
Continuity	5	
Logical/physical Comparison	0.16	
Processability/Release (Summaries/plots)	8	Estimated (test case only)
Design Review (wait)	0	
Design Review	2	Estimated (test case only)
Total CAD Data Verification Days	(23.49 hours)	3 Days
Total 'TDV Subset' Design & CAD Data Verification Days	(26.31 hours)	3.29 Days

Mentor Graphics Logic Entry Demonstration; TDV - Subset Design

A customer using Mentor Graphics Corporation logic design tools would use the native files or an EDIF 'Schematic' path.

The native Mentor Graphics physical interface files, the 'NETS', 'COMPS', and 'GATES' files can be converted to the Cadence Allegro 'Third Party' format. The path used was to convert the 'NETS', 'COMPS', and 'GATES' files to the 'neutral_file' format and use the physical design entry program 'MgcToCad' to create the Allegro format. A separate program could be written to do the conversion if justified by business needs.

When exercising the EDIF data exchange path, the non-standard properties used to convey standard information became very obvious. Cadence EDIF-Read, EDIF-Write were configured to exchange schematic information with Mentor Graphics' Design Architect. However, significant additional library information had to be developed to 'Package' the schematic for physical design after the EDIF conversion occurred. If a number of design conventions were followed when in the Mentor Graphics Design Architect tool, the EDIF transfer could be more effective, however the need for these convention requirements only further decreased the desirability of this path.

The other limitation that becomes apparent in the EDIF exchange path is that full 'EDIF Schematic' replacement is possible but 'EDIF Update' is not. This may be unacceptable to Logic design due to the fact that a replaced logic design may require complete re-verification of the intended functionality.

The EDIF path is possible, but not recommended due to items identified above.

Expected cycle time is the same as the Cadence Logic entry path with the additional cycle time associated with the conversion (less than an hour). Though the Mentor Graphics path has been exercised there is no "non-test-case" experience at this time.

2.4.4.1.3 Physical Entry

In the Physical Entry path scenario, a completed physical design along with a package description and specifications defines a product whose fabrication, assembly, and test is to be completed at the foundry. The interfaces defined are for cases 4, 5, and 6.

Case	Logic Design	Physical Design	Release
4	Customer(Cadence)	Customer(Cadence)	IBM(Internal)
5	Customer(MGC)	Customer(MGC-Gerber)	IBM(Internal)
6	Customer(MGC)	Customer(MGC-GDS2)	IBM(Internal)

The foundry physical entry strategy supports data entry from Cadence and Mentor Graphics design systems. The Cadence input data is the Cadence board file, while the Mentor Graphics input is made up of text based files and Gerber or GDS2 artwork files.

In general the process steps are as follows:

MDS (Manufacturability) Verification & Release

- Conversion to Internal Manufacturing format (NL1)
- Manufacturability verification

- Design Review
- Design Storage/Data Documentation
- Data Transformation

The product specifications and design documentation, described or referenced from the DOE, are used to fully define the product and insure that the solution meets all user requirements. Similarly when test is part of the agreed work-scope on the product being delivered, appropriate test data has to get to the right manufacturing operations.

Text and CAD data converters are used in processing the input data files, and generate GL1 data and other associated files necessary for foundry design checking and release. For Cadence input, the gllout and pin.extract converters are used. The common Mentor Graphics converters are the MgcToCad program, the pin.extract program, and IGS-2. For Mentor Graphics GDS2 input, the GDS2 to GL1 conversion program is utilized while the Cadence Gerber read and gllout programs are used in the Gerber input case.

The outputs of these conversion programs, netlist, nomenclature, and NL1 data, are the inputs to the Manufacturability checking (MDS) and release system. The MDS system performs processability, layer rule, Z rule, and continuity checks on the NL1 data. The final step in this process is a logic/physical comparison, ensuring that the NL1 data from the conversion process physically adheres to the functions defined in the logic netlist.

The design is then be reviewed at a design review, and upon concurrence with manufacturing representatives, released to the ISM data base. The verified CAD data is used in the data transformation, or post processing steps.

Cadence Physical Entry Demonstration

Early in the IBM/Cadence company relationship, a converter was written for the conversion of the Cadence internal database format to the IBM internal format (GL1). Since this path exists, the standard process for releasing physical designs to the foundry is by shipping the Cadence board (.brd) file. The board file provides both the physical and logic information required. Many MCM designs have been released to the foundry from both internal IBM designers and OEM customers who use Cadence tools.

General Process

The general steps within the Cadence Physical Entry process are as follows:

- **Conversion to Internal Manufacturing format (NL1)**
 - GL1 Converter
- **Manufacturability verification**
 - Nomenclature Cell Creation
 - Read Nomenclature
 - Processability/Level checks
 - Layer Checks
 - ⇒ PD checks
 - ⇒ ORBOT checks
 - ⇒ Metal area checks
 - ⇒ Minimum Line Segment Checks
 - Z rules checks

- Continuity
- Logical/physical Comparison
- Processability/Release

McClellan AFB ALC

Process Overview

The development of the MCM began with a hard-copy proposal from McClellan AFB ALC for a solution to their Data Transfer Module (DTM) needs. The proposal outlined the physical and electrical attributes of the devices to be packaged on the substrate. This information, along with the system information including environmental, physical, and power attributes, allowed the application team to generate a preliminary proposal. Working with McClellan AFB-ALC, the application team was able to refine the proposal to provide McClellan AFB-ALC with a cost effective, efficiently manufacturable MCM which met their overall application requirements for the DTM. Final requirements and agreements are documented in the DOE per the 'Packaging Development Checkpoint Process'.

A completed physical design was released to the Foundry. The design data was converted into the internal format, verified against manufacturability requirements, and released. While the logic and physical design was being performed at McClellan AFB-ALC, the interconnect test development was concurrently being done within the IBM Poughkeepsie facility. This concurrent engineering activity allowed for a reduced product cycle time as test was debugged and ready when the substrates completed the die bonding process. The DTM module was delivered 8 weeks after the design data was received.

Conversion to Internal Manufacturing format (NL1)

The conversion went smoothly due to the fact that design kit defined conventions were followed. The entire cycle took about 1 hour and 20 minutes.

Manufacturability verification

This too went smoothly and the design data was verified within a few days. Details are in **Table 2.4-4**.

Documentation and test data release was processed outside of the critical path.

Table 2.4-4 Cycle time breakdown of the CAD Data Verification activities for the McClellan AFB ALC DTM Design

Cadence Physical Design Data Verification	Hours	Comments
GL1 Converter	1.33	gl1out, level modifications
Nomenclature Cell Creation	3	
Read Nomenclature	0.33	
Processability/Level checks	0.16	
Layer Checks		
PD checks	2.33	
ORBOT checks	0.16	
Metal area checks	0.5	
Minimum Line Segment check	0.16	
Z rules checks	0.5	
Continuity	5	
Logical/physical Comparison	0.16	
Processability/Release (Summaries/plots)	8	
Design Review (wait)	0	
Design Review	2	
Total CAD Data Verification Days	(23.63 hours)	3 Days

Additional Demonstrations:

Mayo 'C' and 'D' Test vehicle designs were also received as completed physical designs and released to the respective tool sets. Both these were test vehicle modules that followed no conventions but were successfully built and delivered to the customer. CAD data verification took about 8 days of special processing for the (first) 'C' test vehicle, then about 5 days for the 'D' test vehicle due to development of checking procedures from the first experience.

TDV Subset Design

The general process for the Cadence release path has been outlined above in the Cadence physical entry section. Table 2.4-5 describes cycle times and any discoveries and deviations noted during the actual TDV subset release test case.

Table 2.4-5 Cycle time breakdown of the CAD Data Verification activities for the TDV Subset Design

Cadence Physical Design .brd file	Hours	Comments
GL1 Converter	1	gllout, level modifications
Nomenclature Cell Creation	1	
Read Nomenclature	3	
Processability/Level checks	0.16	
Layer Checks		
PD checks	1.35	
ORBOT checks.	0.16	
Metal area checks.	0.5	
Min. Line Segment Checks	0.16	
Z rules checks	1	
Continuity	5	
Logical/physical Comparison	0.16	
Processability/Release (Summaries/plots)	8	Estimated (test case only)
Design Review (wait)	0	
Design Review	2	Estimated (test case only)
Total CAD Data Verification Days	(23.49 hours)	3 Days

Mentor Graphics Physical Entry Demonstration

The foundry physical entry supports entry from the Mentor Graphics design system using either GDS2 or GERBER as the graphic data transfer medium. In both cases, text files will be used to determine logic and placement requirements, while the routing information will be conveyed by GDS2 or Gerber binary.

General Process

The general steps within the Mentor Graphics Physical Entry process are as follows:

- **Conversion to Internal Manufacturing format (NL1)**
 - ASCII Conversion of Netlist, Footprints, Placement data
 - Artwork Conversion and Editing
- **Manufacturability verification**
 - Nomenclature Cell Creation
 - Read Nomenclature
 - Processability/Level checks
 - Layer Checks
 - ⇒ PD checks
 - ⇒ ORBOT checks
 - ⇒ Metal area checks
 - ⇒ Minimum Line Segment Checks
 - Z rules checks
 - Continuity

- Logical/physical Comparison
- Processability/Release

Gerber - TDV Subset Design

The data exchange from Mentor Graphics utilizes Gerber, augmented by logic and device information in an ASCII format. The ASCII format chosen is the standard Mentor Graphics 'neutral file' from the FABLINK tool. The 'neutral file' is further augmented by the Tech file, that describes the template from which the design was created. This has more information than minimally required but is easy to generate by the customers.

A program named 'MgcToCad' uses the 'neutral file' data and 'tech file' to recreate the device information, placement information, and netlist information, which is then used to create a Cadence .brd file with placed components. The MDS Nomenclature cell is generated from the placed board information. The Nomenclature cell is used to guide the internal checking tools (MDS) to verify the converted Gerber or GDS2 data. The converted and verified CAD data is used to create the substrate opens and shorts test data. The verified design data also supports manufacturing assembly and documentation requirements.

Release of the completed physical design data from the Mentor Graphics tools has been demonstrated. Ongoing refinement is expected as technology and tool developments occur. Details are described in Table 2.4-6.

Table 2.4-6 Cycle time breakdown of the CAD Data Verification activities for the TDV Subset Design

Mentor Graphics Gerber Data	Hours	Comments
MgcToCad Conversion	4	Debug required due to differences in expected pad types, 1 hour for clean run.
Gerber Conversion to GL1	1.5	
GL1 Editing/Conversion to NL1	3.75	Top surface pads were drawn not flashed so surface features from the placed board was required.
Nomenclature Cell Creation	5	Single point nets were not in the netlist, so view names for those pads in NL1 had to be changed.
Read Nomenclature	5	A round off error required modification to roughly 300 pad locations.
Processability/Level checks	0.16	
Layer Checks		
PD checks	0.67	
ORBOT checks.	0.16	
Metal area checks.	1.5	
Min. Line Segment Checks	0.16	
Continuity	0.5	
Logical/physical Comparison	0.16	
Processability/Release (Summaries/plots)	8	Estimated (Test Case only)
Design Review (wait)	0	
Design Review	2	Estimated (Test Case only)
Total CAD Data Verification Days	(32.56 hours)	4 Days

Note that the 'MgcToCad' assumptions can be modified to accept the test case conditions. This would result in a 3 hour savings. Similarly, fixing the round off problems with the pad locations will save 4 hours, and developing an alternate approach to single point nets will save an additional 3 hours bringing the CAD Data Verification time down to 22.56 hours or just under 3 days.

GDS2 - TDV Subset Design

The GL1 editing is required to separate GDS2 layers into GL1 layers and change shape names to those that are processable. (The Gerber method is automatically correctly separated and named.)

The GDS2 data can be processed by the foundry, but is currently inherently more complicated because of the less specific conversion to GL1 and because redistribution/mesh layers in the GDS2 violate ground rules and create self intersecting shapes that have to be edited out of the data.

Details are described in Table 2.4-7.

Table 2.4-7 Cycle time breakdown of the CAD Data Verification activities for the TDV Subset Design		
Mentor Graphics GDS2 Data	Hours	Comments
MgcToCad Conversion	4	Same as Gerber
GDS2GL1	0.25	
GDS2 required pin.extraction	0.58	
GL1 Editing/Conversion to NL1	1.75	
Nomenclature Cell Creation	5	Same as Gerber
Read Nomenclature	5	Same as Gerber
Processability/Level checks	0.16	
Layer Checks		
PD checks	1.33 + (8 see note below)	Self intersecting shapes had to be edited to pass the checking.
ORBOT checks.	0.16	
Metal area checks.	0.5	
Min. Line Segment Checks	0.16	
Continuity	3	Debug, self intersecting shapes detected at this step. Edits and interactions required.
Logical/physical Comparison	0.16	
Processability/Release (Summaries/plots)	8	Estimated (Test Case only)
Design Review (wait)	0	
Design Review	2	Estimated (Test Case only)
Total CAD Data Verification Days	(40.05 hours)	5 Days

Since editing this data would have taken an additional estimated 8 hours, the equivalent Gerber layer data was used for the redistribution/mesh layer. Using the equivalent Gerber layer allowed verification that the rest of the GDS2 data processed normally.

2.4.4.2 Manufacturing Tools Release Paths and Validation

This section will address the data transformation aspects of the release system to support the specific manufacturing tool sets for the Ceramic and Thin-Film MCM manufacturing capabilities. Table 2.4-8 describes the different ways the design features are implemented in each of the technologies.

	Manufacturing Process		
	MCM-D	MCM-C	
Design Feature	Standard/Prototype	Standard	Prototype
Pattern	Expose Mask	Metal Mask	E-BEAM Data
Vias	Laser Mask	Punch Data	E-BEAM Data

Table 2.4-8: Technology feature definition approach (repeat of Figure 2.4-3)

2.4.4.2.1 Prototype

Prototype MCM release has a common strategy for documentation release, and unique paths for transformation of verified design data into tool data. The three transformation options are:

- Ceramic Technology Prototype Tooling
- Ceramic Technology Standard Tooling
- Thin Film Technology Prototype (same as Standard) Tooling

Ceramic Technology Prototype Tooling

As described in the "ASEM Report on the Process and Methodology within the Release System", verified design data and marked up plots are provided to the E-BEAM tool engineers who process the data. The E-BEAM tool does a direct write of the pattern and vias needed for the product.

The Sun Sparc module was built with this tooling. The design data was provided to the Engineer responsible for the Electron Beam (E-BEAM) tool. The engineer converted the data to a tool format, and proceeded with the build of the module. Total processing for the tools was less than 4 hours.

Ceramic Technology Standard Tooling

Data is generated to create the artwork for the masks, the artwork for via inspection masks, the data for the punch (vias) tools, and automatic inspection tools as needed. Due to the increase in the number of tools, the additional work associated with releasing the 'C' standard tooling data is much greater than that of the 'C' prototype tooling path. Cycle time is also affected by the requirement of metal mask fabrication for this process.

The critical path is Design Data on ISM, post processing, Mask EWR generation, and Metal mask delivery. This process has been improved by the integration of the transformation tools within the 'BRX' system framework.

Process Step	Cycle Time	Comments
Design Data Documentation		Plots, markups, summary sheets (part of CAD Data Verification activity)
Mask Control Cards / Post Processing	4 hours	Control cards generated from GLP sheets / through 'BRX' system
Mask EWR	1 hour	'BRX' assisted
Masks Delivered	7 days	Typical cycle
Punch Control Cards	1 hour	'BRX' assisted, Not Critical Path
Post Process / Punch Data	3 hours	'BRX' assisted, Not Critical Path
Inspection Control Cards	1 hour	'BRX' assisted, Not Critical Path
Post Process / Inspection Data	1 hour	'BRX' assisted, Not Critical Path

The following modules were released through this tool set:

- McClellan AFB ALC Data Transfer Module
- Mayo Ceramic Test Vehicle
- National Semiconductor Processor Module

Thin Film Technology Prototype (same as Standard) Tooling - Mayo 'D'

As described in the "ASEM Report on the Process and Methodology within the Release System", verified design data and marked up plots are provided to the release engineers who process the data. The marked up plots are used to order thin film masks and are used to process the design data. Cycle time is affected by the requirement of masks for this process. The critical path is design data verification (discussed above), design data on ISM, data partitioning for thin-film masks, mask data on ISM, creation of the Mask order on the 'Mask Order Processing System' (MOPS), and mask delivery.

Cycle time is minimized by processing the first pattern and first via mask (about a day), to minimize order initiation time, then processing and ordering the rest of the masks while the first are being built.

Current cycle time has been as follows:

Process Step	Cycle Time	Comments
Design Data Partitioning for thin film masks	8 hours	Design data is merged with mask fiducials.
Mask Order/Processing System	1 hour, 10 minutes	Verify windages per shape levels
Pattern Masks Delivered	3 days	Expedited delivery
Via Mask EWR	1 hour	
Post Process Via Mask data	2 hours	
Via Masks	7 days	Optimistic Laser mask cycle

The Mayo 'Thin Film Test Vehicle' was processed through this path.

2.4.4.3 Demonstration Conclusions

The cycle times shown represent more than a 50% reduction. The reduction is due to improvements in the following areas:

- Improved conversion process from commercial design systems and artwork formats to the IBM Internal design data format
- Improved CAD data verification capabilities
- Automated release activities in the 'BRX' framework
- Formalized and optimized prototype release requirements
- Streamlined procedures in the 'E.Fishkill Packaging Development Checkpoint Process'

It is believed that errors have also been reduced by more than 50% by listed improvements, but a larger number of releases are required to verify the exact amount.

Continued cycle time and error reductions are expected as part of ongoing productivity improvement efforts.

Logic Entry

Many products that enter this path have suffered from data consistency concerns between bare die and package part I/O and nomenclature, between PCB connector nomenclature and MCM I/O nomenclature, and between bare die and associated test data.

The bare die I/O and nomenclature issue specifically refers to the fact that the bare die configuration of nomenclature and power pad information is different from the packaged versions of the part. This situation can be improved through the availability of bare die information in the 'Die Information Exchange (DIE) format'.

Similarly, connector nomenclature on a board is different from MCM pin nomenclature. Use of Design kit logic symbol elements for I/O pins will improve this situation.

The test data vs. Die version is another consistency issue caused by the current level of maturity of the organizations providing the bare die.

Physical Entry:

The easiest physical entry path is from Cadence because of the foundry experience base and interchange development effort. Even this path though can be simplified by minimizing the number of individually placed 'pads' on the MCM. Customers are encouraged to have all pads included within footprints for MCM I/O or chip sites.

Gerber and GDS2 formats, originally intended as artwork tool drivers, are used by the foundry as data exchange formats. The difference is that, in a pure artwork tool environment, it is not a major concern whether a shape is created as a single entity (e.g. a flash, or a shape) or whether it is drawn and filled in with lines or shapes. For data exchange, it is important that each feature is represented as a single shape or 'flash' of an aperture. Only lines are drawn, and those lines are drawn from coordinate to coordinate and should begin at the location of a shape (e.g. pad or via). The format in this case needs to be able to represent the characteristics of the technology (e.g. only circles, rectangles and lines, or only polygon pads and circular vias etc.) Also, because Gerber and GDS2 were not meant to be data exchange formats, they need to be supplemented by additional information encoded as conventions or supported by auxiliary files or paper-work. The EDIF-PCB format is currently under investigation for extensions into covering the MCM exchange requirements.

2.4.5 Direct Release Conclusions

Contract objectives and deliverables were met through the investigation of release requirements described in the "ASEM Report on Architecture"; Direct Release Architecture Document, CLIN 0002AJ, the description of the process and methodology of the system in the "ASEM Report on Methodology & Process within the Release System" CLIN 0002AK, and the demonstration described in the "Report on Release System Demonstration" CLIN 0002AL.

Release continues to be complicated by design requirements that are outside of the standard foundry conventions. Improvements in the flexibility of the CAD data verification tools have significantly reduced cycle time and errors in the verification process. Improved conversion programs and methodologies have greatly reduced cycle times involved with processing the variety of formats acceptable to the foundry. Release integration has significantly reduced cycle time and errors associated with processing the verified design data. Industry standardization of MCM and related information formats will further improve release and processability of data from a wider variety of sources.

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2.5 Framework

The framework activity in the contract was identified because of the recognized importance of data integrity and process management in assuring first pass design and release success. This activity also recognized that the design and release process, at the beginning of the contract, operated on information from a number of different sources. From the custom MCM perspective, many steps in the process were performed using manual (data transfers and paper driven) point tools. The intent was to use some framework to begin to link and automate the steps of the process. By linking and automating pieces of the process, it would not only run faster but reduce errors and learning curves associated with staffing these processes.

2.5.1 Introduction

Utilizing a framework was an activity that needed evaluation because of the benefit gains expected from integration. These benefits are enumerated below:

1. Framework reduces cost and turn-around time

Reduced design cycle time implies reduced cost by:

- Reducing design system iterations -- a framework keeps better control of design data.
- Sharing data between tools.
- Providing a cohesive user interface.
- Providing a consistent design environment.
- Providing control of the design process -- the order of design steps.

The above reasons are most notable for cycle time and cost reduction for less experienced personnel. They are more debatable by experts who desire more freedom for special case conditions.

- Initiating foreground or background jobs on VM or MVS from the work-station -- data is passed between AIX and the host. The design process is managed from the system level, not the lower tool level.
- Providing audit control.

These can affect cycle time by helping personnel with general tasks of data transfer and project status which make success easier to achieve.

2. Framework increases quality of product.

When the design cycle is complete, a quality product is assured because:

- A framework maintains design integrity.
- The framework's database manager is used, not individual file structures.
- The correct set of hardware design rules and releases of software tools is used.
- The designer is no longer using multiple stand-alone ("point") tools with individual databases.
- The designer is assured that all design steps have run successfully -- audit control over the methodology.
- All design data for all tools is stored in a single database controlled by the framework.

The quality aspects of framework are again aimed at reducing opportunity for error. In this sense, it allows a reduction in the distribution of cycle time and errors between 'experts' and 'novices' in specific domains.

Initial work involved investigating Framework capability and estimating efforts and pay back associated with the integration of the design and release process in a framework.

2.5.1.1 Design and Release Environment.

The IBM tool set consists of design and release tools from Cadence and IBM. These include Allegro, IGS2, USC, a number of host based electrical and thermal analysis tools, host based documentation and manufacturing release tools. In managing data integrity and process control, both design data management (DDM) and process management (PM) is necessary.

2.5.1.2 Ideal Framework Characteristics

Characteristics of an robust framework are listed in Figure 2.5-1 and illustrate the detail to be considered in developing an integrated process.

2.5.1.3 Framework Evaluations

A requirements and architecture document was created which defined an ideal description of an integrated design system. This was written relative to IBM ProFrame capabilities and CFI 2.0 extensions. Then alternatives were reviewed against that definition. There were three areas to consider:

1. Framework capabilities and extendibility
2. Process flexibility and maintainability in the Framework
3. Maximizing industry benefit from the integration activity

Conclusions drawn from this activity were used to determine an integration approach which would be demonstrable. This is described below.

2.5.2 Framework Evalutaion

Mentor Graphics, Cadence, and IBM Framework options were evaluated. Most of the effort focused on the IBM and Cadence options since no native Mentor Graphics point tools were part of the existing design or release process (i.e choosing the Mentor Graphics framework would only complicate the effort since no existing tools would be integrated naturally).

Cadence had two framework environments, ValidFrame and Design Framework 2. Some confusion existed as to which was appropriate for the larger integration objective and which framework operated with the Allegro tool and which would ultimately be supported by Cadence.

ValidFrame had process management capability with its two components PMAN (process manager) and CMAN (communication manager). PMAN supported launching SKILL programs so additional flexibility was possible. (SKILL being a programming language that can create functions for a variety of special requirements e.g. DDM). Additionally, a new Cadence product was announced, Teamwork Design Manager, that integrated much of the function needed to address process and data management. The Card design environment had used the concepts of Teamwork Design manager in a project called ACE for internal printed circuit board release at some IBM sites. Design Framework 2 was developed mainly for chip design software.

IBM ProFrame has both PM and DDM capabilities and therefore looked like the most advantageous and extendible approach. The drawback of this framework was that Allegro and

other IBM tools would have to be encapsulated in order to allow communication to occur. Another drawback was the fact that there was a very small installed base of this framework so few others would benefit from activity in this area.

2.5.2.1 Overview of the Tool Integration Process

Process integration should follow the CFI definition of the steps involved in tool encapsulation and involve specific personnel skills defined below.

The following is the CFI definition of the five steps involved in the Tool Encapsulation Process:

- **Selecting the Tools.**
 - * Tools are selected by the process developer.
 - * Decide the sequence, conditions, and relationships among tools in the process.
- **Characterizing the Tools.**

The process developer examines the tool's peripherals:

 - * Input/output data/files.
 - * Invocation constructs.
 - * Return codes.
 - * Message/error logs.
- **Defining the Design Methodology.**

The process developer defines the design methodology, including:

 - * Data hierarchy.
 - * Data flow.
 - * Invocation parameters.
 - * Enforced process flow.
- **Generating Encapsulation Wrappers.**

The tool integrator writes the wrappers.
- **Registering the Tool to the Framework.**

The tool integrator registers the tool.

As stated in the IBM ProFrame "Tool Encapsulation User Guide", the following personnel are required in order to encapsulate a tool for use in a process:

- **Process Developer** -- Lead designers who combine tools to form a design methodology (collection of tools) used by designers.
- **Tool Developer** -- Write programs used by design engineers.
- **Tool Integrator** -- Implement, install, and customize the design methodology; write wrappers, programs, shell scripts, or command scripts.
- **Framework Developer** -- Software engineers who write and enhance CAD framework software.
- **Designer** -- Ultimate end-user; execute CAD tools in a formal or informal design methodology to create electronic designs.

- CFI 2.0 Compliant -- Message Classes and Interpreters
- Introduction
- Definitions
- DBMS Requirements
- Library System Requirements
 - General Requirements
 - Check-Out Functions
 - Check-In Functions
 - Add Functions
 - File Promotion Functions
 - Library System Requirements Not Currently Planned
- IBM Framework
 - DBMS -- Design Environment
 - DBMS -- Direct Release Environment
 - Data Repository
 - Types of Functions
 - Tool Encapsulation
 - IBM Framework Components
 - Design Control (Version Management)
 - Controlling Design Data
 - Framework Utilities Provided
- Framework to Framework Integration
- CFI 2.0 Enhancements to IBM Framework
 - CFI 1.0 Features
 - CFI 2.0 Enhancements
 - CFI 2.0 -- Design Representation
 - CFI 2.0 -- Design Data Management
 - CFI 2.0 -- Tool Construction
 - CFI 2.0 -- Tool Execution
 - CFI 2.0 -- Framework Administration
- Security, Backup, Recovery
- Future Direction
- CFI Framework Backplane Example
- IBM Framework Components and Interfaces
- Design Control Structure
- Methodology Management Editor
 - High Level Process
 - Low Level Process
- Data Manipulation in IBM Framework
- CFI ITC Message Server Model
- Inter-Framework Communications
- Framework to Framework Standard

Figure 2.5-1: Framework Requirements Example

2.5.2.2 Process Flexibility and Maintainability in the Framework

Flexibility can be evaluated two ways. First, flexibility can be viewed as Framework flexibility, i.e. by the way and degree to which a process can be implemented. Secondly, flexibility can be viewed as resource flexibility, i.e. the resources required by a business to implement and maintain its tools. The second approach recognizes that to develop and manage a process within a Framework requires skills.

Flexibility was initially looked at from the point of view of which Framework allows the greatest amount of capability or variation in tools and steps within the process. The IBM ProFrame environment seemed to fit this description.

Resource flexibility asks the question, 'How much effort does it take to establish and maintain a skill base for the required activity?' From this light, the framework that was the simplest to work with and the most consistent with other knowledge needed to perform business functions should be considered. Cadence Allegro SKILL and ValidFrame knowledge is of value to general Cadence users and AMPLE knowledge is beneficial to Mentor Graphics users so these seemed to be the most flexible for staffing. Further investigation also showed that most functions could be defined with SKILL and even the cases which required data transfers between many tools could be handled with standard data transfer functions. Similarly, AMPLE could provide the same integration capability for the Mentor Graphics environment. For the case of Release, the similar capability was with the REXX programming language running with a background VM processor (TOOLSRUN account). Release functions operated in host environments, and REXX was an existing release personnel skill base.

Maintainability needed to be considered too. This includes questions as to how much does it cost to maintain the skill base for ongoing support and extensions to processes developed. The business must be able to migrate to new tools and processes as technology and tools progress. This seemed most supportable by implementations in software formats that are useful for design and release personnel to know.

2.5.2.3 Maximizing Industry Benefit from the Integration Activity

Maximizing the industry benefit was one of the objectives of the whole ASEM program. In the case of framework, this came down to the following criteria:

1. How can this activity be utilized by the largest design community?
2. How can the money for this activity be best spent?

When looked at in this light, two facts became obvious. One is that the way to maximize the potential number of users would be to include as much as possible of this effort within the Design Kit that was intended for distribution. The second fact was that the minimum software investment option should be selected so that a larger audience would be able to reap the benefits. In light of design kits though, a process would be beneficial in each of the tool sets native environment, hence a process in the Mentor Graphics tool set, and one for the Cadence tool set.

Release tools are foundry specific, so no apparent industry value could be gained beyond the reduced NRE associated with utilizing the improved process.

Lastly, a number of encapsulation wrappers would be required to integrate the design and release tools into a single framework.

2.5.3 Implementation

Viewing this information from the three perspectives above, the most effective implementation seemed to be the simplest approach. Use of standard Cadence and Mentor Graphics framework and extension language capabilities for design integration and automation and use of host programming language for the release integration and automation. With this choice, there were no message classes that were needed for the IBM User Framework. Communication between design and release did not seem critical because it's a one time transaction and did not need tight integration for improved effectiveness. Communication between Design and Release frameworks was handled by standard data transfer commands (ftp from workstations to mainframe, sendfile and XMIT between mainframe environments). This allowed both design and release to evolve in a way that was most effective for the respective starting points. The details are described below.

2.5.3.1 Framework Integration of Direct Release

As described in the Direct Release Section, the original approach was modified to an evolutionary strategy to eventually support release in a workstation environment. The integration utilized existing tools and skills within the IBM organization. The department responsible for processing the design data understood the point tools and how to integrate tools in a host environment using the REXX language that is portable between mainframe and workstation environments. Under the title of 'BRX', menus and interfaces to design data were prototyped, refined, and used for the daily processing of design data. This development started at the post-processors and moved progressively upstream to the design documentation requirements of the release process.

The following sample of BRX Menus are provided to demonstrate the function of the BRX system.

Initial menu:

PRODUCT NAME.

_____ (? = list)

F3=Exit F12=Cancel

Product Menu: (Zumbro was the code name for the McClellan AFB ALC Product)

PRODUCT ZUMBRO, MAIN.

- _ Product Name
- _ Product Description
- _ Cross Section
- _ GL1 File Names, Metal Mask
- _ GL1 File Names, Punch
- _ Metal Masks
- _ Mylar Masks
- _ Punch Datasets
- _ Orbot Datasets
- _ PE Specs

F3=Exit F12=Cancel

When Cross Section is selected from the main menu, the following appears:

PRODUCT ZUMBRO, CROSS SECTION.
LAYER FUNCTION (BL BS Bn Gn RIT Rn TS Tn Vn Xn Yn
Mn)

1 TS V1
2 V2
3 V3
4 X1
5 X2
6 V4
7 V5
8 X3
9 X4
10 V6
11 V7
12 V8
13 BS

F2=Edit F3=Exit F7=Bkwd F8=Fwd F12=Cancel

When Metal Masks is selected from the main menu, the following appears:

PRODUCT ZUMBRO, METAL MASK SPECS.

_ Metal Mask GL1 Summaries
_ Metal Mask GL1 Images
_ Metal Mask Functional Indexes
_ Metal Mask Part Numbers
_ Metal Mask GL1 Levels
_ Metal Mask Attributes
_ Metal Mask Feature Dimensions
_ Metal Mask Post Processing Jobs

F3=Exit F12=Cancel

When Metal Mask Feature Dimensions is selected for Layer 1 from the Metal Masks menu, the following appears:

Use PF2 if you want to edit.

PRODUCT ZUMBRO, METAL MASK FEATURE DIMENSIONS for MFI V1Q.

IMAGE	LEVEL	GL1 FIRED (in)	MASK GREEN (in)	MASK REF (Y/N)	WINDAGE GREEN (in)	ARTW GREEN (in)	ARTW REF (Y/N)	MAXSEG FIRED (mm)	TAB (mm)
B-LIN	9-RLS10001	.0039	.0038	N	-.0018	.0020	N	0.56	
C-PAD	(6 7)	.0049	.0060	N	-.0021	.0039	N		
D-LIN	8-RLS20001	.0049	.0059	Y	+.0000	.0059	Y	5.00	

2.5.3.2 Framework Integration of Design

ValidFrame's PMAN and CMAN were used as the global process management tools. Automation of individual steps were achieved through implementation of functions in SKILL which became available in the Allegro environment in the middle of the contract.

An initial process flow was established in the PMAN as shown in Figure 2.5-2. This built on a two tier process flow, one for the conceptual through physical design flow and a more detailed layer for the specific physical design flow. Extensions were projected for physical design entry where completed physical designs get transformed into foundry manufacturable data formats and are rechecked against manufacturability requirements. Process steps are initiated by text buttons, data entry is accomplished with SKILL forms, process automation is accomplished by SKILL routines.

2.5.3.3 Benchmarks

Cycle times have been reduced by more than 50% in the integrated release environment. The reduction is the result of elimination of numerical calculation, elimination of redundant data entry, elimination of rework due to errors, and improved job completion status verification.

Specific design cycle time reductions have not been measured but the integrated design environment is much simpler for a new user. Experienced users are not expected to benefit in terms of cycle time, but their susceptibility to typing errors is reduced by the visual interface and they are prompted for typical data rather than having to rely on their experience.

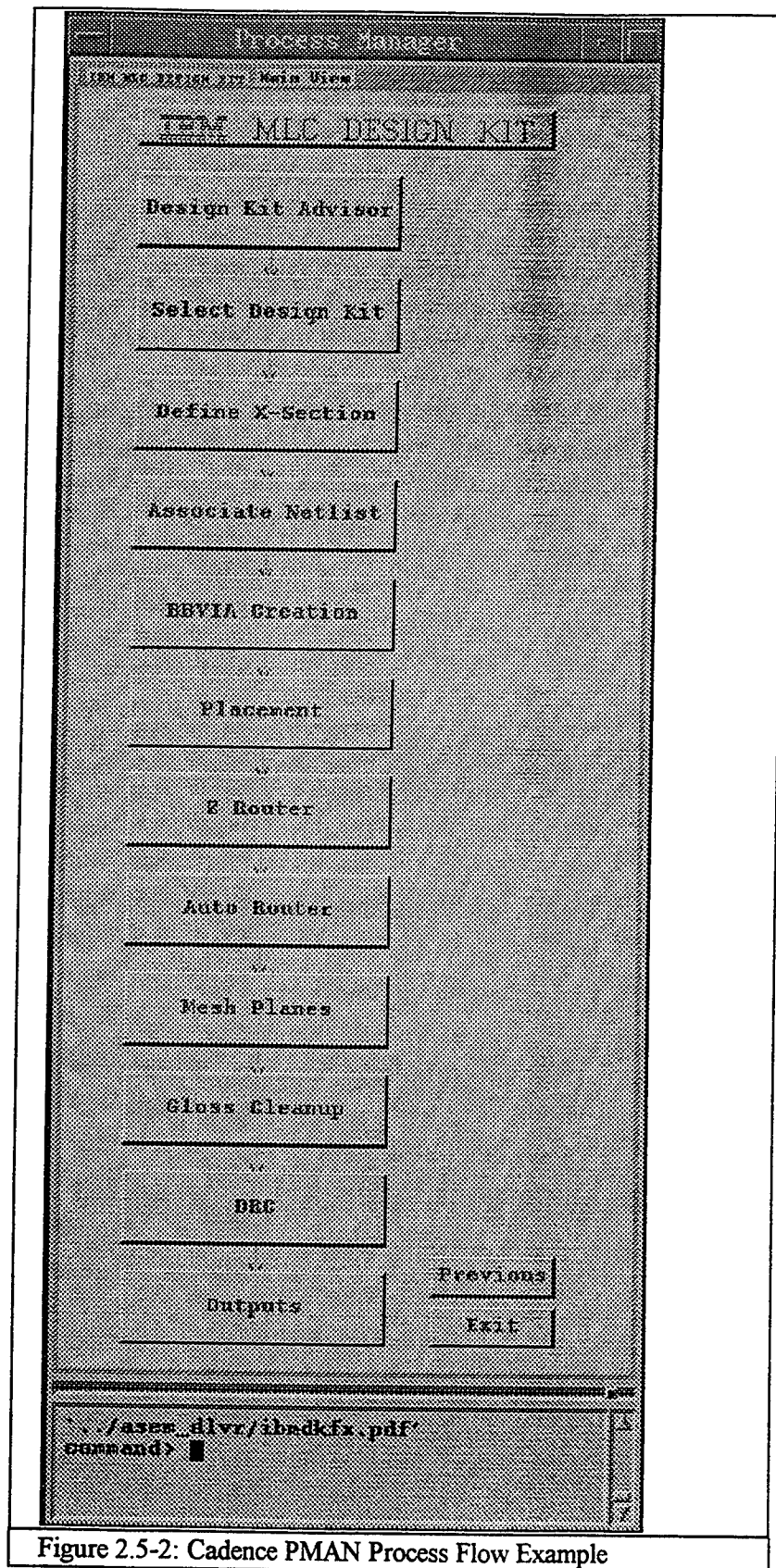


Figure 2.5-2: Cadence PMAN Process Flow Example

2.5.4 Conclusions

Contract requirements were met, no additional framework features needed documentation and data exchange between environments was demonstrated. Process management in framework environments is justifiable to the extent that business conditions can afford the implementation and maintenance of the process. This is dictated by the skills required for process management relative to those required for general business functions. Typically the business case is enhanced if customers can benefit directly from integration, such as when integration activities compliment service offerings like design kits. Significant benefits are expected in the areas of quality and process learning curves within framework integrated processes. Quality is measured by the reduction of errors over the course of many process cycles. Learning curves are reduced by the enhanced structure of the process.

The way a process is implemented is that tools are chosen, wrappers (encapsulation programs) are established to make the tool available for use, and a methodology is described and implemented.

3.0 MCM TEST

Overview

Providing high-quality MCMs at a reasonable cost can be a challenge even in a captive environment, during which both the chip and MCM designs are within a company's control. With an OEM MCM foundry, however, the test environment becomes more complex, as the customer (company ordering the MCM), may not be in a position to control or even divulge the details of the die being used, and be only willing to expend minimal funds to ensure adequately tested product. As a customer-driven facility, the foundry must cater its test strategy to the customer's priorities. ARPA has set a number of specific goals for the ASEM program which are detailed in reference [1].

Collectively, cycle time and cost goals can only be met if all testing operations are extremely efficient, well-defined, and non-duplicative, while flexible enough to serve a variety of MCM products. To meet cycle time and cost goals, work was undertaken contract subsection: 2.1.1.1.4. The task is described as development of a testability strategy and guideline which will support entry points into the IBM foundry at various design levels. One result of this work is a document titled, "ASEM Report on Testability Strategy and Guidelines," ARPA ASEM Document no. CLIN0002AH, 7/31/93 [2] and was delivered to ARPA on 7/31/94. The document contains a proposed strategy for meeting the ARPA ASEM goals for turn around time and cost reduction. The following report expands on the Strategy and Guidelines document and details the test environment, test methodology, implementation of the proposed test strategy and presents the results of testing two different application demonstration vehicles. The test strategy was implemented largely unchanged from the proposed strategy with the addition of test database verification procedures.

The approach used to meet the goals for TAT and cost was to develop a strategy which was appropriate to the business and customer environment with respect to design ownership and tasks. The second element of the approach to meeting our goals was to install appropriate tooling and business processes to support the selected test methodology. The third element in our approach was to benchmark progress in lowering our TAT and NRE cost by monitoring the effort spent in performing test on real MCMs. The results of the benchmarking would verify that the implemented test strategy was in fact producing lowered TAT and costs. The use of actual application test vehicles also facilitates debug of procedures and identifies areas requiring extra attention.

Section Organization

The Module Test section of the report is presented starting with a brief description of the challenges to test and the approaches taken to meet the Foundry project goals.

- Section 3.1 describes the MCM test environment which includes a breakdown of the various types of tests required and issues associated with each test type.
- Section 3.2, Test Methodology, describes the foundry low cost and quick turn around time test methodology. It includes the reasoning for the selection of the chosen test methodology as well as a description of various ramifications implied for support infrastructure and test equipment.
- Section 3.3 is the implementation of the test methodology. It includes descriptions of the hardware tools, software tools, design for test and test database content which are part of the employed methodology.
- Section 3.4, Known Good Die, presents the strategy and implementation of using temporary chip attach technology using single chip modules for production of known good and burned in die.

- Section 3.5, details data integrity problems experienced during the execution of the application demonstration MCM programs and presents a methodology for minimizing data integrity problems.
- Section 3.6 summarizes results from two application demonstration MCM case studies and presents the result of our benchmarking activity.
- Section 3.7 presents key conclusions concerning each area of the MCM test report.

Some material in each of the sections of the MCM Test report overlaps with other sections of the test report. This was done to make each section more readable, hence minimizing the need to reference other sections of the report.

3.1 TEST ENVIRONMENT

3.1.1 MCM Testing Challenge

The key to efficient and effective testing is the development of a test strategy which clearly defines what tests should be applied at each stage of the manufacturing process. The goal of the test strategy is to minimize product life-cycle costs, where these costs are defined as the sum of development cost, production cost, and "imperfect test" cost. Development cost is the non-recurring (volume-independent) cost associated with generating the tests, assessing their quality (e.g., fault-simulation), implementing tests on the tester, and any unique hardware requirements necessary for test application (such as test fixturing). Production cost is the recurring (volume-dependent) cost of testing the MCMs, which includes equipment cost, operating cost and support cost. "Imperfect test" cost is the cost associated with deferring to higher packaging levels the detection of defective product which is generally a more costly practice than detecting defective parts at a lower level of packaging. An optimal strategy balances each of these three cost elements at each test stage so that the total life-cycle cost is minimized, and placement of undue emphasis on one particular aspect is avoided. For example, there may well be fault categories which are either so unlikely or so expensive to detect at a given package level, that it is cost effective to assume that they will be detected later in the production scheme.

One approach used to meet the MCM test challenge for developing an optimum strategy was developed in [3], and was applied for a captive MCM production facility in [4]. In the foundry environment, however, this approach must be altered to reflect the fact that the foundry itself can only control portions of the necessary manufacturing tests, and should incorporate the customer's definition of cost elements, especially when it comes to imperfect test cost. These particular aspects are common to all MCM foundries, and have been addressed in [5,6].

3.1.2 MCM Test Categories

In a generic view of the MCM manufacturing flow, there are five test categories which most likely will be applied as shown in Figure 3-1 and described below.

3.1.2.1 Die Test

Chip level test is the most critical juncture of the test flow. Typically, the yield from this step is dramatically lower than elsewhere in the manufacturing process. Thus, the likelihood that untested circuitry will in reality be defective is an important concern. Additionally, this step represents the minimum investment in materials and labor, and therefore is the ideal point at which defective ICs should be weeded out. Unfortunately, the electrical environment during wafer probing represents the worst conditions that the IC will encounter. Probes provide high capacitive loading, often an order of magnitude higher than seen at the system level. Similarly, the environment is highly inductive, creating a problem when today's high speed, high current primary outputs are switching. This problem is especially acute as the number of I/Os increase. These factors combine to raise the real potential that perfectly good ICs will fail wafer test.

When the ICs are destined for a Single Chip Module (SCM), it is possible to accept a less rigorous test at the wafer level and assume that some classes of defective chips will be detected during single chip module test. If the IC turns out to be defective, the cost impact is minimal, as the SCM is simply discarded and all that is lost is the cost of assembly plus carrier cost.

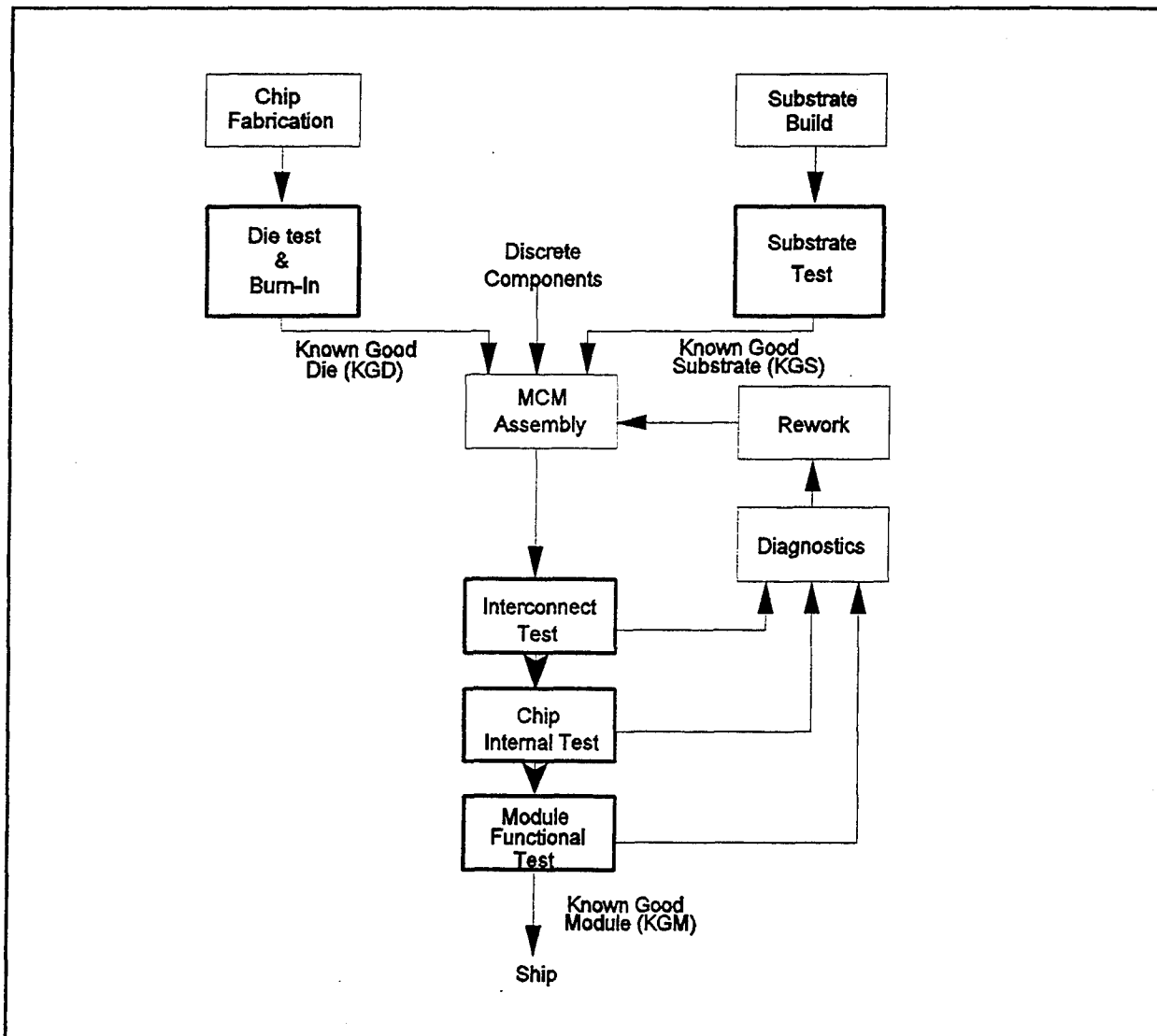


Figure 3-1: MCM Manufacturing Test Process Flow

Reduced testing at the wafer level can be more of a problem for MCM testing, as identifying which of many chips on the MCM is defective can represent a significant cost, plus the cost associated with rework and the potential that the defect will not be adequately diagnosed, thereby placing the entire MCM at risk, a major cost. In some technologies, such as "chips-first" MCM assembly techniques, rework itself may be so expensive as to justify skipping rework altogether, which inherently adds to the cost of providing good

MCMs. To address the need for high quality die, to be mounted on the MCM, many temporary-attach methods have been developed [23]. These approaches mount diced chips onto single chip carriers which can then be subjected to intensive module screens not possible at the wafer level, and may include burn-in. Die surviving such tests are Known Good Die (KGD) and are removed from the carrier and mounted onto the MCM.

3.1.2.2 Substrate Test

Testing of the substrate, onto which the chips will be mounted, is an essential part of the manufacturing process. Such carriers can contain a large number of wiring layers, and high wiring densities. In addition to in-process measurements, an open/shorts test is routinely applied to all interconnections, using either a single or dual probe. As these tests are easily determined from the physical layout, they can be generated directly by the substrate manufacturer, from manufacturing data.

3.1.2.3 MCM Interconnect Test

The interconnect test is the backbone of the MCM test profile. It is used to assure proper electrical continuity between all MCM primary inputs/outputs and the mounted chips, and on all connections between mounted chips. In the process, all interconnecting mechanisms including bonding, soldering, and the complete substrate are tested. This test is key, as it, of all the MCM tests, most directly verifies that the assembly operations were performed properly. On the other hand, the remaining tests tend to verify that damage to presumably good components has not occurred, or to apply tests that could not practically be applied at prior steps in the manufacturing process.

3.1.2.4 Chip Internal Test

The chip internal test verifies that logic circuitry that feeds only other circuitry within the chip itself is tested. Ideally, such circuitry has already been tested during wafer and/or bare die test. There are incentives, however, for repeating this test. First, it is possible that the assembly process, which can include subjecting the die to relatively high temperatures, may induce a metal break or other continuity problems. Secondly, the improved electrical environment at the module level vs. wafer probe can permit higher speed tests to be applied, isolating marginal die. Thirdly, high reliability screens, such as temperature cycling, burn-in, and testing over wide temperature ranges can surface defects missed in prior testing. Given the contrasting objectives between the interconnect and chip internal tests, different test strategies may well apply. It is not a given, however, that the chip logic can easily be segregated as internal vs. external logic. A variety of schemes have been proposed to permit this separation. The most popular approach is through conformance to IEEE Standard 1149.1. This standard [7], known often by its originating group, the Joint Test and Action Group (JTAG), was originally designed to address the problems associated with board level test. It defines a standardized test port interface and communications structure. The primary focus of this methodology is to ease the generation of board interconnect tests (wire tests), by providing latches at the boundary of each board component. These latches are then serialized (daisy chained) to form a single string that is scanable via the 4 pin port on each chip. Additionally, an optional test mode is defined that enables individual component self test. While other approaches exist, such as [4], 1149.1 has developed broad support, and, when implemented on a bare die, enhances that chip's salability.

3.1.2.5 MCM Functional Test

MCM functional test is an at-speed test which is primarily used to screen for parametric variations in die and/or substrates which lead to out of specification MCM performance. There are also benefits in applying a function-oriented test which mirrors actual application as opposed to the fault-oriented tests automatically

generated via EDA systems [8]. These tests can exercise clocking circuitry essential for maintaining high speed performance which, due to its timing nature, must be bypassed during Design-For-Testability (DFT) approaches such as scan-based DFT and 1149.1. A less compelling incentive, but a customer consideration nevertheless, is the desire to verify that the MCM actually performs its intended function. In today's structured design development environments, design verification via software simulators along with static analysis systems should be the prime mechanism for ensuring that the manufactured component performs as expected. Unquestionably, prototype hardware will be rigorously exercised to provide functionality verification, but this is a development, not MCM manufacturing, process.

Finally, as opposed to AC exercise, or 'warm and fuzzy' verification, the MCM functional test can represent the only test available. The MCM customer may, for instance, be simply repackaging a card or board application into an MCM. This customer does not know, or necessarily care, about the details of the chips mounted or contained within. The imbedded chips may not contain any DFT approaches, thus precluding automatic test generation. Additionally, the customer may not be willing to expend the development cost associated with the above alternative test methods.

There are two major hurdles to functional testing. First, it is very difficult to assess the quality of such tests. The trivial example of the 8 input OR block, which requires 9 tests to stuck-fault test vs. 256 tests for functional verification, highlights this dilemma. The importance of quality assessment depends upon the objectives for the test. In 'warm and fuzzy' mode, considerably fewer tests are necessary than in the case where the functional tests are the only ones applied. In any case, some measurable sense of 'coverage' is necessary to define pattern completeness. This evaluation can range from decision path tracing from a flow diagram, to simply counting node toggling.

The second hurdle to functional testing is the inherent difficulty of diagnosis. DFT test patterns typically drive from one latch to another, thus limiting the location of the defect that could induce an observed failure. Functional patterns, with their broad band-width application, typically cycle through a number of register banks before the problem is observable, thus dramatically increasing the number of circuits which may be the weak link. When functional patterns are the prime technique for identifying manufacturing defects, this difficulty in diagnosis can lead to (a) more time-consuming, labor-intensive diagnostic efforts, and (b) a higher potential that repair/rework can not be performed, thus requiring that the failing MCM be scrapped. Both of these can significantly increase product cost. Another snag associated with functional patterns is that the tester may have difficulty in applying the tests exactly as specified. Tester patterns are based upon fixed cycles during which, ideally, input stimuli and output strobes occur at regular intervals. More advanced testers are more flexible in providing a variety of timings for a single I/O, but even these multi-million dollar testers run out of steam eventually. Usage of such testers will in turn increase the production cost, and may cause the functional-test-only approach, which has traditionally appeared to be the low-cost methodology, to be the most expensive alternative, especially as production quantities and reliability goals increase.

3.1.3 Captive versus OEM Foundry Test Environment

In the captive product environmental, all of the previously described test environments are within the control of the manufacturer, and can thus be coordinated and controlled. In the foundry environment, however, this is not the case. Typically, the die are manufactured by another supplier, who may well consider that the logic internal details and tests to be applied are proprietary. While the die supplier can acknowledge that burn-in was or was not performed, the actual quality of the tests applied (a more significant aspect) may not be provided. Lack of details concerning the die, can preclude development of an MCM interconnect test, unless

an accepted standard, such as 1149.1 has been used. Generation of a chip internal test is even more unlikely without knowledge of either the on-chip hardware or some form of standard conformance which enables isolation of the chip from the system it is embedded within and provides a consumer go/nogo test (such as 1149.1 "RUNBIST".) Finally, functional test, developed by the customer using another company's die and the packaging foundry's substrate and assembly, represents this customer's interpretation of how the components will interact, and may be based upon optimistic simulation models.

3.1.3.1 Test Environment Conclusion

All of the above environment factors, coupled with the wide variety of MCM applications, from low-cost consumer applications to high-speed, space-conscious military usage, preclude the availability of a single universally applicable MCM test methodology. Instead, the proper approach for a given package combination must be selected by developing a set of priorities and implementing a strategy which targets specific product goals at each level of packaging.

3.2 TEST METHODOLOGY

The ASEM program identified its priorities by defining a set of rigorous targets for cost and turn-around-time. Such aggressive metrics mandate two overall test strategy themes. First, testing must be non-duplicative. That is, tests should be applied at the earliest package level possible, and should not be repeated at higher package levels unless it can be done so at minimal cost. Secondly, complex components should be assumed to comply to DFT standards. While non-compliant DFT designs may be handled, the methodology should be optimized for DFT-compliant applications.

3.2.1 Assumptions

3.2.1.1 Good Substrates and Good Die

Our developed methodology assumes: good substrates and good die. Defect free die and substrate must be routinely available. Parametric variables in the manufacturing process of both components must be defined with the design kit groundrules. Variations outside the process tolerances should be detected by in-process control measurements, and not by subsequent product test.

3.2.1.2 Design For Test (DFT)

IEEE 1149.1 is assumed as the sole DFT approach. While it is not necessary that all components be 1149.1 compliant, our strategy, which partitions the design into 1149.1 vs. non-1149.1 sections and develops tests independently, will perform more effectively on the 1149.1 compliant portions.

3.2.1.3 Good BSDL and Good Netlist

Any methodology will rely upon the availability of accurate models. The 1149.1 emphasis is centered upon access to the details of 1149.1 implementation, as defined via the Boundary Scan Description Language BSDL (defined in 1149.1B)[9]. The BSDL model is typically provided by the die manufacturer, and should have been verified prior to release. The second hardware model is the netlist of the substrate. The netlist should map to all other logic and schematic models on a one-to-one basis.

3.2.2 Basic Approach: Distributed Testing

The assumptions combine to permit a strategy of distributive testing. Die and substrates will be assumed to be rigorously tested by their manufacturer, precluding the need for retest after MCM assembly. Thus MCM testing will focus on defects induced during assembly, and on testing which is not applicable during die or substrate test.

3.2.2.1 Die Test: Known Good Die (KGD)

The importance of being able to assume high-quality die [10,12] has fostered the formation of an industry group. The focus of this effort, referred to as Known Good Die (KGD), is to develop standards for die suppliers. The KGD emphasis is to provide die which are tested as rigorously as packaged single-chip modules [11]. This, in today's technology, implies that temporary attach or other methods are used to permit chip burn-in, AC, testing etc. Such screening beyond wafer level test is essential to provide adequate MCM assembly yields. Furthermore, the KGD activity is working toward ensuring the availability of physical dimension data, such as pad placement, which is essential to the MCM assembly process. A proposed EIA/ANSI standard for Known Good Die, which defines the design data, electrical test data, quality assurance and reliability provisions was distributed at the 1993 International Test Conference [11]. Finally,

the effort represents a consolidated force encouraging chip manufacturers to provide their ICs in bare die form, a service which some suppliers have been hesitant to provide.

The emphasis on meeting the quality standards defined for the Single Chip Module (SCM) represents a practical, pragmatic approach to KGD. There are however gaps in the approach. First, one can argue that die to be mounted on an MCM need to be tested more rigorously than its SCM counterpart, given the expense of rework and the difficulty of diagnosing faulty components. Furthermore, there is no guarantee that the existing SCM test is adequate even for the SCM. For instance, what sort of defect coverage do the tests meet? What types of defects are covered (DC stuck fault, delay, bridging, etc.) [13,14]? How do the tests target existing production facility defect distributions [15]? While such questions are critical in defining die quality, it is unlikely that they will be directly answered by the die supplier, as they are not yet provided even to the packaged die customer.

In some cases, the die supplier offers the option of purchasing KGD or non-KGD die, where the difference tends to center upon whether or not the die was burned-in. Choosing between the two then becomes a simple exercise in test economics [16,17], where the decision should be based upon the quality targets, cost of diagnosis/rework, confidence in MCM test efficiency, and assumed difference in Defects Per Million (DPM) between the two die screening approaches. Clearly, the best approach from an MCM foundry perspective is that a rigorous test be applied at the die level, where such rigor is defined by measurable high coverage for a variety of DC and AC fault models. Targeting specific fault classes can serve to ensure that the applied tests will continue to provide excellent defect coverage over the evolution of the typical semiconductor process facility.

3.2.2.2 Substrate Test: Known Good Substrate (KGS)

The test objectives for unpopulated substrates are well defined and can be determined from the physical layout. A high quality test is essential, as a defective, non-repairable substrate can result in the loss of all the placed die if detected during MCM assembly.

3.2.2.3 MCM Interconnect Test

The objective of the interconnect test is to verify proper connection between each IC and to the module I/O. Ideally, this is established by developing test patterns that demonstrate that the targeted AC and DC faults do not exist. At issue, then, is to establish which fault classes will be targeted, and on what nets. The primary fault mechanisms typically assumed for interconnect wiring are opens and shorts. Open/shorts tests, which are easily applied on unpopulated substrates with direct access to each net node, are more difficult when the net is subsequently bounded by placed chips and cannot be probed. In such cases, tests must be applied by deriving a set of test patterns that logically initialize the chip driving the source of the net and clocking data across the net into some other chip, whose captured state is then read out.

Conformance to 1149.1, in which standardized scanable latches are placed at each chip I/O, permits this sequence to be easily implemented. In the open/shorts test environment, a sequence of states are placed upon all interfacing nets which can test for any net to net short, as well as a net open. Such tests can be developed independently of any physical placement/routing information and require only a net list showing chip interconnections and BSDL representations for each die. While non-trivial, this test generation can be considered a reformatting of standardized tests (walking ones/zeros, counting, etc.), and is independent of the logic function of the imbedded ICs. Interconnect test generation algorithms are well covered in [18,19]. The standardized nature of these tests, and the ease of generation, given a correct substrate net list and die BSDL,

make this an ideal test to be generated by the foundry itself. By performing this step on its own, the foundry can control output format, tests applied, and can capture diagnostic data from the boundary scan tools.

Foundry test generation also provides more flexibility in tester hardware configuration. This flow is illustrated in Figure 3-2. Totally 1149.1 compliant MCM designs, have, thus far, been a rare commodity. Industry surveys have found that only 40% of board designs, the more traditional arena for boundary scan, actually use boundary scan. In the case of mixed 1149.1/non-1149.1 circuitry, test generation becomes more complex. It is approached by creating partitions between logic that are totally 1149.1 and the non-1149.1 circuitry. The non-1149.1 clusters are extracted by tracing back until 1149.1 latches are encountered, and by tracing forward to 1149.1 latches. Such clusters can contain a collection of non-1149.1 ICs. Tests are then generated assuming that the boundaries of the cluster are primary I/O. The boundary scan support software then, using the BSDL and netlist, converts these patterns into a series of scan sequences through the 1149.1 components, and also generates the test sequences for the compliant network.

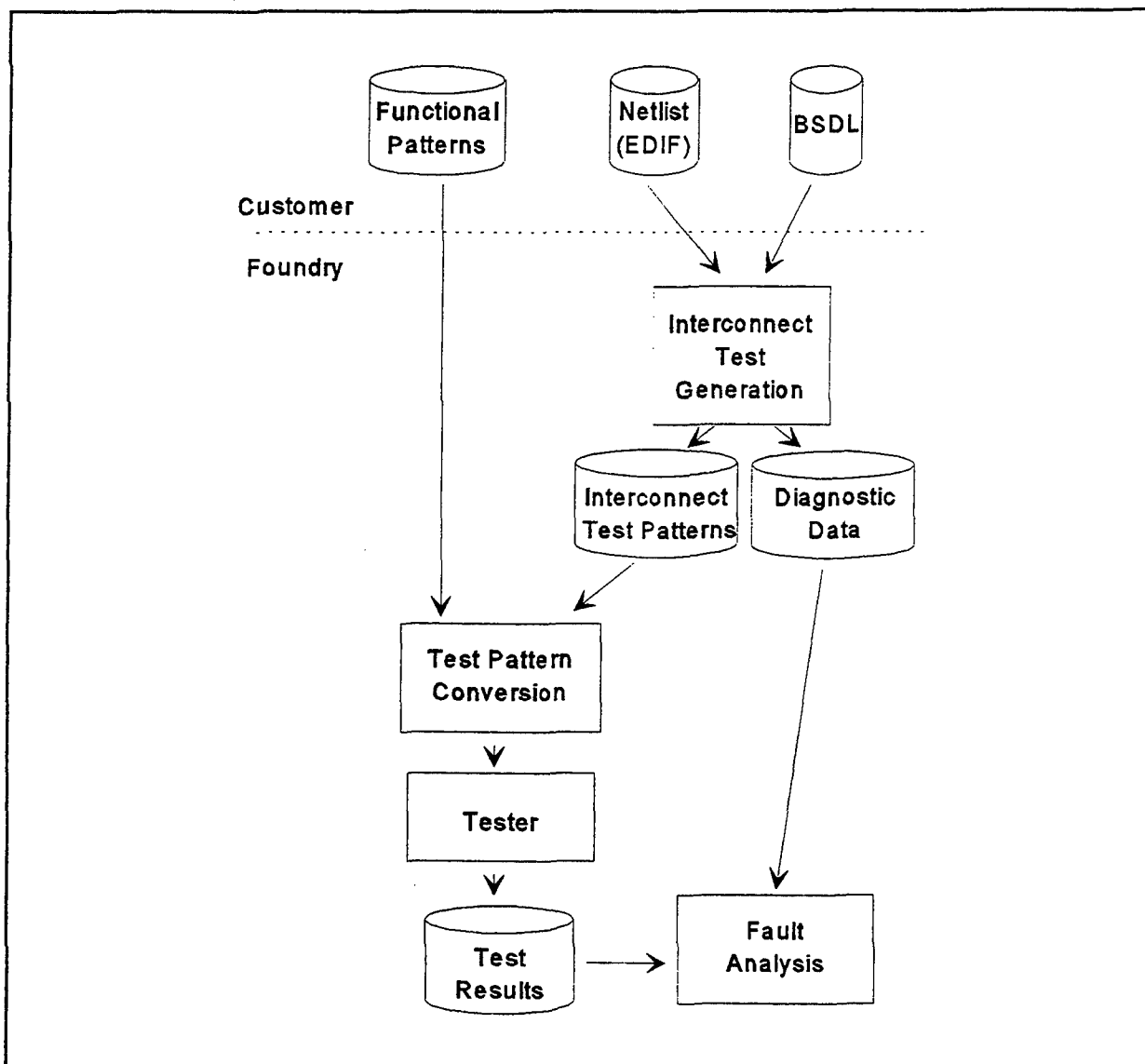


Figure 3-2: Test Pattern Generation for 100% 1149.1 Compliant Designs

At issue is the generation of tests for the cluster network. The details of the internal chips may not be available, thus making both test generation and simulation (both to verify fault coverage and pattern integrity) difficult. Also at stake is the fault model which will be assumed during test generation. Today's automatic test pattern generators typically use the single stuck-at fault model. While this model covers open faults, it is inadequate for shorting, or bridging faults. On the other hand, generating complete open/shorts test as in the 1149.1 case can be impractical due to the large number of states that would have to be propagated forward and backward through the non-1149.1 cluster for each applied pattern. Such a task is not only CPU intensive (and thus costly), but may be impossible in many cases. For this reason, the stuck fault model is the only realistic fault model given today's EDA facilities.

On the other hand, when all logic components are 1149.1, and the only other die on the MCM are non-1149.1 memories, a complete open/shorts test is readily accomplished. This is due to the standardized operation of most of today's memory die. While at this stage, memory test pattern generation is manually performed, automatic generation should not be far in the future.

Given the familiarity of the foundry with the objectives for open/shorts testing, and with a variety of memory configurations, the generation of interconnect tests for MCMs with the logic/1149.1 and memory/non-1149.1 die sets is best performed by the foundry. Where more than just memories are non-1149.1, the difficulty of test generation is less predictable. In such cases, the clusters should be extracted and single stuck-at faults assigned to the interconnect circuitry. Automatic test generation would then be run to achieve whatever level of coverage the customer is willing to support. Manually generated patterns may also be necessary to improve the coverage. Test generation for these non-1149.1 clusters should be performed by the customer, not the foundry. This allows the customers to determine how much money and time they are willing to expend to achieve the test quality level they deem necessary. The foundry would then take the responsibility for incorporating these cluster tests into the foundry generated 1149.1 compliant tests. This flow is illustrated in Figures 3-3 and 3-4.

In the illustrations, the test generation flow has started with partitioning of the 1149.1 circuitry from the non-1149.1 components. If all components are non-1149.1, the entire logic representation (assuming it is available) is presented to the ATPG software, and stuck fault tests should be generated. In this case, all tests are generated by the customer and shipped to the foundry.

3.2.2.4 Chip Internal Test

The ability to apply tests to the internal logic of the chips mounted into an MCM, while not as critical as interconnect testing, can still significantly improve the quality of the MCMs shipped. It is thus in the best interests of both the foundry and the customer to perform this test. While still permitting broad flexibility in implementation details, 1149.1 does provide an optional standard instruction sequence to enable built-in self test (RUNBIST). Hardware on the chip is included (such as pseudo-random pattern generators, signature analyzers, etc.), and the steps necessary to perform this test are documented in the BSDL [20]. This standardization thus allows the foundry to implement BIST for each 1149.1 component with this capability. Self test can also be implemented outside the realm of the Test Access Port (TAP) controller, either on a 1149.1 or non-1149.1 chip. In this case, it would be up to the customer to develop the patterns and provide them to the foundry, in a manner similar to functional test patterns, as described below.

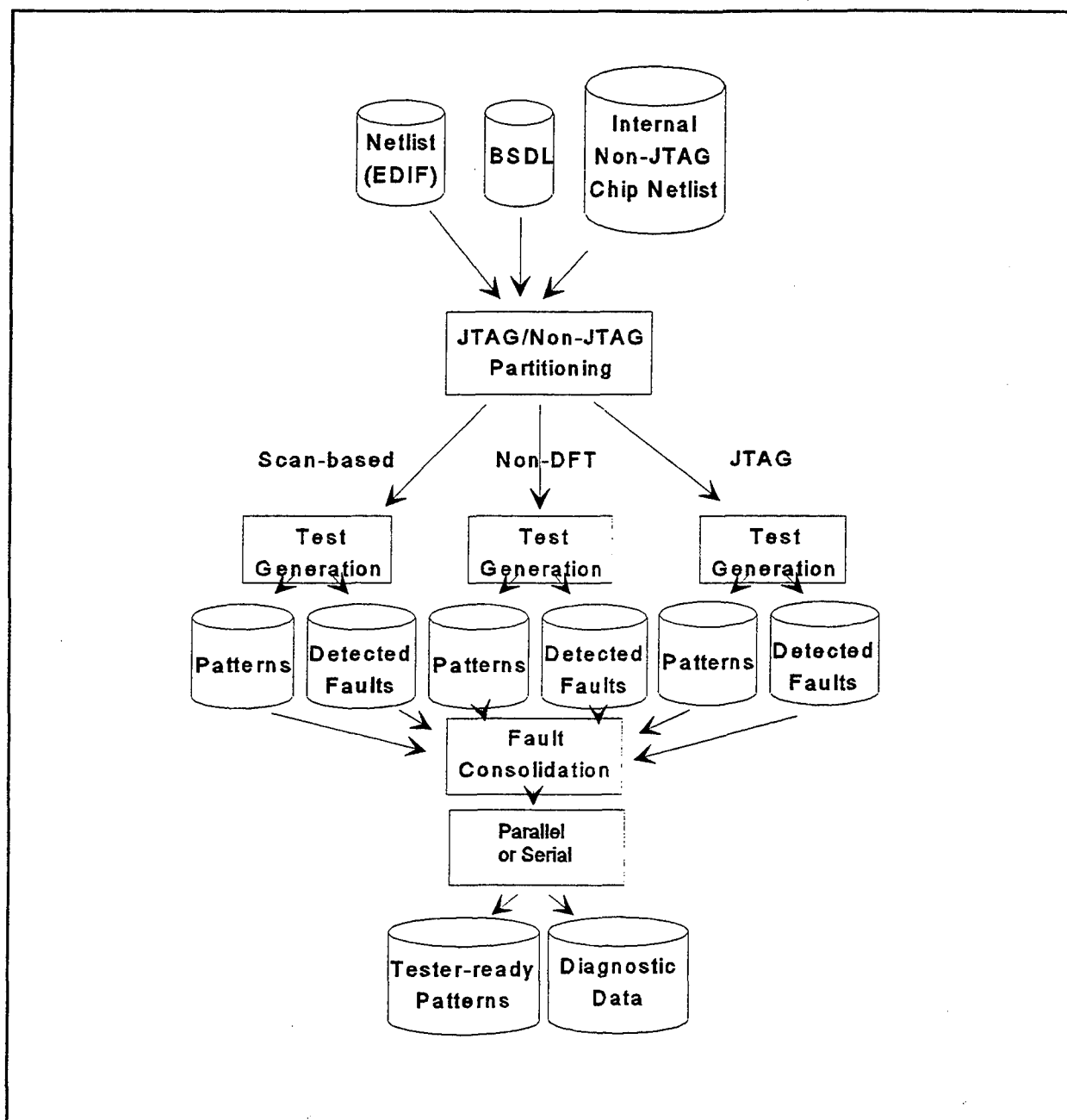


Figure 3-3: Flow for Mixed 1149.1 and Non-1149.1 Die.

3.2.2.5 Functional Test

Of all the MCM test types, the functional test represents the greatest risk to the foundry. Where the difficulties associated with functional patterns has previously been described. Key to developing an approach for these patterns is to first identify which are, of a number of possibilities, the objectives for the test. If verifying the performance of the MCM is the prime objective, the patterns should be designed to exercise the timing-critical paths. On the other hand, if functional verification is prime, as many distinct operations

should be exercised as possible. Finally, if this represents the sole MCM test, attention should be paid to exercising as many chip interconnections as possible, and doing so in a sequence that enables diagnosis.

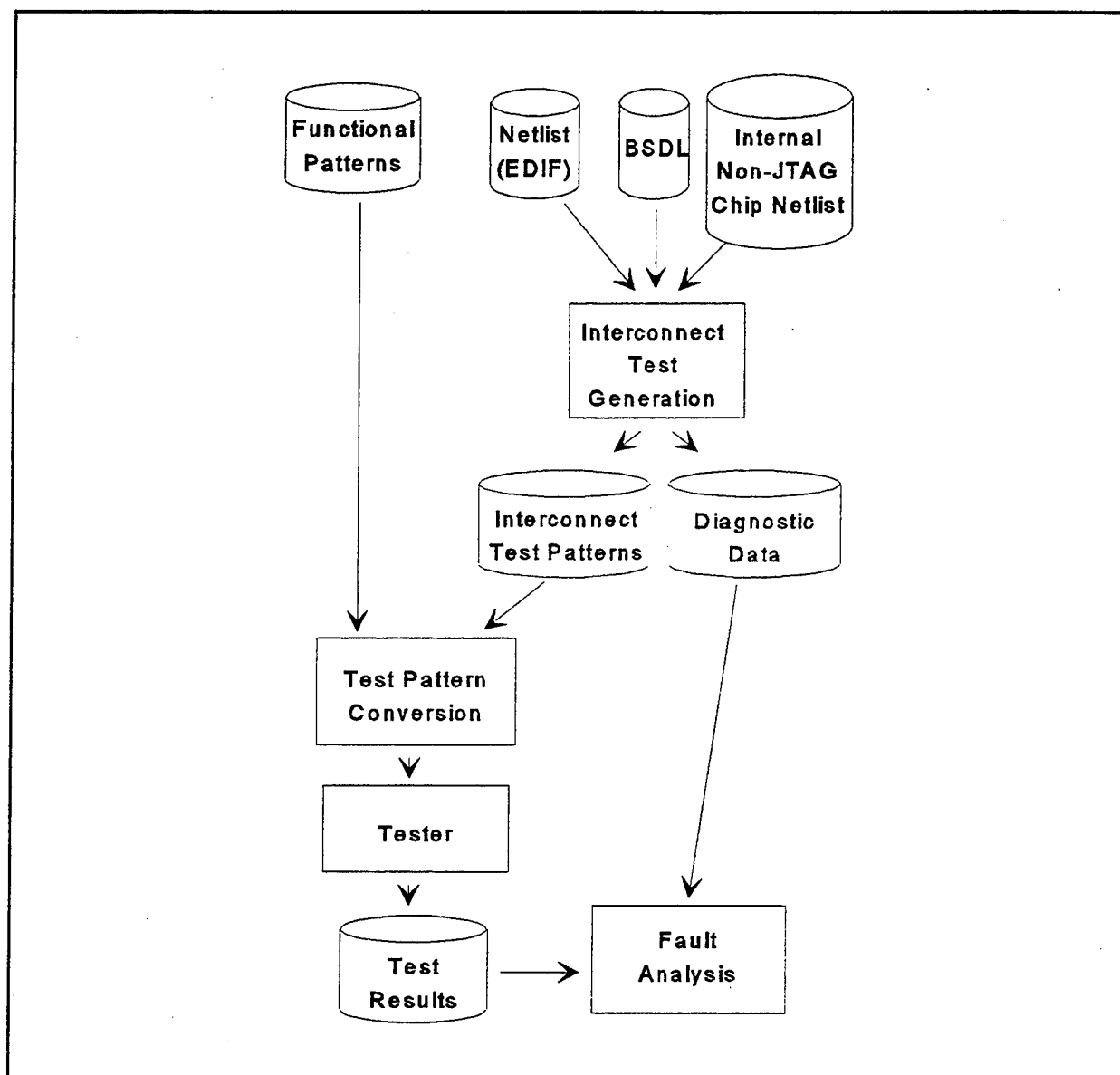


Figure 3-4: Flow for Mixed 1149.1 and Non-1149.1 Die.

Regardless of the objective, however, steps must be taken to ensure that the tester is capable of applying the patterns. These considerations must be accounted for prior to simulation of the patterns. While post processing tools, such as software from Test Systems Strategies Inc (TSSI), are available which tend to take a free-form pattern set and structure it into the cycle-based form necessary for tester application, such efforts are often doomed as they pre-suppose the acceptability of altering the timing of signals without changing the response timing. Instead, the stimuli must be converted into a cycle-based form first, and then the simulation performed. This will ensure that the impact of any timing edge movement can be reflected in the output response.

Even with this pattern structuring, enough variables remain for functional patterns to endanger manufacturing cycle time commitments from the foundry. This then implies that either hardware delivery dates must be left open, or that specific turn-around times be provided for foundry supplied tests only. A preferred alternative, that meets the typical customer's interest in receiving initial hardware as soon as possible for engineering evaluation, while avoiding placing the customer in the production volume manufacturing flow, is to have the customers perform MCM functional test within their own shop. Given today's high yielding MCM processes, it is reasonable to assume that a high percentage of initially delivered MCMs are defect-free and should thus pass correct functional patterns. This permits complete debug of the functional patterns by the customer who has the documentation required for identifying design flaws versus manufacturing defects. Once the patterns are verified as correct by the customer, they can then be transferred to the foundry and applied for production hardware. The key to this strategy is that the customer and the foundry have comparable tester facilities. This can be accomplished either by the foundry usage of advanced general purpose VLSI ATE, or by the sharing of test fixturing via the 'golden module' approach.

3.2.3 Implementation Aspects of Test

There are two key elements to the implementation of this methodology: EDA software support and selection of test equipment.

3.2.3.1 EDA Software Support Elements

Ideally, test generation software should provide the following attributes:

1. Die-level automated 1149.1 compliance verification. This includes checking the logic to ensure that the die hardware correctly implements 1149.1, and also the automatic extraction of a BSDL representation.
2. A single consolidated logic model, reflecting the test strategy that will be applied for each MCM component. Specifically, if the component is 1149.1 compliant, the representation should be BSDL-based. For non-compliant designs, a primitive logic level description would be necessary. RAMs and ROMs should be considered as primitives.
3. The ability to automatically partition the 1149.1 and non-1149.1 representations so that the non-1149.1 clusters can be extracted.
4. An extraction/test generation approach that maximizes complete open/short testing, while reverting to stuck-at fault detection when necessary. This includes consolidating both fault coverage metrics, so that excess patterns are not generated.
5. Support for scan DFT approaches, such as Level Sensitive Scan Design (LSSD), for those components that are non-1149.1. Ideally, scan and 1149.1 could be completely mixable, so that scan-based designs would receive the same level of test coverage as 1149.1 components.
6. Usage of industry standard pattern formats, such as WAVES (IEEE Standard 1029.1), to remove dependencies on specific EDA packages.

3.2.3.2 Test Equipment Implications

Given the aggressive cost targets defined for the ASEM program, extreme care must be taken in selecting the test equipment used during MCM testing. The tester selected will depend primarily on the tests to be applied. In 1149.1-based design environments, low-speed, low-pin count testers can be used, minimizing manufacturing costs. In this environment, 1149.1 devices are added to the test fixture to provide stimuli to the MCM primary I/O. This approach precludes the application of parametric tests, such as input and tri-state

leakage, tests which may be either completely skipped, or applied on other testers. Also precluded is the application of broad-side functional patterns at AC speeds.

The next better test system, given the low pin count requirements of this approach, is the usage of a high-performance, but low pin count tester. In this approach, high speed pin electronics is used to provide a functional at-speed Built-in Self Test (ACBIST), assuming the components have this capability implemented in hardware. As tester cost very much depends on the number of pins, this permits the usage of high-tech equipment at a reasonable cost. In those cases where high speed functional patterns will be applied, and/or manufacturing cycle time is to be minimized, the usage of high-speed general purpose test equipment can more easily be justified. This is especially true for the case in low-volume applications, where the actual tester usage is minimal. Given the broad range of ideal test environments, the ideal foundry would have access to a wide variety of testers, and thus be able to optimize for a specific application.

3.2.3.4 Format Standards

While standards have been defined for the three major sources of input for testing, each has its own special considerations. EDIF 2.0.0 is widely supported for defining netlists and schematics. However, the broad flexibility defined within the standard is rarely completely implemented within a given EDA system. Additionally, its loose structure allows different usage of EDIF elements. The resulting, less than rigorous, interpretations complicate general purpose EDIF capture software. On the other hand, BSDL, as defined by the proposed standard 1149.1B, is well documented.

The difficulty here, independent of the standard itself, is getting reliable BSDL for die. As the BSDL is not a necessary input to die manufacturing test, the die manufacturer has no strong incentive to ensure accuracy. Released BSDL should be verified by generating 1149.1-based tests on each chip in a single-chip (SCM) configuration and then either simulating these tests using the full logic representation by applying the patterns at the tester. The broad support for EDIF and BSDL does not hold true for WAVES. While most of the major EDA suppliers intend to ultimately support the import and export of patterns in this format, the capability does not exist today. Criticism is wide-spread, and often focuses on the difficulty in expressing timing data. In the absence of an industry standard, conversion packages, such as TSSI have become a de facto standard, by providing the ability to go from a variety of EDA systems to a variety of testers. This availability of a viable alternative in turn lessens the incentive for EDA suppliers to invest in WAVES support, further entrenching the alternatives.

3.2.3.5 Data Integrity

A key element in successful transfer and use of data in a multisupplier and multiuser environment is that various elements of the data resources should map on a one-to-one basis and the use of clear and unambiguous naming conventions. In a vertically integrated design environment, these issues are often automatically handled since only one source of design information exists. However, in a distributed design and test environment several sources of information may exist which do not use the same format or naming conventions. It is important at the beginning of the system design phase to put in place a process to ensure that cohesiveness and correctness in the design database is maintained.

3.2.4 Diagnostic Implications

An essential element of providing a low-cost MCM assembly capability is the ability to easily identify which component is defective and rework it. 1149.1-based designs provide superior fault isolation for the interconnect circuitry and die internal logic if BIST is implemented. In most cases, a repair decision is based

upon the cost associated with the repair process versus the cost of the raw materials such as dies and unpopulated substrates. For instance, flip-chip mounted MCMs are significantly more economic to repair than wirebonded or TAB interconnect assembly techniques. An economically viable rework process improves effective manufacturing yields, and reduces product cost. In those cases where the diagnostic procedure is more intensive, such as in the non-1149.1 designs, or for functional test patterns, it becomes more likely that repair will be abandoned, depending on the percentage of MCMs failing this test type and the value of the MCM components.

For prototype MCM development module I/O pins specifically added for test purposes may greatly enhance the test coverage and diagnostic capability through improved observation and control during interconnect or functional test. In many cases additional pins may be added with negligible additional costs. The added pins are particularly useful for MCMs using flip chip bonding because of the reduced visual inspection capability as compared with wirebond methods. However the addition of net branches and extra signal line length will alter the electrical characteristics of the net. Changes in reflection characteristics, crosstalk, and di/dt coupling noise must be incorporated into the system level simulation to ensure proper functioning of the design.

Examples of Design-For-Test practices:

1. Add an observation pin between each device in the 1149.1 scan chain.
2. Scan chain order is important. Select the die with the most module I/O observability for the module TDI.
3. Add module I/O for key control signals. Such as Output Enable for an SRAM memory bank.
4. Use as many module I/O as are available to improve observability.
5. Staged assembly during prototyping to minimize fault possibilities during initial bring up.

3.2.5 Methodology Conclusion

To meet the aggressive ARPA goals of reduced NRE cost and turn around time for low volume MCM development, a module test methodology requires some basic assumptions be made, such as KGD, KGS, good BSDL, good netlists and must provide an appropriate minimum set of tests. In an environment where Known Good Die and Known Good Substrates are available, we believe OEM customers are best served by providing a test set which concentrates on verifying bond and MCM trace continuity. Additional tests are provided only where the test environment is compatible and the design and schedule permit. IEEE Standard 1149.1 provides a highly efficient framework for implementing this test approach.

3.3 INTERCONNECT TEST IMPLEMENTATION

Introduction

The MCM test offering which meets the ARPA NRE cost and turn around time goals exploits the emerging use of the IEEE 1149.1 standard. The 1149.1 methodology provides an efficient and transportable method for accomplishing MCM assembly verification by providing electronic testing of interconnects and bonds. Given an assembly comprised of known good components, the most likely source of failures will be manufacturing defects related to the assembly process. This is an observation which IBM MCM test shares with board manufacturers and provides justification for the effort spent on fault isolation associated with assembly verification test (often referred to as Interconnect Test). The assembly verification test is analogous to that used by circuit board manufacturers after board assembly and before system functional test and includes reliance on the use of Known Good Die (KGD) in the MCM or in a card assembly to ensure high first pass yields. High first pass yields also require the MCM substrate to be a "Known Good Substrate" (KGS) and that the design and simulation tools be properly adapted to the material system characteristics. Physically, interconnect testing is performed using a 1149.1 based flexible fixturing scheme which enables reduced turn around time and reduced costs through ATPG and reuse of fixture components. An added benefit of the 1149.1 testability standard is that it provides the means to initiate an electronic structural test of die through the use of 1149.1 accessed Built In Self Test (BIST).

Interconnect Test Overview

The test process begins with early involvement with the customer concerning the manufacturability and testability of the design. A preliminary evaluation of the first pass yield of the module is estimated based on customer supplied MCM design and die yield data. The data considered should include test/yield information for each Design For Test (DFT) feature, at both the die and module level, the module signal architecture, and signal/power specifications. Designs which include some 1149.1 die or are 100% populated with 1149.1 die generally fit the criteria for low cost assembly verification. Given a design which fits the low cost interconnect test process, detailed information requirements are requested from the customer. The information requested comprises a subset of the total module or system design information and includes device interface descriptions, Boundary Scan Description Language (BSDL) for 1149.1 compliant die, module I/O data and process information.

Test patterns for the module are obtained using Automatic Test Pattern Generation (ATPG) and include all nets terminated in at least two 1149.1 boundary cells. ATPG is accomplished using Teradynes' Victory™ software package and the test patterns are output as a Serial Vector Format (SVF) test file. Fault types addressed by ATPG are single stuck-at fault models such as stuck driver or shorted/open nets. ATPG coverage includes MCM I/O since we include a 1149.1 based test fixture in the ATPG database. Coverage is extended to nets terminated by non-1149.1 devices using manually generated patterns which are applied to the device(s) or interconnects under test using 1149.1 test resources. A Victory software tool, VCCT, is used to serialize manually generated test patterns and output an SVF test data file for use by the test equipment. Interconnect test coverage, assuming a single stuck at fault model, can approach 100% for designs with sufficient boundary scan die and/or appropriately designed test vectors.

The MCM is bond and interconnect tested a number of times during the prototype bond and assembly process in order to assure that assembly, capping and handling do not introduce defects into the product and are not passed on as a defective assembly to the customer. The most critical juncture in minimizing test turn around

time is the first pass at newly assembled MCM part numbers. A problem with either the test information database or test generation process can introduce unacceptable delays into the MCM build schedule. These potential delays can be minimized by generating and applying tests to a prototype printed circuit board (PCB) version of the to-be-built MCM during the MCM build cycle. Prototype PCB (or brassboard) testing can identify design errors as well as database errors such as incorrect BSDL description. The use of Brassboard design verification by the system designer is strongly recommended before undertaking MCM prototyping.

Known Good Die Overview

Known Good Die (KGD) play an important role in providing a known die quality value for reducing the complexity and cost of module level testing and diagnostics. The widely accepted definition of KGD states that the die should be of similar quality to that of a single chip packaged part. This means the die should perform at-speed and within the published specifications. Many die suppliers are currently gearing up to provide KGD through the use of Temporary Chip Attach (TCA) methods or through the use of more sophisticated wafer level testing. At the present time however, few die suppliers offer a competitively priced selection of KGD. Instead, what suppliers offer is a *not* at-speed functional wafer level test, combined with a Lot Acceptance Test (LAT.) The LAT is performed by packaging samples of die from each wafer and running these parts through the normal packaged part test program. The fallout information from this test is used to predict the actual fail rate expected from the bare die when they are run at-speed.

At IBM we currently support TCA packaging for C4 die. The TCA substrate uses a metalized ceramic or multi layer ceramic carrier in combination with palladium dendrite land pads for the die I/O bumps. Die are compressively held in place by a sprung plate assembly which is an integral part of the heat sink assembly. The TCA module is designed to be similar to the footprint and electrical characteristics of packaged parts using the same die. The package similarity allows the TCA module to be inserted into the die suppliers test process flow with a minimum of process development or cost. Alternatively if test vectors are available (not often the case) the TCA module can be tested on in-house Automatic Test Equipment (ATE.) A third process, which inserts the TCA module temporarily into the prototype printed circuit board for a system level functional test, is also possible but carries a higher risk from the diagnostic point-of-view and is not well suited for volume production. The advantages provided by the prototype PCB system functional test are that it provides an alternative if a complete ATE test is not possible. However, this approach carries a higher risk from the diagnostic point-of-view because the system test patterns, which are typically used, are not designed for fault isolation.

The following sections of the report will expand on the various elements of the test methodology which we have implemented. A discussion of the requirements for our ATPG software platform and the selection criteria for the ATPG software will be followed by a brief description of the MCM fixturing scheme we have implemented to reduce the cost and improve the Turn-Around-Time (TAT) of our assembly verification process. Following this, the elements of the test database which we require and how we generate test vectors for the MCM will be described. Next, the test process itself is described and includes the rationale for using the customers prototype PCB as part of the test debug process. The section will conclude with a description of our benchmark process and present benchmark test cost and TAT data.

3.3.1 Software Platform

The software requirements for implementation of a 1149.1 assembly verification test are that; the software should be able to check syntax, read and parse Boundary Scan Description Language (BSDL) files, integrate

these files with an MCM netlist, provide ATPG and produce a machine independent test vector file. Additionally, the software should support application of alternate source test vectors by providing appropriate serialization and test vector files for use by 1149.1 MCM and tester resources. Another requirement concerns support of the software over time by the software manufacturer. The desired software support would provide long term software maintenance with an apparent resource base (i.e.: well established support) to support revision engineering and distribution. Finally, the software manufacturer should have in place a plan detailing future enhancements to the software and a plan for future growth of their product in the test marketplace.

While there are several suppliers of 1149.1 test generation tools, only one was found to meet our selection and requirement criteria. The tool we selected is marketed by Teradyne and is called "Victory." This tool provides all of the previously mentioned features. It also provides several additional support features such as EDIF NETLIST input. **Figure 3-5** illustrates the basic environment and functions of the Victory tool. Teradyne has both experience in the test arena and has a significant infrastructure which helps to support the ongoing development and deployment of the Victory product across Teradyne and other test equipment hardware platforms. Notably Texas Instruments uses the Victory ATPG function in it's "ASSET"TM benchtop test system. Additionally, Teradyne has worked with several electronic test development vendors to develop a tester independent output file specification. The test data file specification is called Serial Vector Format (SVF) and provides a straightforward means of transferring Victory generated test data output to non-Teradyne test equipment.

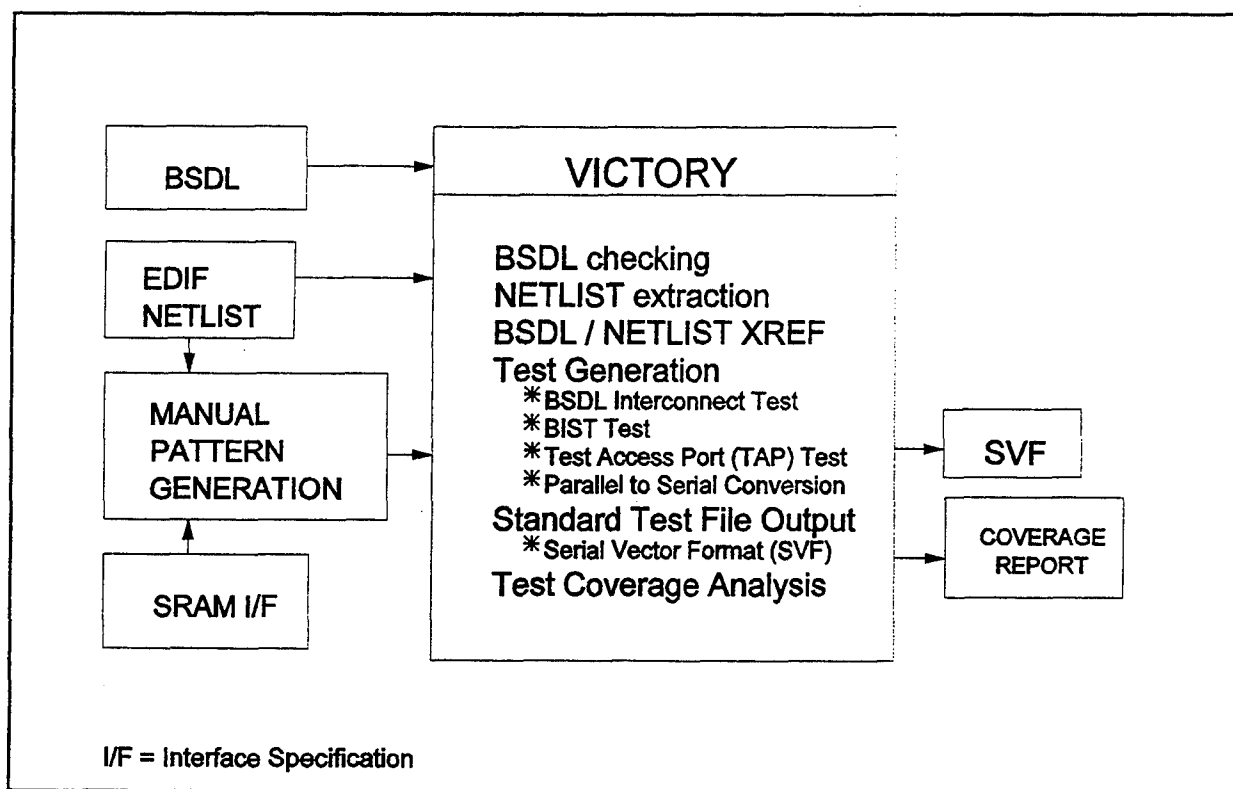


Figure 3-5: Automatic Test Pattern Generation (ATPG) for Interconnect Test

3.3.2 Flexible Fixturing Hardware

In order to reduce the NRE cost and TAT associated with providing fixturing and thermal management for uncapped MCMs a semi-standardized fixturing scheme has been implemented. Referring to Figure 3-6, the main components of the setup are a bank of IEEE 1149.1 based devices which provide drive and observe to the MCM I/O, a signal and power redistribution daughter card, a pneumatic Zero Insertion Force (ZIF) socket and dry nitrogen impingement cooling. SVF test data is translated on a PC and is supplied to the 1149.1 test electronics through our interconnect test system.

Savings in fixture cost and TAT are realized because only a relatively simple printed circuit daughter card needs to be fabricated for each new MCM part number. The card redistributes wiring from the tester and power supplies to the appropriate ZIF connector pin. Switching between different product fixtures requires that only the daughter card be swapped, cables reconnected and the back side of the double sided ZIF socket engaged. The information required for fixturing a specific MCM comes from the test database and includes netlist, module level connector, physical/electrical schematics and thermal information.

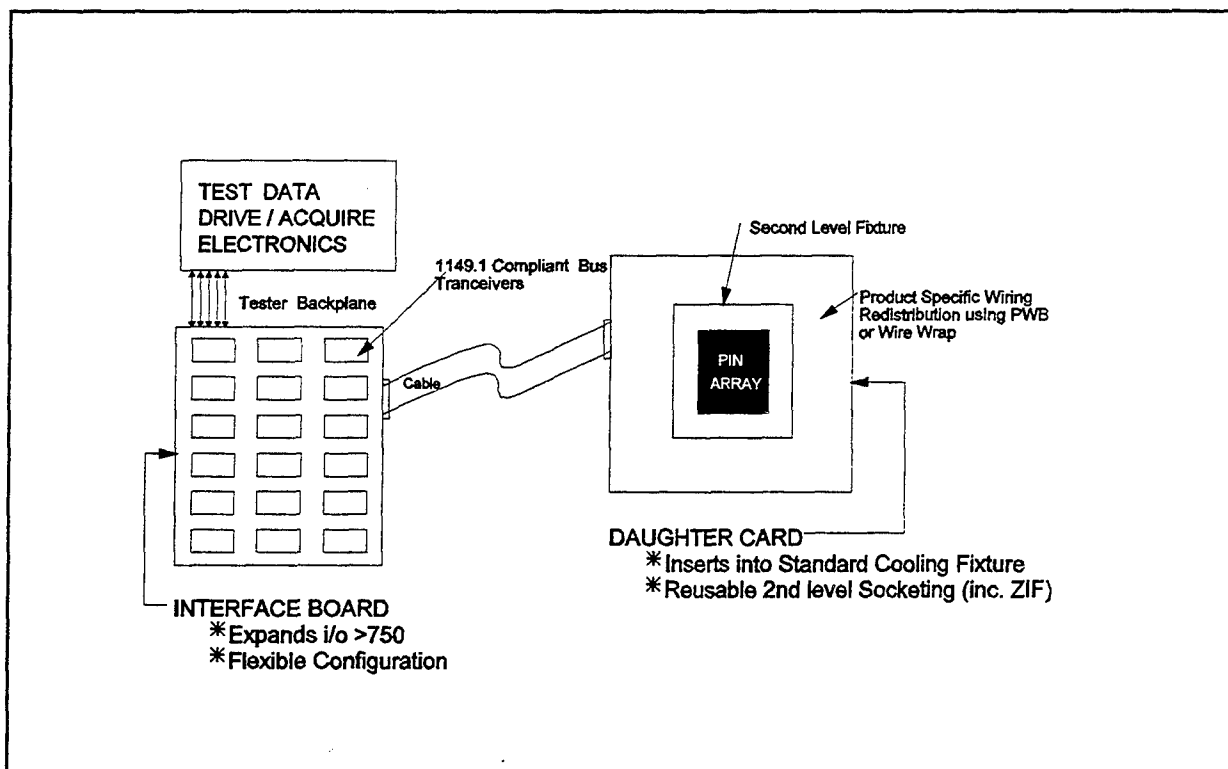


Figure 3-6: MCM Interconnect Test System

Thermal management for uncapped MCMs is provided by dry nitrogen impingement cooling. The test fixture has a doorlike cover which contains a standard sized gas distribution gallery. The gallery cover plate closest to the MCM under test consists of a plate with tubular orifices which, when the door is closed, directs the nitrogen flow directly onto the chips requiring cooling. The readily replaceable cover plate is simple in

design, and inexpensive to fabricate, thus reducing the cost and TAT associated with thermal management during uncapped testing of MCMs.

3.3.3 Database

The information required for testing MCMs covers most aspects of the design. Test database information needed for a module comes from several sources. Typically the OEM customer will provide design specification and die descriptions and the substrate foundry will provide physical dimension information for the substrate, MCM I/O, cap and heatsink. **Figure 3-7** lists the major elements of the test information database required to perform interconnect assembly verification test. An example of a more detailed

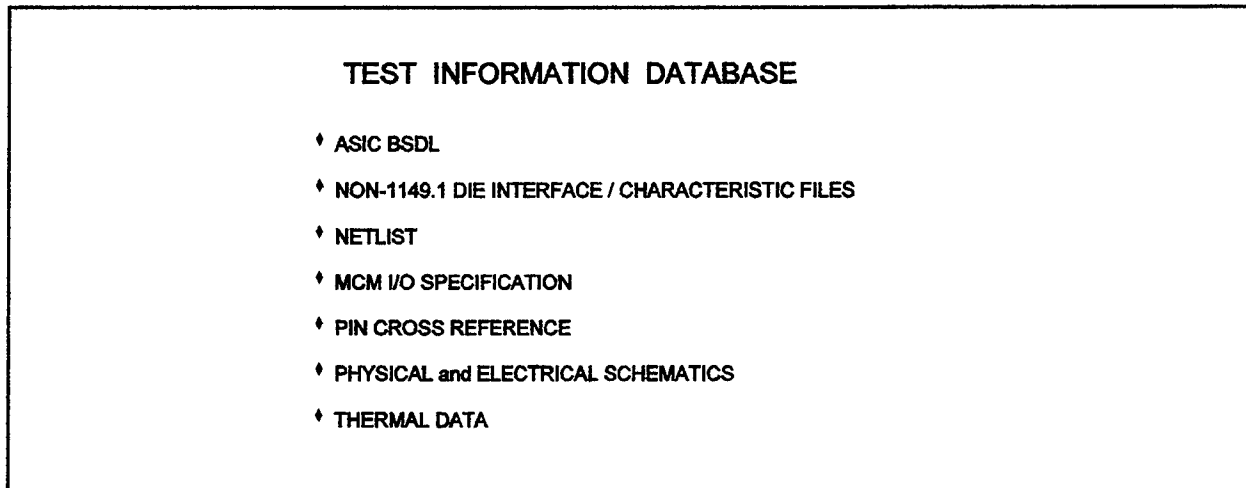


Figure 3-7: Test Information Database

worksheet is provided in **Figure 3-17** in **Section 3.5, Data Integrity**. Functional test on ATE or system level test is handled on a case-by-case basis. **Figure 3-8** illustrates the general flow of test data and where in the process data conversion and vector generation occurs for interconnect and functional test.

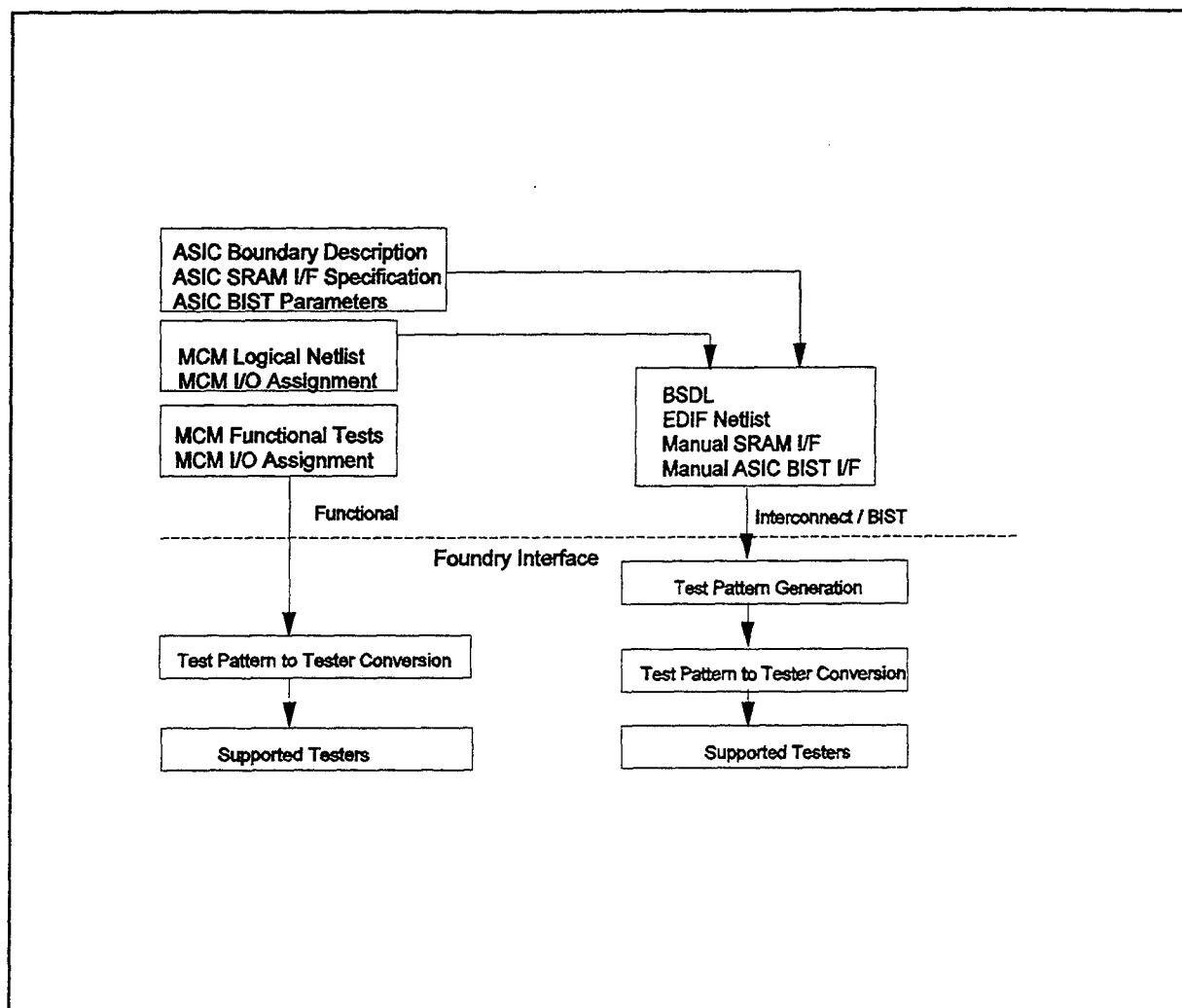


Figure 3-8: Test Generation Process

3.3.4 Test Vector Generation

The inputs to the ATPG portion of the test vector generation software consist of device BSDL, netlist, scan path definitions, non-1149.1 device characteristic models and nomenclature translation tables. Given correct database information the ATPG portion of the test can be generated in a very short time (<1hr.) If construction of characteristic model files is performed manually, the task can often be performed using device specification data sheets within one day. However, if the information database contains conflicting nomenclature or the BSDL files have unresolved conflicts in their internal descriptions and/or missing BARE_DIE pin name descriptions, the resolution of naming issues can be time consuming.

The Victory ATPG software provides three distinct sets of vectors. Each vector consists of drive data, driver enable data, expect data and mask (care/don't care) data. The expect data is an appropriate response vector, for each vector generated, which is used with the mask data to allow comparison with the observed response. The first set of two vectors is a stuck driver pattern where all drivers are set to the same value followed on the

next cycle by their complement. The second set of vectors enables drivers on the opposite ends of the nets from the stuck driver vector set and is also set up as a stuck driver test. The number of vectors in this set is governed by the net with the greatest total number of individually controllable drivers (D) and is equal to $2*D-2$ (* = multiplication). The third set of vectors is a counting pattern and its complement. The counting pattern vector, which is a minimum number vector set, guarantees that every net will be at an opposite state to every other net at some time within the vector set. This guarantee provides the ability to detect and diagnose any single net-to-net short or detect any multiple net shorts. The number of vectors in the set is governed by the number of testable nets (N) and is equal to $2*\log(N+2)$. Further information about the test vector sets and the significance and format of the various tools can be found in literature and training manuals available from Teradyne.

Manual test pattern generation is performed using product data sheets, module netlist and 1149.1 device models. The patterns are crafted using appropriate vector types, as described in Section 6.3.2.7 ADV1 Test, and appropriate timing and control signal levels as described in the device data sheets. The patterns applied are specifically developed to stimulate an interconnect fault type and capture a result which allows as specific a diagnosis as possible. Often, as in the case of memory devices, the control signals are not directly observable so opens or shorts faults on these lines must be inferred from the read write behavior of the device. The test patterns are written in a Victory specific parallel vector format. The format relates the parallel vector format file to the netlist and topology files and generates intermediate mapping files which map the non-1149.1 test nodes to 1149.1 drive/receive resources. The final step, also performed by Victory, serializes the data into a machine independent SVF test vector file. The serialization process may also be used on any cycle based parallel vector set which meets the drive/receive capability available through 1149.1 based and/or other controllable tester resources.

3.3.5 Test Database Verification

Database verification plays an important role in meeting our short turn around time commitments in the OEM market. Figure 3-9 illustrates the process flow incorporating the prototype PCB test verification procedure. As the figure illustrates, MCM hardware is not available until near the end of the build and delivery schedule. Debugging incorrect test data and/or hardware can take considerable time and effort and usually cannot be reliably accomplished in a 1-2 week time frame. The use of the prototype board, even if it is not exactly the same as the MCM design, allows debugging and verification of BSDL, netlist and nomenclature issues, characteristic device models, test patterns, power and initialization turn-on and turn-off procedures. If all database information is correct, database verification can be accomplished in short order (<2-3 days.) Manually generated test patterns can also be verified if the prototype board uses the same netlist as the MCM. Otherwise, the data used for manual pattern generation can still be verified for syntax and nomenclature. The time required for this activity is dependent on the complexity of the test patterns which must be developed. Non-1149.1 based machine generated test patterns supplied by the customer can also be verified using this procedure. However, failures which may occur are often difficult to diagnose.

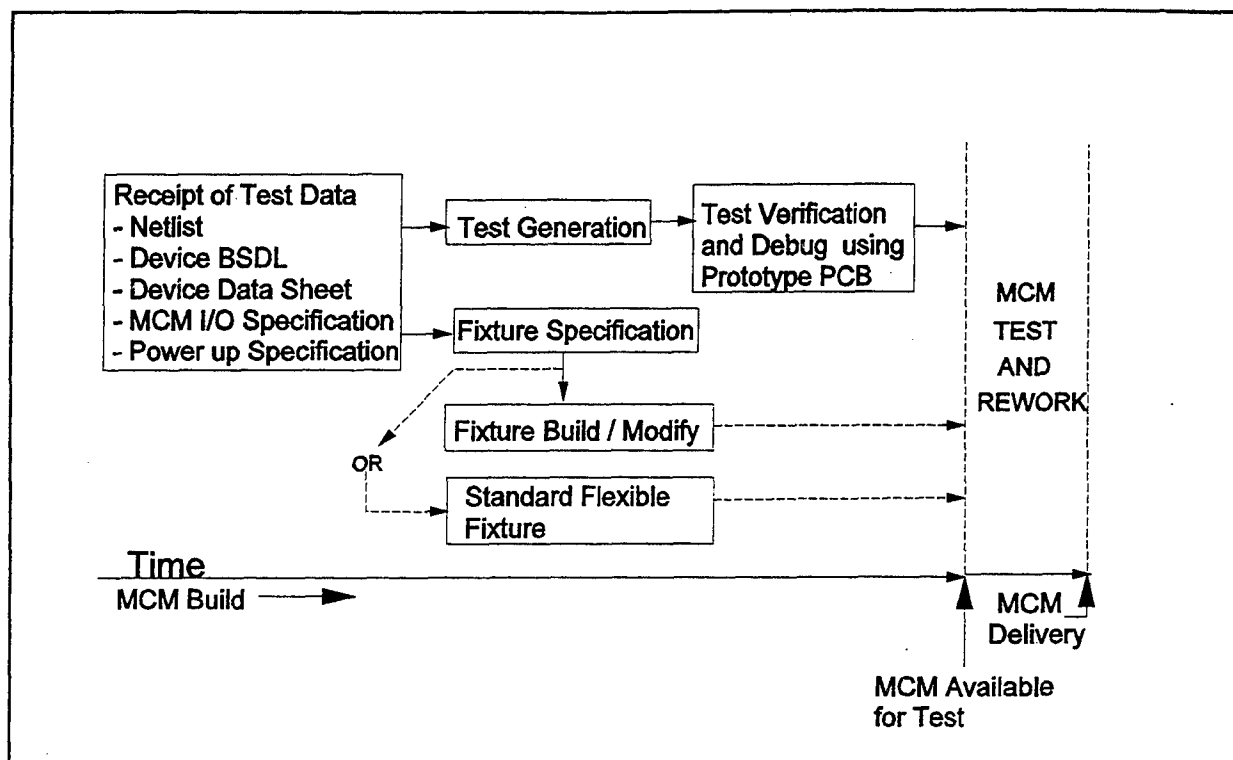


Figure 3-9: Interconnect Test Assembly Verification, 1149.1 Based

An additional use for the prototype PCB is as a functional screen for TCA modules destined for use in the MCM. If a true KGD is not available, the use of the prototype PCB, modified with ZIF sockets to accept the TCA module, may be justified depending on prototype MCM yield management data. As with test vectors generated by a remote design system, functional screening code should be tightly organized and documented in order to maximize the diagnostic utility of the screening procedure.

We also find that BSDL data can be verified by testing a single chip module. The single chip module is socketed (at different times), in two separate ZIF sockets. The first socket is used to check the scan chain length, Test Access Port (TAP) and all bidirectional driver receiver pairs. Since the input side of a bidirectional port is wired internally to its associated output, the drive and receive capability of the ports may be readily determined. The second socket provides pin-to-pin connections between appropriate signals on the device under test by 'wrapping' drivers to receivers. Using the pin-to-pin netlist for the second socket (the "wrap" fixture), the ATPG tool is used to generate a test of all interconnected leads. This test provides verification of driver/input BSDL descriptions for all types of ports when combined with the results of the test using the first socket.

3.3.6 Interconnect Test

Once assembled MCM hardware is received, the MCM specific load board fixture is mounted to the thermal management fixture and tester. The first step in the test process is a parametric characterization of power and ground planes for proper resistance values. ESD diode characterization may also be performed to check for MCM lead-to-die signal I/O continuity. Once the MCM is socketed and cooling gas flow is established,

module power is applied along with any necessary signal preconditioning and then a check for in-limit current draw is performed.

The next step involves application of a Test Access Port Integrity Test (TAPIT). The TAPIT verifies scan chain connectivity from TDI to TDO, test clock and TMS distribution, die ID code (if implemented), bypass registers and functionality of the 1149.1 device(s) instruction registers. The TAPIT test is followed by the interconnect test proper and application of any non-1149.1 test patterns. Comparison failures in any of these tests generates a test data failure file which is used for diagnostics. Diagnostic analysis returns a repair order specifying which die must be reworked. After die rework the MCM is retested.

Once the MCM passes interconnect test, it is returned to assembly for capping and heatsink attachment. On return from capping, the MCM is again tested for interconnection integrity to ensure shipment of a known good module to the customer. The second MCM retest can be eliminated in volume manufacturing if capping induced defects are demonstrated to be insignificant.

3.3.7 Test Implementation Conclusion

The implementation of the interconnect test has been successfully accomplished and is demonstrated in the case studies in Section 3.6. The 1149.1 based test methodology has a key dependency which is a reliance on industry wide support and adoption of the 1149.1 standard. Once the 1149.1 standard becomes more widely used, as seems to be happening, costs associated with debugging incorrect or incomplete BSDL descriptions should be reduced thus reducing NRE costs. Summary of the key features and how they are implemented are listed below.

Features	Implementation
• Automatic Test File Generation	Teradyne's Victory Platform
• Ease of fixturing constraint	Flexible and standardized electrical and thermal fixtures
• Eliminate Data Integrity concerns	Rigorous and standardized test plan, customer interface and data verification using brassboard prototype and single chip module testing
• Known Good Die	Temporary Chip Attach implementation
• Improved diagnostics and test coverage	Added probe points, Manual test pattern generation

3.4 KNOWN GOOD DIE (KGD)

3.4.1 Introduction

One of the major obstacles the MCM industry faces today is lack of technology and infrastructure to support a low cost KGD process. Lack of KGD impacts MCM yields, which must therefore rely on a more costly rework process to produce a Known Good Module (KGM). Unknown die quality also introduces added complexity in module testing and the diagnostics process which leads to unanticipated higher costs for a completed module. KGD is one of the most discussed topics in MCM community today because of its key role in enabling a manufacturable MCM [10-12,23-25].

For the ASEM application, ADV1 (SUN MBUS Super Cache) MCM, the die set (two logic and eight SRAM dies) were originally designed and fabricated for wirebond applications. The die were all converted to a C4 type interconnection. Because of the complexity of the two logic chips (processor and cache control), uncertainty associated with the C4 conversion process and unknown die quality, a decision was made to use a KGD process for all the die used for ADV1.

3.4.2 Parameters for KGD Implementation

The KGD process consists of three major parts which must be considered concurrently:

- (1) Design and fabricate Temporary Chip Attach (TCA) modules
- (2) Chip attach/detach processing
- (3) Chip testing

Since the test vectors for the two logic chips were not available, the decision was made to use either Suns ASIC tester or the Sparc 10 system box from Sun for at-speed functional test of the large Super Sparc and MXCC ASICs. The SRAMs would use an IBM developed memory tester for an at-speed functional test.

Once the test hardware was determined, the next step was to focus on designing the ceramic Pin Grid Array (PGA) for the TCA module. The design of the ceramic TCA carrier for the large ASICs was chosen to closely match the physical parameters of the existing commercially available SCM packages. Key items of similarity were the X,Y and Z dimensions, pin length, pin diameter and pin layout which allowed the TCA module to be plug compatible with their commercial counterparts. The design input data was a hard copy of signal-to-pin connections provided by Sun. Because we did not have a verified soft copy of the netlist for the ASIC SCMs, a substantial amount of time was consumed manually checking the cross reference for pin assignments, pin locations, die pad locations and die pad assignments. Electrical analysis was performed to ensure that the packaged chips would function at the intended system speed (50 Mhz).

IBM Microelectronics Division has developed two processes for C4 chip KGD applications.[25] The Reduced Radius Removal (R3) process has been used as the manufacturing KGD process for internal KGD product fabrication. The second IBM developed KGD process provides a mechanical connection between the die C4 and Palladium dendrites plated on the pads of a Multilayer Ceramic (MLC) or Metalized Ceramic (MC) substrate. The integral heatsink/pressure plate ensures intimate C4/dendrite contact during chip burn-in and test. The chip clamping fixture has an insert sized to match the backside area of the chip, as shown in Figure 3-10 and is designed to exert a controlled vertical force on the back side of the chip. The vertical force used to hold the C4 ball and dendrite pads together is proportional to the torque applied to the top subassembly center screw. The heat sink, which extracts heat from the back of the die, will dissipate 27 watts

of power at an air flow of 400 lfp/m at 30 degrees C. The dendrite KGD process handles chips with higher power than the R3 KGD carrier.

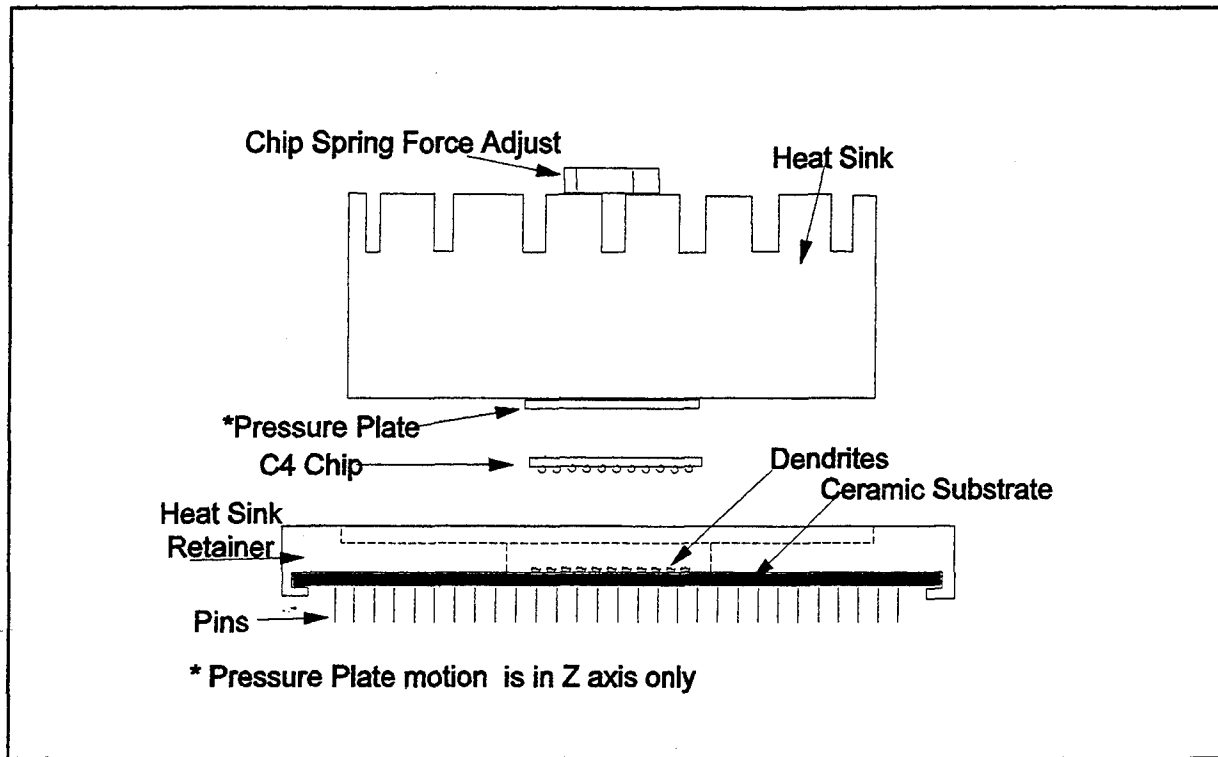


Figure 3-10: Temporary Chip Attach Single Chip Module (TCASCM)

Because of the relatively high power dissipated by the two logic dies (~10 watts) on the ADV1 MCM and considering that the original Sun SCM uses an efficient heat slug and pagoda heatsink, we determined that a heatsink had to be used during the chip test. Therefore the dendrite TCA process was selected for our application.

Once the decision was made to use the dendrite TCA process for the large ASICs, we decided to also use the process for the SRAMs. The TCA carriers for the two logic chips were designed using standard 50mm Multi Layer Ceramic (MLC) technology. The TCA carrier for the SRAMs was designed using standard 28mm Metallized Ceramic (MC) technology. A process flow [25] for KGD temporary chip attach is shown in Figure 3-11. Figures 3-12 and 3-13 give the schematics of substrate layout and list key parameters for the two logic TCA. A comparison between the commercially available SCM packages for the Super Sparc and MXCC and their TCA counterparts is presented in Tables 3-1 and 3-2.

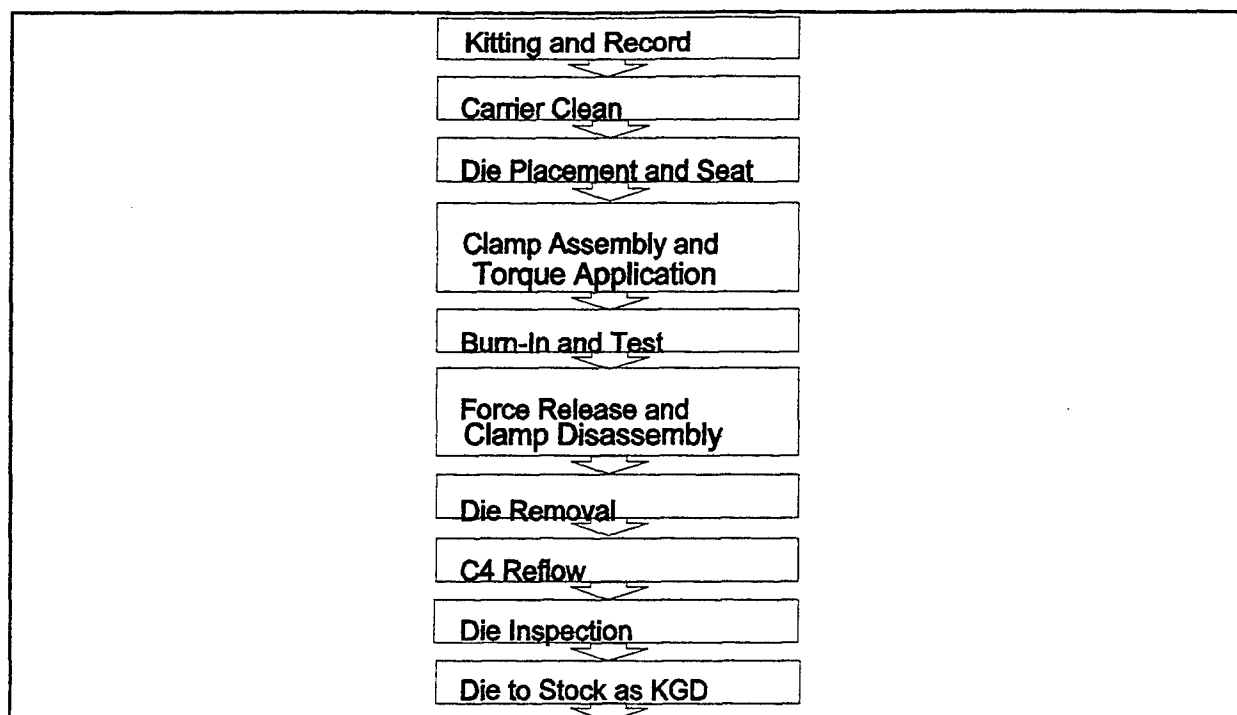


Figure 3-11: Temporary Chip Attach (TCA) Process Flow

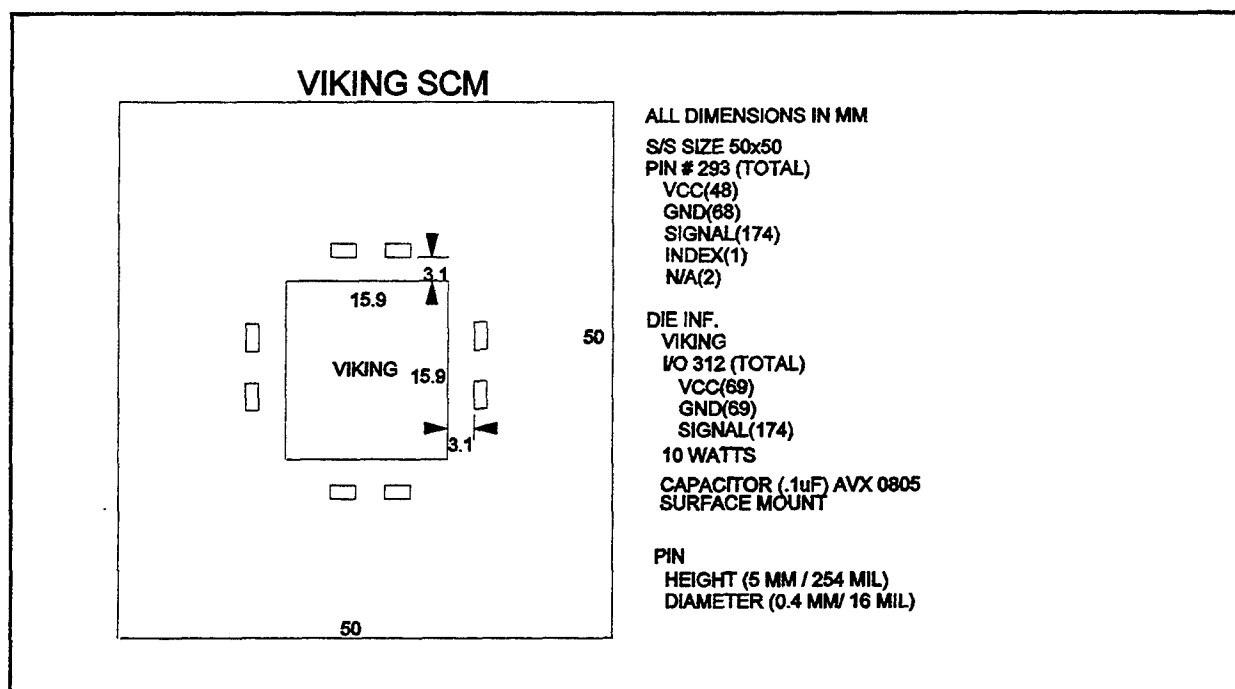


Figure 3-12: Viking (Super Sparc) TCA Single Chip Module Layout

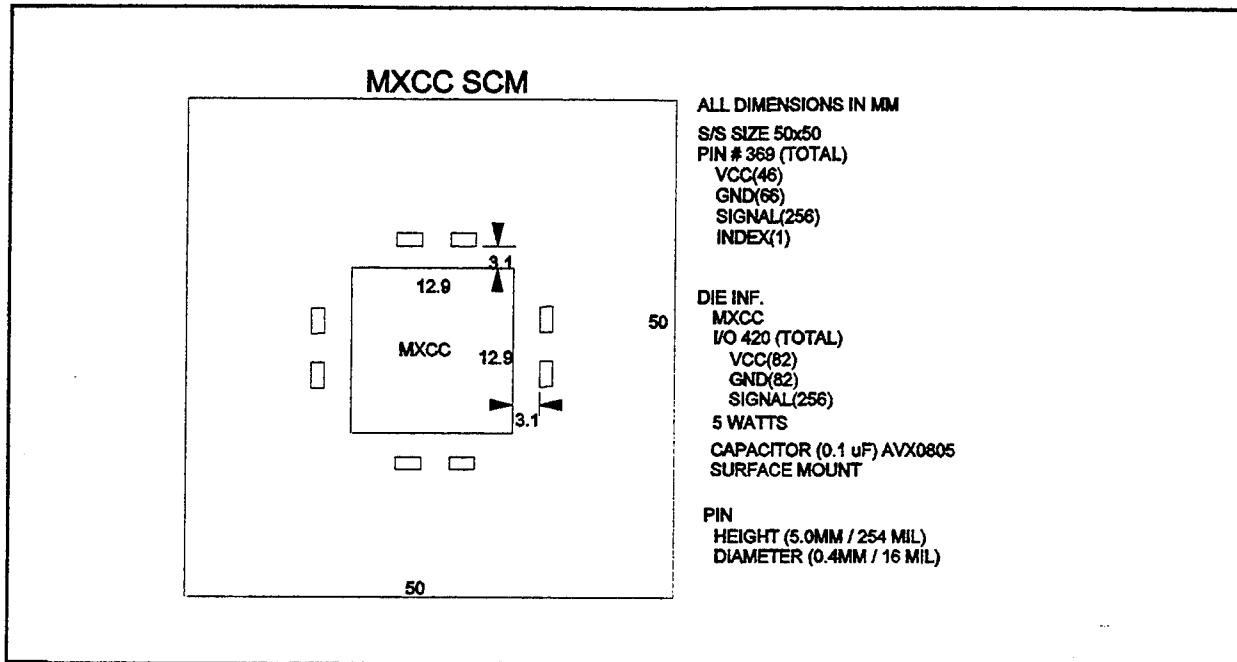


Figure 3-13: MXCC (Cache Controller) TCA Single Chip Module Layout

	SUN SCM	ASEM SCM
*S/S SIZE (MM)	47.24 +/- .45	50
PIN PATTERN	18x18 + 17x17	18x18 + 17x17
PIN-TO-PIN PITCH (MIL)	100 INTERSTITIAL	100 INTERSTITIAL
PIN DIA. (MIL)	16	16
*PIN HEIGHT (MIL)	133(180 - 47)	204(254 - 50)
TOTAL PIN #	293	293
VCC	48	48
GND	68	68
SIGNAL	174	174
N/A	2	2
INDEX	1	1
	CAVITY DOWN	NO CAVITY
*S/S THICKNESS (MIL)	90	77 (7.7X10)
* CAP	COPPER BLOCK	ALUMINUM
* HEAT-SINK	PAGODA/STUD	FINNED
* NOT THE SAME		

Table 3-1: Viking (Super Sparc) SCM Package Comparison

	SUN SCM	ASEM SCM
* S/S SIZE (MM)	47.24 +/- .45	50
PIN PATTERN	18x18 + 17x17	18x18 +17x17
PIN-TO-PIN PITCH (MIL)	100 INTERSTITIAL	100 INTERSTITIAL
PIN DIA. (MIL)	16	16
* PIN HEIGHT (MIL)	133(180 - 47)	204(254-50)
TOTAL PIN #	369	369
VCC	46	46
GND	66	66
SIGNAL	256	256
N/A	0	0
INDEX	1	1
	CAVITY DOWN	NO CAVITY
* S/S THICKNESS (MIL)	90	77 (7.7X10)
* CAP	COPPER BLOCK	ALUMINUM
* HEAT-SINK	PAGODA/STUD	FINNED

* NOT THE SAME

Table 3-2: MXCC (Cache Controller) SCM Package Comparison

3.4.3 KGD Test and Conclusion

SRAM mounted on TCA carriers were tested using an IBM developed memory tester. Standard memory test patterns were successfully exercised at speed (20ns cycle.) However, the two logic die were tested in two parts.

1. Test the chip to substrate interconnect and associated circuit functions such as the 1149.1 port, scan path, and driver/receiver functionality using the device BSDL, netlist and Texas Instrument's ASSET scan test tool. The TCA modules were inserted in a special Low Insertion Force (LIF) socket which matches the existing SUN SCM packages. The LIF sockets and the test itself were baseline tested using commercially available SUN SCM for the Viking processor and MXCC cache controller die.
2. Functionally screen the TCA die using MBUS circuit cards modified with LIF sockets which accept the TCA modules. The MBUS cards with the TCA modules are tested using the power on self test of the Sparc 10 system in which they are embedded. The MBUS cards were baselined as being good using commercially available SCM parts.

Known good commercially available SCMs for the Viking and MXCC part numbers were used to debug the test process (hardware and data.) Since chip test was not performed after C4 bumping, the KGD test process

represented the only means for achieving the KGD objective prior to the module interconnect test. Defective die were sorted out and discarded before mounting to the MCM substrate. The combination of verified BSDL descriptions and die screening greatly reduced the uncertainty of the module test environment and simplified module test diagnostics. The KGD test reaffirmed the importance of the KGD assumption put forth in the module interconnect test methodology.

3.5 DATA INTEGRITY

Introduction

In addition to Design For Test (DFT) features it is equally necessary to have complete and correct information for test engineers to generate test files and design test hardware. Acquisition and maintenance of an error free MCM data base environment is a challenging task. The MCM database contains chip, substrate and module information comprised of various physical, electrical and thermal characteristics obtained from several sources, both internal and external to the foundry. In Section 3.5.1, we will describe today's MCM infrastructure and show examples of why it is difficult to achieve a defect free data environment. How we have dealt with these problems will also be discussed. We will also show that the additional costs incurred in working through data integrity problems can significantly impact both NRE costs and TAT. Finally we will present suggestions which may enable an error free test data environment.

Data integrity problems [28] may stem from many sources including missing or incomplete hardware descriptions, incorrect hardware descriptions and/or nomenclature mismatches. The impact of data integrity on TAT is illustrated in Figure 3-14. Time (and labor) added to test file generation and test debug due to bad data contribute significantly to higher NRE cost and longer TAT. The figure compares the TAT for our past practice with two applications we tested using the 1149.1 methodology. Each of the applications used mixed non-1149.1 and 1149.1 die on the MCM and as such was not expected to compare exactly with the 100% 1149.1 goals. Each case required manual test pattern generation which helps to account for the amount of time spent for Test File Generation (TFG) and debug. However, because of data integrity issues, only one of the applications met its projected TAT goal. The goals for each area are detailed in the Test Implementation section of this report.

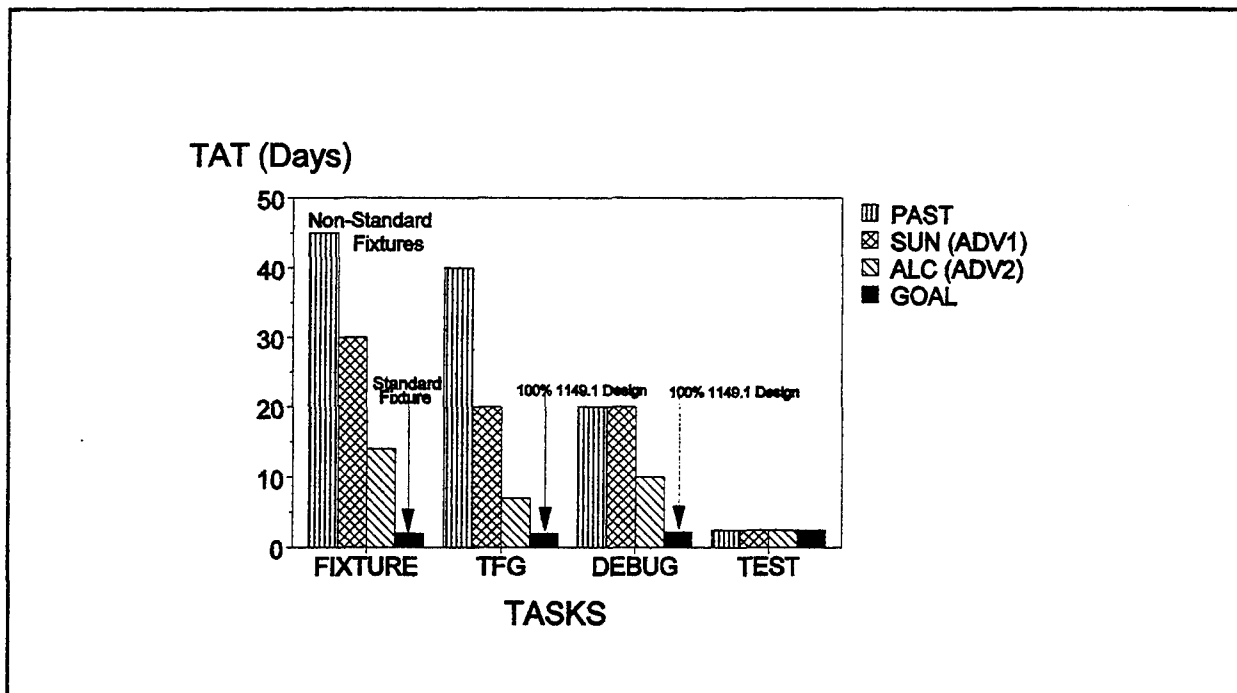


Figure 3-14: Estimates of Time Spent on Test Tasks (Past, Actuals, and Goal)

For convenience, we divide the data integrity issue into two forms. The first is associated with data; such as incomplete data, data which contains errors or unverified data. The second form is associated with the quality of components such as KGD and other hardware quality issues. Since the KGD issue has been discussed elsewhere [9-11,23-25], we will focus discussion on data problems related to device hardware descriptions rather than hardware quality specification issues.

3.5.1 MCM Environment

Examining the module test process flow in Figure 3-15, one will realize that the complexity of module test environment is caused by the fact that MCM foundry deals with three different kinds of products (chip, substrate and system.) In acquiring data, the foundry interfaces with two other types of foundries and also receives data from possibly three different product design (EDA) systems. In this environment the MCM foundry owns or controls only the substrate design, electrical parameters, fabrication and test, and module thermal design. Typically die, module and system design are not directly controlled or even connected to the MCM foundry. In addition, one MCM may contain several different types of die, which are designed using different design systems and are fabricated by different die foundries. Furthermore, die manufacturers are in general reluctant to release die design information or to change their data structures and interface protocols for economic or legal reasons. Also contributing to the complexity of the data base environment is the diverse skill base including electronic and substrate designers, thermal engineering, assembly engineering, test engineering, etc.. Efficient coordination of effort and information exchange between these groups requires the practice of concurrent engineering.

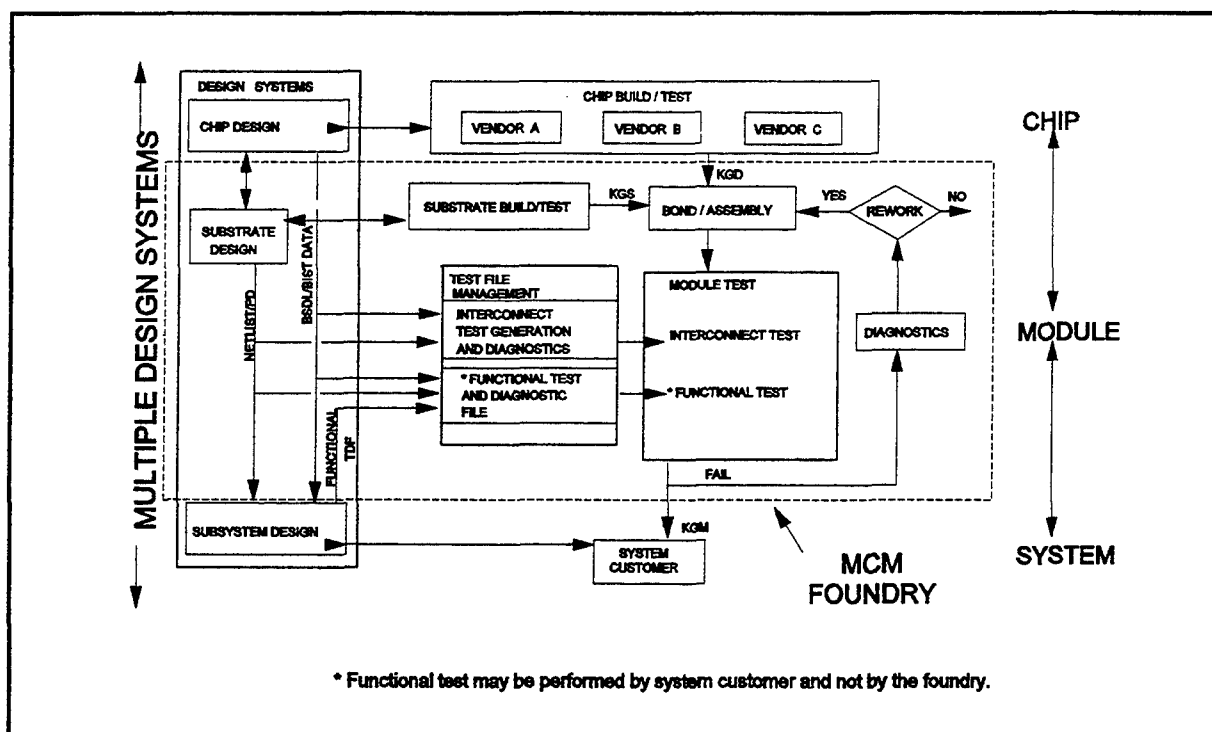


Figure 3-15: Module Test Environment

Data integrity Problems we have experienced can be classified into three categories. (1) Inconsistent data, (2) incomplete data, and (3) incorrect data. Examples of the commonly occurring problems are listed in Table 3-3.

- (I) Inconsistent data:
 - (a) Electrical (logic) and physical data do not match
 - (b) Substrate, die signal and pin (pad) nomenclature do not match
 - (c) Substrate schematics and netlist do not match
- (II) Incomplete data
 - (a) Detailed thermal data for testing environment missing
 - (b) Electrical data (such as chip grounding) for testing environment missing
 - (c) System Power-up procedure for test not completely defined
 - (d) Chip Interface information missing (parametrics)
 - (e) Chip BSDL information not complete
- (III) Incorrect data
 - (a) Chip BSDL data incorrect and/or not verified
 - (b) Power-up procedure incorrect
 - (c) Versions of BSDL do not match chip hardware

Table 3-3: Classification of Data Integrity Problems

Discussion

As previously discussed, most of the data integrity problems we have experienced are related to the multi-design, multi-product and multi-foundry environment. Eventually the industry will overcome data integrity problems by adopting standards for data interfaces, data structures, KGD definition, KGD quality assurance procedures, die descriptions and substrate descriptions. Work in these areas is already underway as evidenced by the IEEE 1149.1 standard, foundry EDA design kits [26] and other efforts. Note that even with standards in place the usage of such standards will require experience and agreement between concerned parties regarding interpretation and actual practice. In the mean time, we have derived and practice a methodology which reduces the occurrence of data integrity problems and minimizes the impact of existing data integrity problems.

3.5.2 Data Integrity Methodology

1. A single interface between the foundry and customer.

By a single interface we mean a focus person who will log and distribute information and materials as well as coordinate technical contacts. More importantly, we also mean the customer will be responsible for chip information input to the foundry as described in [27] rather than the foundry acquiring chip information from a third party vendor. The use of a single interface forces coordination of effort and facilitates data tracking, data revision control and timely data distribution. Information distribution controls are important for an error free data system and for the protection of intellectual property rights between the foundry and customer.

2. The MCM foundry defines the foundry/customer interface.

The interface includes assignment of technical resources, business procedures, process flow/logistics and requirements for customer supplied data. A description of the customer interface environment and an example of a test data requirement worksheet used for module test are given in Figures 3-16 and 3-17 respectively. The worksheet is modified for a specific product and clearly defines what information the customer and other groups in the foundry must provide. The worksheet is defined during the product definition phase and is reviewed at the completion of module design.

3. Chip information is supplied from the customer.

With the exception of foundry supplied chips, all chip related information is acquired from the chip supplier by the customer. The chip data is then forwarded to the MCM foundry after resolution of revision and naming conventions. Lead, pad or net names must be in agreement with both supplied physical drawings, schematics and test data.

4. Electronic or soft data exchange.

This practice helps to minimize errors caused by manual transcription.

5. Database management.

A system which enables all correspondence and data to be revision controlled and accessible on a need to know basis by engineers and designers. A key document in this system is a "history" file which contains a summary of engineering and design changes. The data management system is a key element in facilitating a concurrent engineering environment.

6. Data and Netlist verification.

Before we reach a error free data exchange environment, test data, such as BSDL, netlist, power-up procedures, schematics and lead/pin nomenclature are verified before prototype MCMs are available in order to minimize the impact of data and hardware debug on planned MCM delivery. Verification of hardware descriptions against hardware can be performed by utilizing prototype printed circuit boards(brassboard) which are built by system designers as design verification tools. Single Chip Modules(SCM) and/or Temporary Chip Attach(TCA) SCMs can also be developed to debug test fixture hardware, BSDL descriptions, test vectors and test procedures. This practice, though effective at helping to keep the TAT low, is labor intensive and adds directly to the NRE cost of a prototype MCM.

7. Quantify added NRE costs due to data integrity problems

We believe that the most effective way to solve the data integrity problem is to directly tie MCM prototyping costs with quality of data. Quantifying the cost savings associated with error free data exchange can provide leverage for resource allocation directed at standards development and implementation as well as internal business process improvements for both the foundry and its customers. Such improvements to TAT and cost will encourage more system designers to use MCMs as their packaging solution. The foundry should develop

a process to link the cost associated with bad data to the source of the information and resolve the cause of the data integrity problem as early as possible.

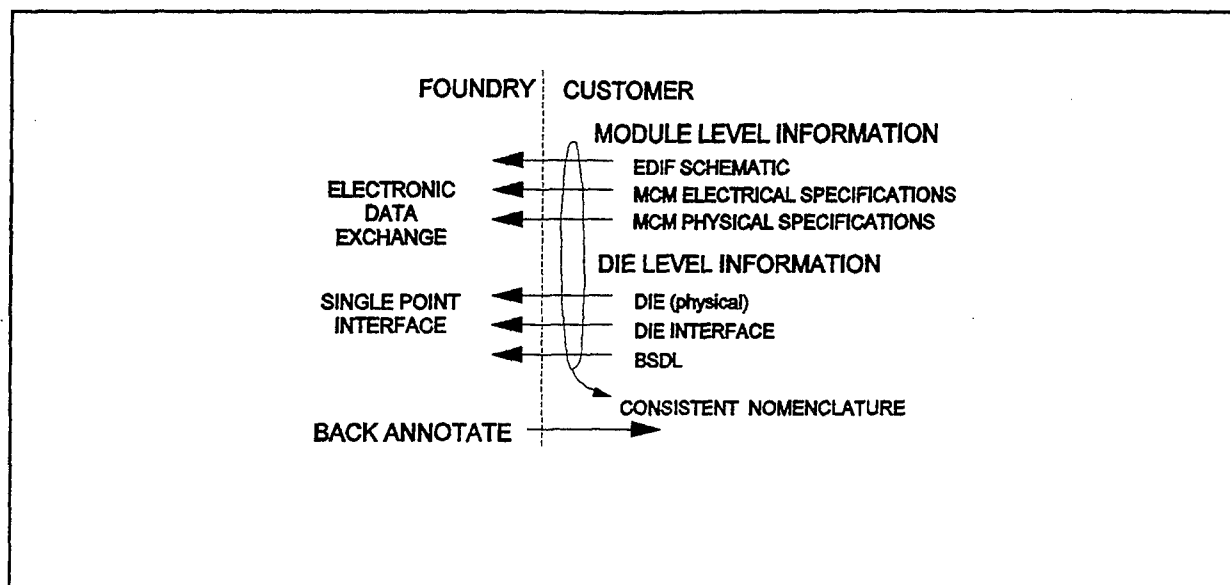


Figure 3-16: Test Data Customer Interface

Documentation is provided to the customer which provides a measure of costs incurred in fixing the data they have provided to the foundry. The documentation is intended to help the customer lower their NRE costs for future MCM prototypes. NRE savings provide motivation for the customer to improve their data handling practices and/or provide leverage against their chip suppliers to improve the accuracy and scope of chip documentation.

Test Data Requirements

General requirements:

- All Data provided in softcopy form. (Schematics and data sheets are acceptable in hardcopy but are preferred in softcopy)
- TIME and DATE stamped, Revision number and source(who)
- Signal / Lead names <= 6 characters
- If nomenclature differs for lead, signal or net name between schematics, data sheets or BSDL then a global cross reference must be provided.

The following supports 1149.1 based bond and assembly verification test. Please check off items supplied and note the format.

1. Validated BSDL for each 1149.1 compliant die.
 - ☐ Validation provided by ALC
 - ☐ BARE_DIE PHYSICAL_PIN_MAP description included.
2. NETLIST
 - ☐ Allegro format (ALC)
 - ☐ EDIF (netlist) format (ALC optional)
(note this is different from the ibm foundrys' "EDIF schematic" entry format)
 - ☐ External physical design entry(eg. in GL1)
 - ☐ other industry standard entry (describe)
3. NON-1149.1 die interface description
 - ☐ Active die (ALC , FPGA and EEPROM)
 - ☐ Passive die (IBM, 0805 capacitor)
4. Physical schematics
 - ☐ Die (ALC , FPGA and EEPROM [preliminary drawings received already])
 - ☐ MCM (ALC [preliminary layout drawings received already] IBM to provide final MCM dimensions)
5. Electrical schematics
 - ☐ Die (ALC, active die terminal characteristics only)
 - ☐ MCM Signal Architecture (ALC)
 - ☐ MCM electrical schematic (ALC)
6. Thermal data
 - ☐ Die (From data sheets)
 - ☐ MCM level(ALC)
7. Module I/O specification
 - ☐ PIN FUNCTION / NAME DESCRIPTION
 - Must account for all MCM leads by function(eg.in,out,bidi(system controlled) tristate(1149.1 controlled), VCC(volts), GND, TAP, CLK, fixed value, or other...
 - ☐ Safe Power on / power off sequence
 - Must account for all MCM leads
8. Cross reference
 - ☐ Net, signal, lead name listing providing name equivalence

Figure 3-17: Example of Foundry Test Data Interface Worksheet

3.5.3 Data Integrity Conclusion

Low cost and quick TAT MCM product development depends on error free data exchange environment. The long term solution to the data integrity problem can only be achieved by establishing a standard data exchange interface and data management system. The key to effective implementation relies on the foundry's ability to quantify the cost associated with quality of data and the ability to show MCM users that poor data input to the foundry contributes directly to higher NRE costs and longer TAT. In the short term, a precisely defined interface structure, disciplined data control system, and data verification procedures help to minimize the impact of data integrity problems on NRE costs and TAT.

3.6 MCM CASE STUDIES

3.6.1 Demonstration Vehicle Test Summary

The information presented in this section will be related primarily to how well the case studies met the requirements and assumptions as presented in the methodology section of the MCM Test report. The two case studies are reported in detail in Section 6 of the report. The information is presented in Table 3-4 and shows which methodology assumptions were met. The impact of deviations from the assumptions on NRE cost and turn around time is presented as a form of benchmark data in the second part of this section.

ASSUMPTIONS	SUN SPARC MCM	MCCLELLAN ALC DTM (Data Transfer Module)
Netlist	Yes Data integrity problem	Yes
KGS	Yes	Yes
KGD	No	Yes
1149.1	Yes < 100%	Yes < 100%
BSDL	No	No Minor data integrity problem
Functional Test	No No support effort	Yes

Table 3-4: Methodology Assumption Adherence Comparison - ADV1 versus ADV2

The functional test plan plays a key role in enabling not only a module level test but impacts the outcome of key requirements for module interconnect test such as KGD, KGS, and data (such as BSDL and netlist) integrity. Commitment to develop, simulate and perform appropriate functional tests at the die and module level enhance the likelihood of successful designs on the first pass.

3.6.2 Benchmark Results

3.6.2.1 Test Process Components

In order to quantify and track planned improvements to NRE costs and TAT, the test process was broken down into significant areas as illustrated in Figure 3-18. TAT benchmarking data is reported in Figure 3-14 for fixturing, Test File Generation (TFG), debug and test. The TFG category combines both automatic test file generation and manual test pattern generation activities. The customer interface, test plan and diagnostics, concern initial customer contacts, premanufacturing planning and test failure diagnostics respectively. Improvements to our customer interface process have been made based on a refined knowledge and communication of data requirements through the use of test data requirements checklists which are used during the Request for Quote (RFQ) and foundry entry process. The customer interface process has further been improved by providing customers with test guideline and test definition documentation. Test plan development has been streamlined by carefully defining the services and capabilities of the foundry test group and then mapping customer requirements to the capabilities.

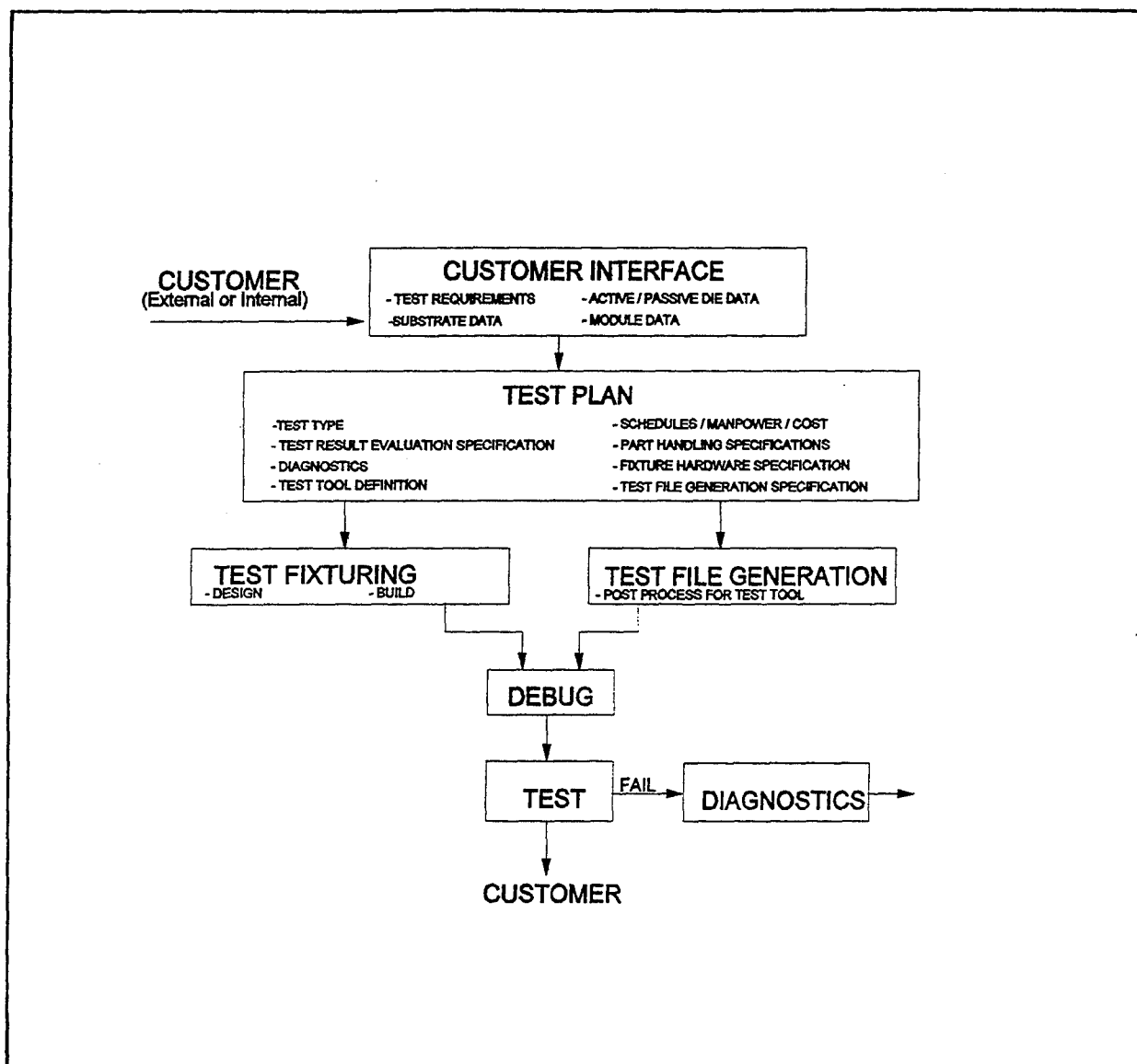


Figure 3-18: Test Process Components for Benchmarking

3.6.2.2 MCM Test Benchmark Data

Figure 3-14 reports benchmarking data for two Application Development Vehicle (ADV) MCMs and compares the resulting engineering time to an estimate of our previous practice and to our goal for each activity. Detailed descriptions of the two ADVs are presented in Section 6 of the report.

As previously discussed, MCM fixturing for test NRE and TAT reductions have been implemented using a flexible fixture and thermal management scheme. Our goal in design and integration of the fixture is to spend no more than 2.5 engineering days on this activity. The current process time for daughter card design and fabrication is approximately four weeks, which can be improved if necessary, using a quick turn around PCB fabrication service. Since the daughter card process time fits within the MCM substrate fabrication

schedule and thereby does not gate the MCM delivery schedule, the lower cost regular TAT PCB fabrication service is used whenever possible.

Reductions in the amount of engineering NRE and TAT for Test file generation have been accomplished by using a commercially available ATPG software package. The base processing time for the ATPG portion of the test file generation time can be quite low. But for the case of the two ADVs, it also includes the engineering time for manual test pattern generation. Raw process time for test file generation is only slightly greater than the amount of engineering days consumed. Suggestions for improvements to the software, which improve its utility and help to shorten manual test serialization times, have been communicated to the software vendor for further product enhancements. Additionally, the foundry has been serving as a Beta test site for future release versions of the Teradyne's Victory ATPG software package.

Debug is the most variable component of the benchmark activities and tends to add significantly to NRE if the test data provided to the foundry is not correct. The goal of 2.5 engineering days spent on test data verification and debug of the tester fixturing is estimated based on 100% correct input data to the process. Recognizing that this often may not be the case, the original selection of a standard test methodology greatly reduces the learning curve associated with each new part number. A firm understanding of the 1149.1 test standard and its application helps to minimize the time required to pin point errors in hardware descriptions or other associated data and in this regard has already proved itself.

The final benchmark category is the test itself. While our goal in this case is the same as our previous practice (see Figure 3-14), we felt it is important to monitor the time spent to ensure we were meeting our TAT commitments. This is important because in the process schedule, particularly for the first prototype parts, fixture debug and test are concurrent activities which may directly impact the committed MCM delivery date. Our data shows we were able to meet our commitments without adversely affecting final MCM delivery. However, the ability to meet the test time goal was paid for by more engineering time spent in up-front test file generation and data verification activities associated with the fact that we did not have an error free data interface/exchange system.

3.7 MCM TEST CONCLUSIONS

A module test methodology for low NRE cost and fast turn around time ASEM applications has been developed. The methodology was implemented in the IBM Microelectronics Division foundry to provide service for OEM applications. The methodology has been applied to two ARPA ASEM funded application MCMs and several other OEM customers. We believe that the ASEM objectives for module test are achievable. However, the module test plan developed must strictly follow the methodology guidelines:

◆ Assumption Conditions Met

- I. KGD and KGS
- II. Good BSDL, netlist and module data

◆ Design for Test

- I. Die - Sufficient mix of 1149.1 die to enable high coverage interconnect test
- II. Substrate - Add test and control points, check electrical impact
- III. Staged assembly of prototypes

◆ Distributed Test

- I. Substrate Test
- II. Interconnect test
- III. Chip Internal test - as required for MCM die-by-die test
- IV. Module functional self test - by foundry if implemented
- V. Functional test - by customer

◆ Data Integrity Conditions Met

- I. Standardized customer interface documents
- II. Design review checks

◆ Design and Data Verification

- I. Prototype printed circuit board verification
- II. Simulation - by customer

The MCM test challenge should become easier over time, due to the following trends:

- ◆ Broader 1149.1 compliance, for both logic and memory chips
- ◆ Wider availability of Known-Good Die
- ◆ Improved EDA support

The effect of these improvements will be to focus attention away from the solved problem of interconnect and BIST testing into functional test improvements. Essential to cost-effective functional testing is the ability for the EDA system to operate on hierarchical representations of the MCM. For instance, it should be possible to generate and simulate patterns using a model of the MCM in which the MCM is described in a combination of VHDL, BSDL, and gate level descriptions. Further development work is needed in various aspects of hierarchical test generation [21], including; propagation of interconnect fault models through behavioral descriptions; behavioral fault models; behavioral test generation; hierarchical extraction of MCM tests from system design verification patterns; behavioral level delay fault models; performance pattern coverage metrics; diagnosis oriented test pattern generation.

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4.0 C4, WIRE BOND, AND TAB INTEGRATION

As an ASEM foundry, IBM recognizes the need to produce MCM's that incorporate flip chip, wire bond, and tape automated bonding (TAB) die attach technologies. IBM MCM products have traditionally used solder flip chip (i.e., C4) as the primary means of die attach whereas the overwhelming majority of single chip products have used wire bond or TAB. Thus, the primary goal in Task 2.2.1 is to demonstrate all three die attach techniques on a single module. On a larger scale, the task supports the overall project goal of making the IBM East Fishkill foundry accessible to external customers (both military and commercial). This includes not only incorporating external devices, but also developing and exercising processes that reduce both the turn around time and cost for MCM manufacturing.

This section discusses the test vehicle created to demonstrate the interconnection technology, the physical analysis of the test vehicle, and the cost reduction practices developed with this vehicle.

4.1 MCM TEST VEHICLE(TECHNOLOGY DEMONSTRATION VEHICLE)

4.1.1 MCM Test Vehicle - Methods

The build of the Technology Demonstration Vehicle (TDV) substrate was a multi-step process. It consisted of a technology survey, process flow definition, design, fabrication and assembly. Methods for each of these are described below.

The ASEM program was geared primarily toward the MCM-D type substrate, which consisted of deposited dielectric and metal thin films. At the time of project start-up, four thin film processes were available at the IBM East Fishkill site. Each process was capable of producing a one-plane-pair structure (5 metal layers) with a 50 ohm characteristic impedance. All four processes were thoroughly investigated, and their strengths and weaknesses were noted. The process chosen was the one that closely resembled that used to fabricate the MCM for the IBM ES-9000 mainframe, i.e., a polyimide dielectric with copper conductor that is defined by subtractive etching. Although this process had not been used for a qualified, non-planar thin film vehicle, it was felt that it would be most successful. Also, the clean-room facility would be available within the time frame needed for the project.

Once the technology was defined, a preliminary process flow was assembled. It was decided that, for the projected design groundrules, the first four metal layers would be fabricated by subtractive etching, i.e., sputter deposit the full thickness of the conductor and etch away the unwanted regions. Because of the unique nature of the top surface metallurgy (see Section 4.3.1), evaporation would be required. This process flow was consistent with that available in the foundry at the time.

The initial process flow and preliminary conceptual design for the TDV were presented to Dr. Naclerio in February, 1993. After review, both required alteration. Specifically, Dr. Naclerio requested that a finer pitch TAB die and plate up processing be incorporated. Both of these were accomplished. The TAB die (see Section 4.1.2) was purchased from Microelectronics and Computer Technology Corporation. Plate up processing was scheduled to be available in the fourth quarter of 1993. However, this was accelerated into the third quarter to accommodate the TDV. To gauge a comparison of subtractive etching with plate up, we decided to fabricate the TDV with the first two metal layers (M0 and M1) with subtractive etching, the second two (M2 and M3) with plate up, and the top surface by evaporation.

In support of the overall project objectives, it was decided that the TDV should be designed using Cadence Design Systems Allegro-E software. If successful, this would signal that the foundry could accept an external design done with the software. The C4 and wire bond test chip portion of the TDV design was taken from an existing IBM ceramic test vehicle. A new design was used for the TAB die. Each of the test die was a passive device, i.e., no active circuits. An initial design was completed and reviewed with RELTECH. After the review, it was decided that an active circuit (a ring oscillator) and several thin-film diagnostic features should be added.

Once the design was completed, preparations for manufacturing were begun. It was decided that the TDV should be built as 4 pieces per laminate. An alignment scheme was designed such that any multi-up vehicle (2 or more pieces per 127mm laminate) could be built with that scheme (see Section 4.3.2). Next, all required fixturing for the processing was built. Laminates were released to the thin film foundry

period of three weeks during August, 1993. The foundry processed the TDV substrates in a class 100 clean room environment.

Because of the mixture of interconnection methods (C4, W/B, TAB), it was necessary to develop a process flow for module assembly (see Figure 4-1). It was required that a thermal hierarchy be devised that would allow solder processes to be completed before wire bonding or lasersonic TAB attach. For the C4 process, a flux was applied first and die placement was done using a manual die placement tool. The module was then placed into a belt furnace to flow the solder. After solder flow, the module was subjected to flux cleaning in 90°C xylene. For the wire bond and TAB processes, a silver-filled die attach material was first dispensed onto the die attach area. Next the die was placed using approximately 600 grams of force. The module was then placed in a box furnace to cure the die attach material (150°C, 1 hour). The wire bond electrical connections were made by an automatic tool using the wedge bonding technique. Al/Si (1%) wires 0.00125 inch diameter were used. The TAB electrical connections were made using lasersonic bonding to attach the outer leads. These connections were done primarily on an automatic tool, however, a manual tool was used on leads which had incoming alignment defects. The die attach processes were done in a class 10,000 pilot bond and assembly facility.

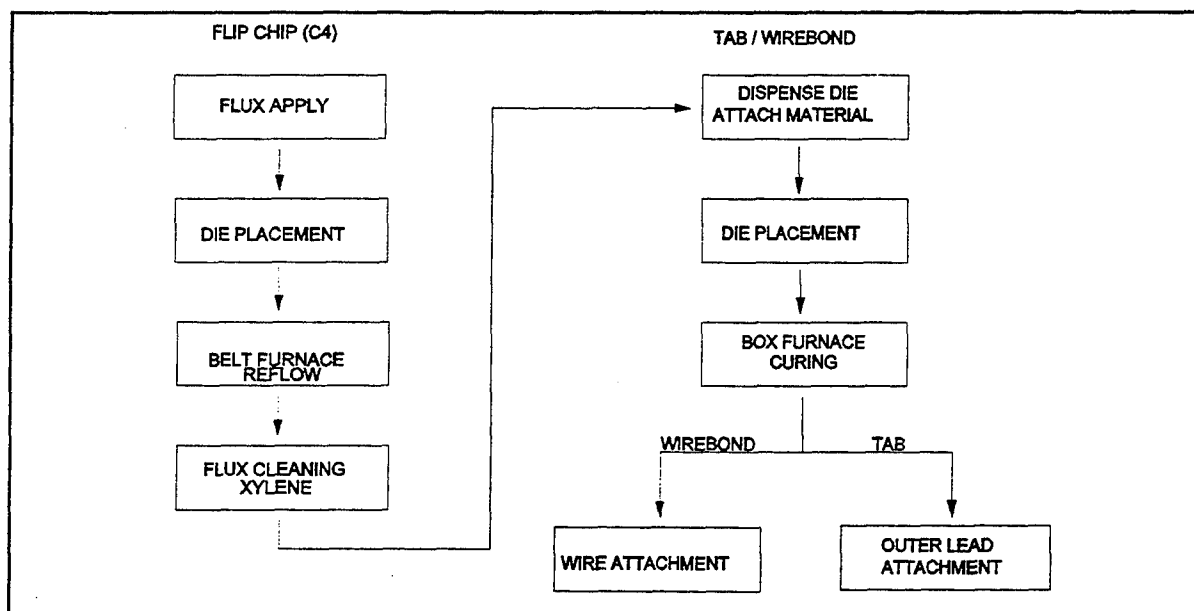


Figure 4-1: Module Assembly Process Flow

In order to facilitate electrical testing and environmental stressing, it was necessary to design a hermetically sealed carrier for the TDV. The design process was similar to that described for the TDV substrate although it was evident a priori that the carrier would be strictly multilayer ceramic. A technology survey was done to determine the best sealing method. Once the sealing method was chosen, the process flow was automatically defined. The design was accomplished quickly using the Allegro E software. The finished carrier was 72mm square and incorporated a 70mm square Kovar metal lid for sealing. This lid size was the largest ever attempted for Kovar in the foundry. The sealing method used was one in which only the edges of the carrier were heated (seam sealing). Due to the large lid size, it was

necessary to further develop this process which was done in conjunction with Solid State Equipment Company, the seam seal tooling supplier.

The final step of the module assembly process was to bond the finished substrate (after die attach) to the ceramic as if it were a large wire bond die. After the die attach material was cured, the bonds were made between pads on the substrates and those on the carrier (Au ball bond, 0.001" wire). The carrier is heated to 150° C for this operation. The wirebonds are then inspected after which the lids are attached. The above process was done in the Interconnection Development facility in the foundry.

After the completion of seam sealing, the modules were characterized electrically. For the testing, a 10 mA current was used on the test chips, and a 100 mA current was used on the via resistivity structure.

4.1.2 MCM Test Vehicle - Results

A description of the TDV substrate is given in Table 4-1 and a cross sectional view is shown in Figure 4-2. The TDV was designed with groundrules for a 50 ohm characteristic impedance. To achieve this, the conductors are copper with a line thickness of 5 microns. The dielectric layers are polyimide with a thickness of 12.5 microns. The devices attached to the substrate are described below:

- **TAB TEST DIE** (1 per substrate) - The TAB die is a 328 lead test vehicle obtained from MCC. Both the inner and outer lead bond pitches are 0.004" (0.102 mm) and the leads are 0.002" (0.051mm) wide. The die has a quadruple track over most of its area and daisy chain connections around its perimeter. The bond to the substrate is made using lasersonic bonding, a Au-Au diffusion bond.
- **WIRE BOND TEST DIE** (2 per substrate) - The wire bond die is a 9.4 mm test vehicle built by IBM Burlington and has 280 I/O. The die pads are 0.100 mm square on a 0.200 mm pitch. The device contains 4 heaters (8 Watts power dissipation), temperature sensors, and daisy chains at the perimeter. The connection is a wedge bond to the substrate with Al/Si (1%) wire that is 0.00125" (0.032 mm) in diameter.
- **C4 TEST DIE** (1 per substrate) - The C4 die is a 13 mm test vehicle built by IBM Burlington and has 2401 I/O (not fully populated). The solder balls are 0.125 mm in diameter on a 0.250 mm pitch (a high Pb/Sn alloy). The solder balls are all connected on the die.
- **OCTAL INVERTER (WIREBOND) DIE** (2 per substrate) - The octal inverters are the only active dice on the substrate. They are 1.9 x 2.8 mm with 0.100 mm square bond pads. They are attached by Al/Si wedge bonding. The two dice are separated by 40 mm and are wired to each other through the substrate to form a ring oscillator circuit. The oscillation frequency is 5 MHz.

The TDV carrier is shown (schematically) in Figure 4-3. It consists on 10 layers of alumina ceramic, each of which has a metal pattern screened onto it, and is sintered together. The carrier provides an electrical path from pins on the bottom side (which plug into a socket) to wirebond pads on the top side. Additionally, a 2 mm wide seal band is provided on the top surface for brazing a 70 mm square Kovar lid. The pins form a 64 mm array on 2.54 mm centers (625 pins total). The TDV substrate is joined using a standard die attach material Au bonding is used to make the electrical connections (0.001" wire).

TECHNOLOGY:	Thin films (Cu/Polyimide), 60 mm square 5 Metal Layers (2 subt. etch, 2 plate-up, evap. TSM Alumina base (1.5 mm thick)
WIRING:	0.025 mm signal lines, 0.1 mm pitch (200 cm/cm2) 0.015/0.050 mm diagnostics
INTERCONNECTION:	C4 (flip chip), wirebond, TAB (lasersonic) Wire bonded to ceramic carrier (or cavity) Staple bonds (microconnection) 552 I/O (edge pads)
DEVICES:	4 passive, 2 active dice Discrete capacitors
DIAGNOSTICS:	Transmission lines Capacitors (intra and inter-layer) Via resistivity TSM Adhesion Intentional line defects
PACKAGING:	10 - layer alumina, 1.5 mm thick, 72 mm square Kovar lid (peaked at center), 0.010" thick Au/Sn braze, seam sealed (hermetic) 625 I/O pin grid array

Table 4-1: Technology Demonstration Vehicle Description

As mentioned previously, both the substrate and the carrier required some development work in order to achieve a cost reduced process. For the substrate, three of these cost reductions are described in **Section 4.3.2**. In addition to the cost reduction achievements, the TDV was the first vehicle built in the high volume foundry with plate up processing. Plate up processes had been previously developed, but not transferred to the factory. The process transfer was made for the TDV, however, differences in the tool sets (between development and manufacturing facilities) and the large active area resulted in a significant amount of additional development. One example of this was the need to define a completely new set of exposure and photoresist development parameters. Initially this resulted in a high degree of rework and substantial yield loss, however, once the necessary development took place the substrates were processed with much higher yields and confidence. The majority of yield loss occurred in the first plate-up layer (signal -X). The second plate-up layer was processed smoothly and with high yield.

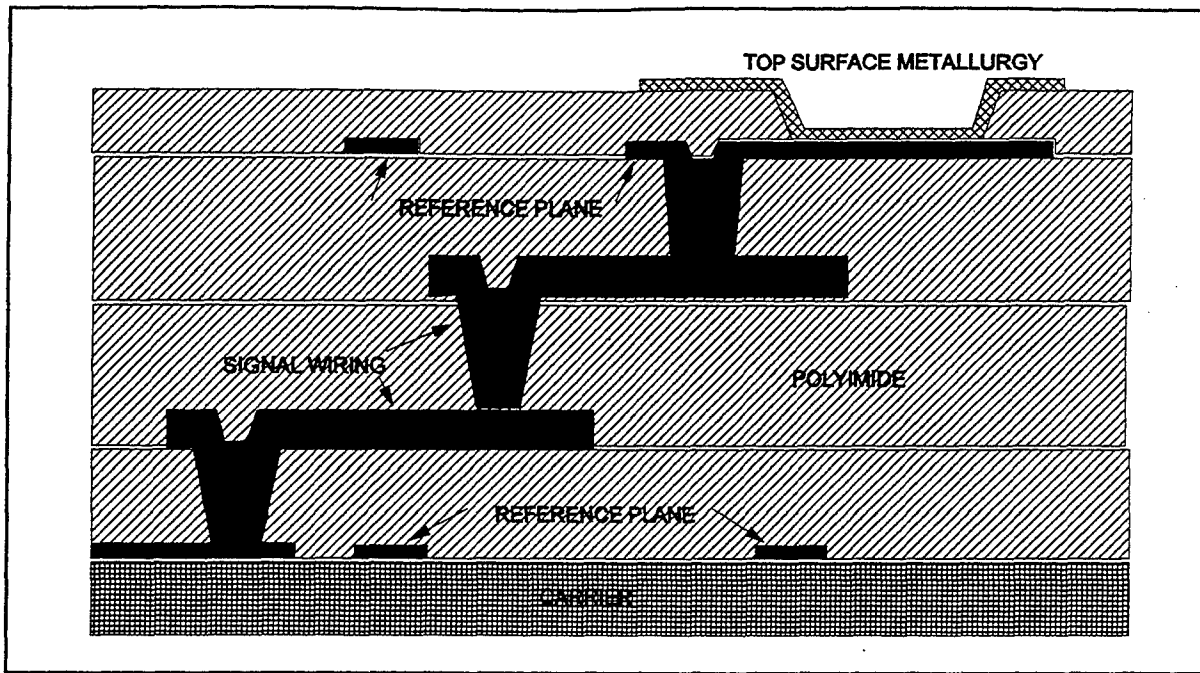


Figure 4-2: TDV Cross Section

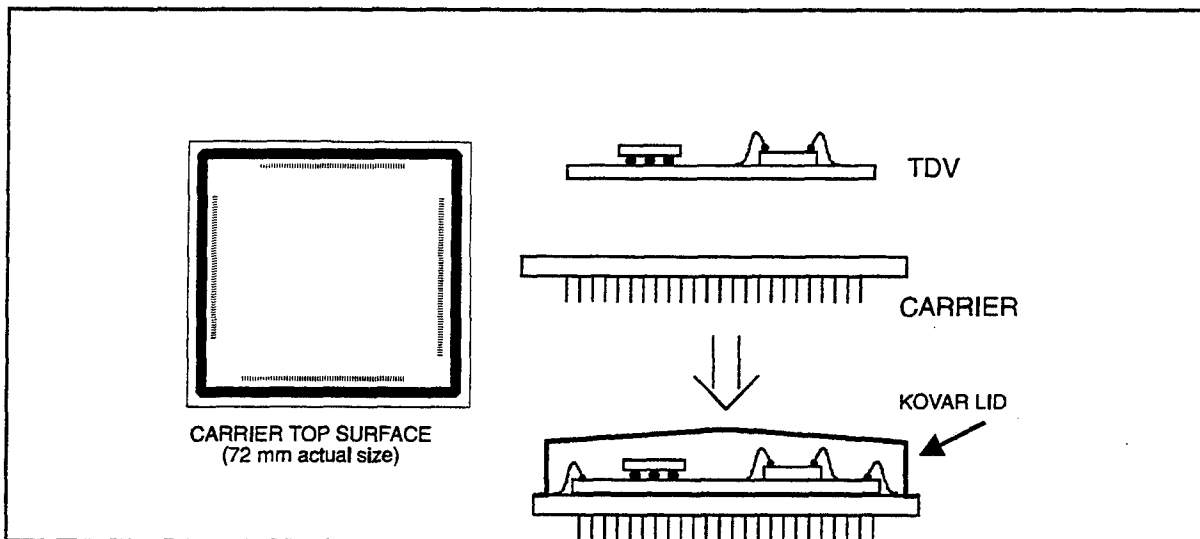


Figure 4-3: TDV Carrier

The TDV carrier also required some development in order to attach the lid and form a hermetic seal. As mentioned earlier, the metal lid was the largest ever used in the foundry. The development work involved optimizing the design and process parameters simultaneously. In particular, the lid and braze preform thicknesses were varied to allow flexibility during seam sealing. The seam seal parameters (power, feed

rate) were varied until a reliable hermetic seal could be obtained. The results showed that the most reliable seals were obtained with a lid thickness of 0.010", peaked along one axis to minimize "oil canning", and a braze preform thickness of 0.0048" attached to the lid. The most relevant seam sealing parameters were a power of 1500 Watts and a feed rate of 60 inches/minute. Leak rates of 8×10^{-10} atm-cc/sec of helium (measured after 12 hours bombing at 45 psi He) were obtained using these parameters. Although oil canning was not eliminated totally, it was controlled well enough to allow a clearance of at least 0.5 mm between the bottom of the lid and the highest wire bond.

Because the TDV incorporated three types of die interconnection, a process flow for joining had to be developed. The final process flow is shown in Figure 4-1. In developing it, the thermal requirements of each process were taken into account. The higher temperature processes being exercised first. All of the modules received the C4 test die, which involved a thermal excursion to over 300° C. For the substrates receiving capacitors, the solder was flowed onto the joining pads during the C4 cycle, and the capacitors attached in a second, lower temperature reflow. Next, the Ag filled die attach material was dispensed and the wire bond and/or TAB dice were placed. After die placement, the substrates were annealed at 150° C to cure the attach material. Each substrate experienced one or two of these cycles. Wirebonding and lasersonic TAB were done prior to the joining of the substrate to the carrier. The substrate is then placed onto the carrier as if it were a large wirebond die. The final steps are an inspection, carrier wirebonding, and module sealing. Verification of the entire process was gained by electrical and physical testing.

The foundry delivered 82 electrically viable TDV substrates and 85 carriers. Additionally, 22 mechanically good substrates were delivered. Of the 104 total substrates, 96 received all three types of die. 77 of the electrically viable substrates were bonded to carriers. From the 77, 40 substrates were shipped to RELTECH for use in their testing program. The others were used for the electrical and physical testing described in section 4.2.

Another foundry "first" was that both the TDV substrate and carrier were designed with Cadence Design Systems, Allegro-E software. The substrate design was completed first. It took approximately 2 man-months longer than the anticipated time which was based on the IBM internal design system. However, by completing the design with external software and having that design built successfully, it demonstrated that the foundry was able to accept designs from external sources. To our knowledge, the TDV was the first thin film module ever designed with the software. By the time the carrier was designed, the foundry had gained more experience with Cadence software, and that design was completed very quickly (less than two weeks).

Finally, another benchmark for the foundry was that the TDV was the first thin film vehicle built for an external customer using the International Standards Organization (ISO) 9001 procedures. Also, the dual/multi use specifications and standards being proposed by RELTECH can be very nearly met by having ISO certification.

Electrical testing of the TDV was done in two stages. The first stage consisted of opens and shorts testing and occurred prior to dicing of the four-up laminate into individual substrates. The tests involved checking over 1000 nets per substrate (4000/laminate). The second stage was done after full module assembly was completed. This stage consisted of a continuity check, or a four-point resistivity check depending on which circuit/net was being tested. The test file for the assembled modules contained 117 points. The validity of the interconnection process was gained by noting that the electrical characterization immediately after assembly was very consistent from module to module, and that very

few previously unknown defects occurred. The average number of opens occurring per module vs. the test conditions is shown in **Table 4-2**.

In **Table 4-2**, Pre-conditioning incorporates the following:

- Temperature shock (-40 to 65° C, transition time less than 15 sec); 1 shock cycle per hour; 5 cycles.
- Random vibration (acceleration amplitude approx. 1.8 G RMS; 30 min./axis)
- Vibration sweep (5-500-5 Hz at 0.44 octave/min; 0.3 G acceleration; 0.5 mm displacement; 1 hr/axis)
- Impact shock (X and Z axes; 50 G; 5 msec; 3 repetitions).

The high temperature aging is done at 150° C for 500 hours. The thermal cycle treatments are from 0-100° C and 3 cycles per hour are done. The temperature and humidity (T/H) stress is done at 85° C and 85% relative humidity.

<u>Test Condition</u>	<u>Sample Size</u>	<u>Average Number of Interconnections Opens</u>
As Assembled	25	0.24 (1 module with 5 unexplained opens)
High Temperature Aging	4	0.25
Pre conditioning	5	1.2
100 Thermal Cycles (w/preconditioning)	2	0
500 Thermal Cycles (w/preconditioning)	2	0
1350 Thermal Cycles (w/preconditioning)	3	0
300 hours T/H (w/preconditioning)	6	0.3 (1 TAB net, 1 WB net open)

Table 4-2: Avg. Opens Occurring per Module vs. Test Conditions

The only significant changes occurred during pre-conditioning. Most likely, the resulting opens occurred at the Au perimeter bonds. During that phase of fabrication some inconsistencies in the wire bonding tool were observed, and a variation in pull strength was obtained. After the inconsistencies were corrected, higher and more consistent pull strengths were obtained. Inspection of the TAB and wire bond dice after pre-conditioning supports this conclusion since no wire/lead breaks or peels were evident. The opens that occurred during T/H stressing most likely occurred during pre-conditioning (electrical testing was not done immediately after pre-conditioning).

4.2 PHYSICAL TESTING

4.2.1 Physical Testing -Methods

Destructive physical testing consisted of the following:

1. **C4 die tensile pull:** A stud is adhesively bonded to the back side of the die using a commonly available cyanoacrylate adhesive. The stud is grooved so that it can be clamped by a special fixture that inserts into the upper crosshead of an Instron tensile testing machine. The substrate is held fast by a clamp on the lower (fixed) crosshead. Once the substrate is mounted, the test is conducted at a strain rate of 5 mm/min. at room temperature. The force and failure mode are recorded.
2. **Wire bond loop tensile pull:** The substrate is mounted on an X-Y translation stage. The hook used to pull the wires is connected a transducer that measures the force (load cell). The hook is lowered to a position just above the substrate. The stage is moved until the wire to be pulled is directly above the hook. The wire is pulled at a strain rate less than 50 mm/min at room temperature. The force (up to a maximum of 20 grams) and failure mode are recorded. Both the Al/Si wedge and Au Ball bonds are tested using this method.
3. **TAB outer lead tensile pull:** This procedure is identical to the wire bond loop tensile pull. However, both the inner and outer "keeper" bars (strips of polyimide that hold the leads in place for bonding) must be removed prior to the test.

4.2.2 Physical Testing - Results

A summary of the physical test results is given in Table 4-3:

<u>Condition/Test</u>	<u>Wirebond loop</u> <u>AlSi (grams)</u>	<u>Wirebond loop</u> <u>Au (grams)</u>	<u>TAB OLB peel</u> <u>(grams)</u>	<u>C4 pull tensile</u> <u>(lbs)</u>
As-assembled	7.2	7.1	> 20	198
Ambient Age, 150° C 500 hours	5.4	9.8	> 20	210
Pre-conditioning	7.3	9.0	> 20	199
100 Thermal cycles (with pre-condition)	7.4	9.4	> 20	203
500 Thermal cycles (with pre-condition)	8.2	10.0	> 20*	215
1350 Thermal cycles (with pre-condition)	8.3	9.9	> 20	199
300 hrs temp/hum (with pre-condition)	7.5	9.6	> 20	215

Table 4-3: Physical Test Results as a Function of Stress

To place the data in perspective, the Military Specifications (883) for wire bond loop pull strengths are 4.0 and 3.0 grams for Al/Si and Au wires, respectively. The IBM specification for the C4 die tensile pull is 120 lbs. No specification exists for the TAB outer lead bond pull strength, so we adopted an ad-hoc standard of 16 grams minimum (Note: if treated like a wire, the military specification would be 8 grams). The asterisk (*) at 500 thermal cycles represents the observance of an anomalously low TAB OLB pull strength (16.5 grams) on one specimen. On this particular die, it was nearly impossible to remove the outer "keeper" bar without distorting the leads. This may have affected the results.

The decrease in Al/Si wire bond strength after high temperature was expected, as was the increase in Au wire bond strength. These were simply due to the aging characteristics of the two types of wire. No unusual failure modes were observed. The Al/Si wires failed within the wire at either bond site. The Au wires, after aging, failed within the wire predominantly at the site at which the tensile force was applied. Before aging the Au wire failures were near the bond sites.

The TAB OLB peel strengths remained constant throughout the environmental exposure with the exception noted above at 500 thermal cycles. This signifies that the laser sonic process used was quite robust.

The initial C4 pull strengths were maintained throughout the pre-conditioning and the T/H stressing which signified that the packages remained hermetically sealed. This is verified by the electrical test results. Additionally, no C4 electrical failures were observed with accelerated thermal cycling up to 1350 cycles. This is a noteworthy result that is better than our initial expectations. We expected to observe failures at several hundred cycles due to fatigue cracking that arises from the cyclic stress applied to the solder joints. This stress results from a difference in thermal expansion coefficients between the ceramic base (which constrains the polyimide motion) and the die itself. The solder connections at the corners of the die experience the most strain, and are prone to early failure. Under our test conditions, a "front" of cracked C4s would move toward the middle of the die as cycling continued. This behavior has been well characterized in the past for ceramic only modules through modelling. It has also been modelled for substrates that have relatively thin polyimide layers (e.g. 15 microns). We observed evidence of C4 cracking only after 1350 thermal cycles. It occurred at distances from the neutral point (DNP) greater than approximately 6 mm (the maximum DNP is 8.8 mm). As expected, the maximum cracking occurred at the corners of the die, however, it was confined to less than 20 percent of the contact area. This degree of cracking is not sufficient to cause a measurable change in the net resistance in the TDV.

The TDV has two features that make it different from past products, which are the polyimide thickness and the contact metallurgy. These two features may explain how the C4 results vary from the existing models. The thick polyimide may absorb some of the stress that is induced during thermal cycling, and the intermetallic layer formed during solder reflow may have different mechanical properties from the traditional metallurgy (see Figure 4-4). Most likely, the polyimide thickness is the dominant factor. Investigation of these possibilities is beyond the scope of this project. However, the results have generated an interest within the East Fishkill foundry and most likely a further study will occur.

4.3 COST REDUCTION RESULTS

4.3.1 Cost Reduction -Methods

Direct cost reduction practices involved the implementation of a single top surface metallurgy that is compatible with C4, wire bond, and TAB interconnections. Also, several changes were incorporated in the TDV processing that will reduce NRE for subsequent thin film substrate builds. These are described at the end of this section.

Interconnections that use solder have different requirements from those that use thermosonic or ultrasonic bonding. The main difference is that the solder must interact with the Ni and Cu in the contact metals, whereas the wire should be isolated from the contact metals. The traditional approach to achieve this on a single module is shown in Figure 4-4 (A). It is a "dual gold" structure, which requires extra lithography and deposition steps to achieve. In our approach, a single gold contact layer is desired as in Figure 4-4 (B). The principle behind using a NiCo alloy (instead of Ni) is that it allows the solder to interact with Cu, and prevents out-diffusion that may render the Au unbondable to wire. The advantages of the single gold layer approach are that it allows one metallurgy to be compatible with C4, wire bond, and TAB interconnections. Also, it eliminates an extra lithography step from the process. The cost benefits of such a structure are shown in Table 4-4.

<u>COST SAVINGS/MODULE</u>	<u>PLATED</u>	<u>EVAPORATED</u>
Raw Machine Time	6.3 %	2.1 %
Materials, direct	-----	\$30
NRE (mask savings)	1	1

Table 4-4: Cost Savings for Single Gold Contact Layer

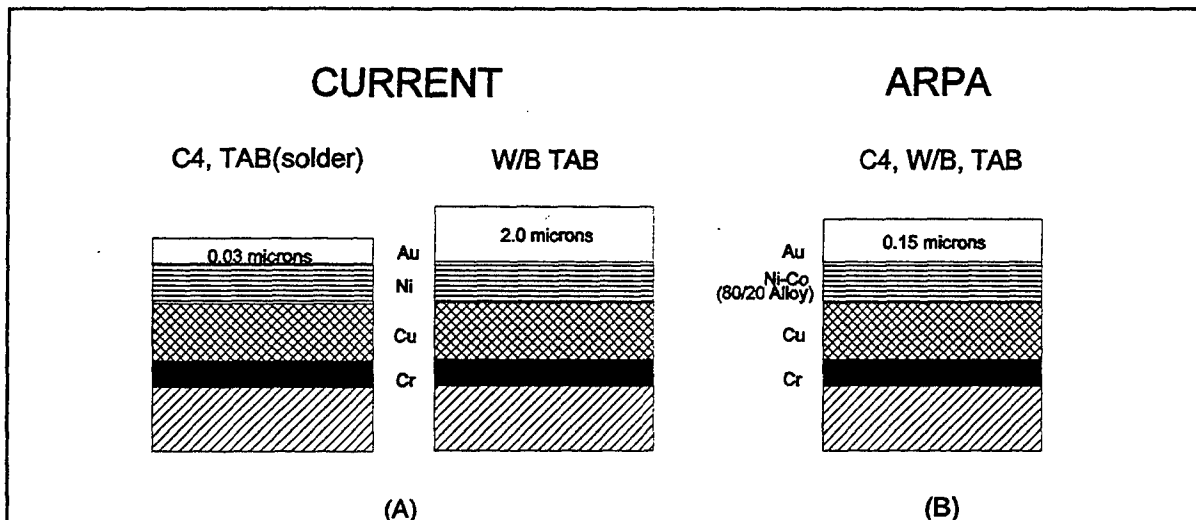


Figure 4-4: TSM Strategies

To determine the feasibility of such an approach, we requested help from the IBM Research Division. They built a series of "surrogate" structures that could be tested. This allowed a pilot study to be completed without disrupting normal processing in the foundry. The surrogates consisted of either 82mm Si wafers or 127mm glass-ceramic substrates, onto which a 9 μ m polyimide film was deposited. Subsequently, the contact structures were deposited via evaporation (the process used in the foundry for contact metallization) through a metal mask in a pattern onto which C4 test die could be attached, and wire bonding practiced. Various substrates had various Au thicknesses.

Upon receipt of the surrogates, a wire bond exercise was done. First, 60 stitch bonds of AlSi (1%) wire were made and pulled. The pull strengths and failure locations were noted. Then, 30 C4 test chips were joined, and new wire bonds were made after the reflow. The wire bond pull tests were then repeated. Additionally, 10 of the C4 chips were pulled and the strengths and failure modes noted. Wire bonding and chip pull exercises were conducted as joined (C4), and after 3, 6 and 11 reflows.

From the above testing, the appropriate Au thickness was determined and a pilot run was made in the foundry. After completing the analysis of the foundry deposited layer and a short wire bond exercise, we considered that the process was transferred and it was used on the TDV.

As mentioned earlier, there were several accomplishments made in the design and processing of the TDV that will contribute to cost reduction for subsequent vehicle builds. Among these are:

1. Development of a standard alignment scheme and fixturing.
2. Increasing the allowable active area on the substrate.
3. Reducing the cycle time for polyimide cure.

Results of these measures are described in the following 'Cost Reduction Results' Section.

4.3.2 Cost Reduction - Results

4.3.2.1 Top Surface Metallurgy

The dual thickness Au structure was designed to meet IBM specifications and requirements. In particular, it was felt that any module incorporating mixed interconnections would require at most 3 solder reflows. Thus, our strategy was to determine the contact structure that would meet such a requirement with a 2X margin of safety (i.e., 6 reflows). The requirements for most external customers however, would be less in terms of process reflows.

The top surface metallurgy (TSM) was described in Section 4.3.1 (see Figure 4-4). The final Au thickness was reached by examining the data in Tables 4-5 and 4-6, which represent wirebond and C4 pull strength, respectively. In Tables 4-5 and 4-6 the sample codes are as follows:

- C127A, F127A, F127B: Surrogate fabricated in Yorktown, 127 mm square substrate.
- S082A, S082B: Surrogate fabricated in Yorktown, 82mm wafer.
- T127A: Surrogate fabricated in East Fishkill thin film foundry, 127 mm square substrate.
- W0212601: Actual mechanically good TDV

Table 4-5 represents wire bond loop pull strength (grams) for 0.00125" AlSi (1%) wire, wedge-bonded, as a function of the number of solder reflows. The values represent the mean of at least 50 pulls. Au ball

bonding is also done on certain specimens. Table 4-6 represents C4 pull strengths (lbs.) as a function of the number of solder reflows. The values represent the mean of 5-10 chip pulls.

<u>SUBSTRATE</u>		<u>PULL STRENGTH / PROCESSING CONDITIONS</u>				
<u>Code</u>	<u>Au Thick (nm)</u>	<u>As-dep.</u>	<u>1X reflow</u>	<u>3X reflow</u>	<u>6X reflow</u>	<u>11X reflow</u>
C127A	100	>7.5*	8.2	9.3	9.1	---
F127A	80	7.3	9.5	9.5	8.0 #	---
F127B	220	9.3	10.2	9.1	11.7	9.2
S082A	80	10.1	---	---	---	---
S082A Au wire .001"	80	7.9	---	---	---	---
S082B	220	11.9	---	---	---	---
S082B Au wire .001"	220	8.4	---	---	---	---
T127A	150	9.0	9.3	---	---	---
T127A Au wire .001"	150	8.4	8.6	---	---	---
W0212601	150	11.5	10.7	10.5	---	---
W0212601 Au wire .001"	150	9.6	9.6	---	---	---

Table 4-5: Wire Bond Loop Pull Strength vs. Number Reflow Cycles

The wire bond data (Table 4-5) shows that all pull strengths substantially exceed Military Specifications of 4.0g and 3.0g for AlSi and Au wire respectively. The standard deviation is approximately 1g for all substrates tested. The nominal strengths are higher on the S082 series due to larger pad sizes. The asterisk (*) for C127A represents an anomalously low value due to variations in the wire bonding tool used for the study. The tool was serviced soon thereafter and the problem was corrected. For F127A, the pound sign (#) indicates that a significant fraction of peel failures occurred with an average strength of 6.5g (the normal failure mode is a break in the wire at the "heel" of the bond). For these samples, the value at three standard deviations was at or below the minimum strength required by the military specifications.

<u>SUBSTRATE</u>		<u>PULL STRENGTH / CONDITIONS</u>					
<u>Code</u>	<u>Au Thick. (nm)</u>	<u>As-joined</u>	<u>3X</u>	<u>6X</u>	<u>11X</u>	<u>Tcyc.</u>	<u>Impact</u>
C127A	100	22.0	22.2	21.0	---	---	21.6
C127 B	100	23.0	---	---	---	23.0	---
F127A	80	25.4	27.5	24.5	24.5	---	---
F127B	220	27.0	21.9	21.6*	17.6*	---	20.3*
S082A	80	----- (Strength exceeds that of wafer)-----					

Table 4-6: C4 Pull Strength vs. Number of Reflow Cycles

The C4 data (Table 4-6) shows that all values exceed the IBM specifications for the chip size and C4 count used. However, for the values denoted with the asterisk, significant levels of contact metallurgy failure at the chip were observed. Also, defects such as voids and de-wetting in/of solder were observed in the asterisk denoted samples. Despite the high pull strength value, those specimens do not meet the IBM failure mode criteria for C4's. The normal failure mode is one in which the solder develops a neck during the pull which subsequently breaks.

From Tables 4-5 and 4-6, a clear dichotomy can be seen. Thick Au layers result in good wire bond performance but poor C4 performance through multiple reflow cycles. Conversely, thin Au layers result in good C4 performance but poor wire bond performance through multiple reflow cycles. Thus, an intermediate thickness would represent the best compromise between the two. The result is that 150 nm Au thickness was chosen for use on the TDV. Both C4 and wire bond joining to this contact structure were successful. In 30 modules, two reflows were done before any wire bonding was attempted. No problems related to contact metallurgy were observed. In fact, some of the highest Au ball bond strengths (up to 10.5 g average) were obtained on finished TDV substrates after at least one reflow.

In Table 4-4, the cost benefits of using this TSM structure were shown. The foundry delivered 102 substrates with the evaporated TSM of which 82 were electrically good. Thus, the cost savings in direct costs were \$2460. An additional cost savings, similar in magnitude, was realized due to the decrease in raw process time to produce the TSM.

4.3.2.2 Miscellaneous Cost Reduction

Prior to manufacture of the TDV, no external product had ever been built as a multi-up (i.e., step and repeat the module pattern on a laminate). The TDV was built as a four up and had a larger active area than the standard internal product. It had an active area of 119.2mm square on a 127.5mm laminate, which was the largest active area ever attempted. Standard product has an active area of 114mm square. As a result, the standard practice of placing the alignment fiducials in a symmetric pattern in the outer corners of the laminates had to be changed. The fiducials on the TDV were placed slightly offset from the X and Y centerlines, alternating between the 2 locations on adjacent layers. As a result, marks on every other layer were stacked. In order to achieve this, special frames were constructed to protect the marks

during metal deposition. In practice, the laminate was rotated 90 degrees for each metal layer deposition thereby producing the stacked fiducials.

This alignment scheme was successful and no adverse effects in pattern overlay were observed. It has become standardized and can be used on future OEM product built in the high volume foundry. The cost savings associated with this is completely in non-recurring engineering (NRE) and is significant. In the past, an alignment scheme would be devised for each product. This would take one man-day of design time, one man-day for a design review, and some process/tool time for verification. Additionally, a new set of protective fixtures for metal deposition would be required for each design. These fixtures have strict requirements for flatness and shape that increase the cost to approximately \$400 each. Typically, 16 are used in production for volumes similar to the TDV. Thus, the total cost savings is \$6400 plus two man-days of fully burdened design labor.

The very large active area of the TDV resulted in some processing challenges to overcome, which were due primarily to the buildup of polyimide at the edge of the laminate. Some operations that would normally be done automatically had to be done manually. In general, the yield decreases as the number of manual steps increases. The TDV was no exception, although most of the defects resulting in yield loss were confined to a small band approximately 0.6mm wide at the edge of the active area. Based on this experience, it was felt that the largest active area that could be processed with high yield is 118mm. This has been adopted as a groundrule in the foundry. Using this active area groundrule, many of the manual operations can be converted back to automatic, resulting in reduced turn around time and cost. An additional benefit is that the maximum size for multi-up substrates is increased to 59.1mm for 4-up, 38.9mm for 9-up, and 28.9mm for 16-up.

One other process modification designed to reduce cost and cycle time that was incorporated was a reduced cure cycle for the polyimide (PI) cure. The standard cycle runs approximately 13 hours and is a stepwise cure to 400° C. The new cycle has a continuous ramp to 400° C, and takes approximately 3.5 hours. For the TDV, this represented approximately a 3% savings on raw process time. It is expected that future products will benefit from this much more than the TDV as there was significant rework associated with the TDV due to the developmental nature of the vehicle.

4.4 CONCLUSIONS

In almost every sense, the TDV was a development vehicle that pushed the East Fishkill foundry to new limits. From design through die attach, new processes were attempted.

Design: Because the TDV was the first thin film vehicle designed with Cadence Allegro-E software, knowledge was gained that was useful in formulating the design kits. For example, it became clear that automatic mesh generation, redistribution, and mesh cutout routines would be necessary to reduce the design time substantially. All of these have been written and incorporated into the design kits. Additionally, routing strategies have been optimized based on the TDV, and the appropriate parameters have been incorporated into template board files provided with the kits.

Processing: The TDV build brought about innovations in processing that resulted in cost reductions as described in detail above. Additionally, the timing of the build was such that plate-up processing was brought into the high volume foundry ahead of schedule. The learning gained by that accomplishment has been applied to new products that have been processed there with high yield. Also, the TDV build has resulted in an increase in the allowable active area on the foundry's standard form factor. This results in savings to customers because a greater number of substrates can be processed per laminate.

Interconnection: The results described above show clearly that mixed interconnection is feasible on MCM-D products. The experience gained by building the vehicle has been useful in setting design groundrules for both wire bond and TAB contact pads. The TAB OLB had the finest pitch of any TAB device attached to an IBM module. The fact that approximately 100 TAB dice could be bonded automatically is ample proof that the lasersonic process is viable as an interconnection technique.

Packaging: The flat carrier with a peaked Kovar lid was chosen as the lowest cost hermetic solution to packaging the TDV. Although we were able to bond the TDV to the carrier, the long wire run and bond depth are impractical for most environments when the substrate is greater than 50mm square. We would recommend that such an approach be limited to substrates less than or equal to 44mm square. An informal survey reveals that modern wire bond tools exist with such capabilities. Additionally, the smaller size would extend the thermal cycling lifetime of the hermetic seal, although we did not observe any hermeticity degradation under the test conditions used here.

Although the TDV was a development vehicle in almost every sense, it performed very well under typical IBM test conditions. These tests were meant to simulate, in an accelerated fashion, the types of stresses that the module might undergo in a commercial or consumer environment. Although a full product qualification was not attempted, the results obtained above combined with the learning suggest that the TDV could be fully qualified to IBM standards. Stressing of 38 modules to Military Specifications will be conducted by RELTECH. It will be interesting to compare those results with the ones described here.

5.0 INFRASTRUCTURE

There are a number of infrastructure issues that needed to be addressed in order to improve industry availability and acceptance of MCMs. These included:

- Definition of standard substrate sizes and I/O assignments; to increase reuse of design data, manufacturing and test fixtures, and to reduce NRE costs and cycle time
- Definition of foundry interface specifications; to assist customers in being able to use multiple MCM foundries
- Definition of design kit standards; to assist foundries in defining their technology to the variety of commercially available design tools
- Definition of standards for Electronic Data Books; to improve transfer of component data between design tools
- Solutions to MCM test issues such as: chip sets with a variety of testability features, known good die, and test file generation
- Solutions to address the interconnect technology issues such as; helping the industry understand flip chip (IBM C4) technology and interconnect reliability

This infrastructure section describes activities that addressed the listed MCM concerns and worked towards enhancing MCM technology acceptance in the industry. Four areas of infrastructure will be described in the following sections:

- Application Demonstration (Substrate Standardization)
- CAD Infrastructure (Customer-foundry interface specifications, Electronic Data Books)
- Module Test (Testability, Known Good Die, Test File Generation)
- Interconnection Technology (Flip Chip, Interconnect Reliability)

Additional details can be found in contract deliverable "Report on Infrastructure Plans and Accomplishments, Final Report", 0002AQ.

5.1 Application Demonstration

The major infrastructure accomplishment resulted from work with ISI, the Mayo Foundation, and internal applications team activity. Additional, less measurable, results came from industry interaction at conferences and meetings.

5.1.1 ISI/MOSIS

The University of Southern California's Information Sciences Institute's (ISI's) charter was to form an MCM brokerage service to facilitate foundry access for smaller customers. The model for their operation was the MOSIS service for application specific integrated circuits, in which several different designs are combined into a single mask set that can be run in a single foundry. By doing this, the non-recurring engineering charges (NRE) can be spread over several customers, thus lowering the total cost to each. In the ISI model, individual substrate designs would be submitted and combined electronically. Subsequently, ISI would provide a complete set of exposure masks (and substrate test vectors). A requirement for smooth operation and low cost is to standardize the designs as much as possible (i.e. substrate size, pad layouts, etc.).

The ASEM team has worked closely with ISI to put the model into practice. Initially, a complete set of thin-film technology ground rules was provided to ISI so that they could gain familiarity with the E.Fishkill foundry capabilities. A set of proposed standard sizes was also provided. In fact, the resulting ISI standard sizes (i.e., 25, 37, 47 and 57 mm square) were very close to those proposed by IBM. Following this initial activity, ISI toured the foundry and met with us to determine the best processing scheme to use in our factory. It was decided that a full field approach (as opposed to step and repeat) offered the maximum benefit in terms of low cost. Thus, a full set of (metal expose) mask specifications and the necessary alignment fiducials (in electronic form) were provided. IBM was the only supplier chosen by ISI that formed vias by laser ablation. Because the laser mask process is proprietary, specifications could not be provided. However, it was decided that alignment fiducials (and locations) could be provided, thereby allowing ISI to produce electronic versions of laser masks, which could then be built by IBM. ISI was supplied IBM MCM-D design kits for the Cadence and Mentor Graphics design tools. In addition, special data formats to support the uniqueness of the ISI/IBM relationship were developed for substrate opens/shorts test data. While ISI was preparing two 37 mm designs for a qualification run, a "test mask" was generated and shipped to IBM. This was used to build a single metal layer on a 127 mm substrate. The resulting metal pattern was measured, and alignment of the substrate on other foundry tools was attempted (with success). Once this process was verified, ISI was given instructions to proceed with a complete mask set.

Initial parts are to be delivered in December 1994 and ongoing regularly scheduled builds are planned.

5.1.2 Mayo Foundation, Special Purpose Processor Development. Group

Another of the activities, which was part of the infrastructure task, was the involvement with the Mayo Foundation's Special Purpose Processor Development Group. Mayo is one of the other ARPA ASEM Contractors. Their goals for the ASEM Program is to take the currently available MCM technologies and determine/demonstrate the maximum rates of operation.

The infrastructure activity that occurred during this ASEM contract focused on passive designs for both MCM-C and MCM-D substrates. The passive design is the standard Mayo passive MCM design. It consists of various line structures that will be evaluated in terms of impedance, loss, crosstalk, etc. Mayo performed the design and layout with the help of the University of Wisconsin at Milwaukee. The interface with IBM was at the completed physical design level. Consultation on the use of the IBM Design Kits, IBM Design Ground Rules, and the IBM Manufacturing process was also provided. Mayo has plans to share all their results with IBM and the rest of the ASEM community which have supplied or will supply passive substrates. These vendors are nCHIP, ISA, Hughes, Georgia Tech, Texas Instruments, Acsist, Motorola, and MicroModule Systems.

The standard passive coupon which Mayo has been evaluating has specific lengths and spacings, simple basic structures, the same design for all the contractors, and the same set of tests performed on the completed modules. Of the ASEM contractors, IBM will be the only one to supply a MCM-C vehicle. IBM will also supply a MCM-D vehicle.

The MCM-C passive coupons was 127mm x 127mm Alumina ceramic. It was 15 greensheet layers thick with top surface probe pads as module I/O. The substrate was build using IBM standard multi-layered ceramic manufacturing process including mechanical punch for substrate personalization and immersion gold top surface plating. The MCM-D passive coupons was a

60mm x 60mm multilayer thin film package on a blank Alumina ceramic substrate. This five layer thin film structure was built using IBM's 25 μ lines on 100 μ center groundrules.

Mayo's high speed testing methodology was identified for both the active and passive coupons. Testing of passive coupons is performed using a 0-26 GHz sweeper in combination with cascade probes. The preferred probe has it's signal line bracketed by ground lines. This topology can be seen in the TSM layout. The design of the passive coupon explores signal power loss by probing a variety of line topologies including closely coupled and mitered corner lines.

The 'C' and 'D' passives were delivered in October 1994 and are under test at Mayo.

5.1.3 Hardware Standards

The team leaders in each of the IBM ASEM task groups have put together a list of MCM features that should be included in industry standards discussions.

For example; An application questionnaire has been generated based on input from the design, modeling, thermal, encapsulation, and test groups. The key technology and business items were included. The questionnaire has been distributed to the foundry for comments. This questionnaire has become the standard for the IBM foundry and will be used in discussions with other foundries about standardization. Discussions with other foundries about the questionnaire has not yet begun.

5.1.4 Industry Conferences and Meetings

In addition, team members have participated in the following conferences and ARPA team meetings.

ARPA ASEM conference - Phoenix, Arizona March 23-24 1993

IEEE MCM conference - Santa Cruz, California March 22-25 1993

GOMAC '93 - New Orleans, LA November 1-5, 1993

ARPA EP&I Conference. Marina Del Rey, CA., 2/94: Several Papers; Presented by Y.Ting, H.Clearfield, L.S.Su, and N.Volkringer.

ISHM '94 - Denver: Paper Presented "50MHZ MCM-C Processor Module with Flip Chip Technology" By W.Miller, Y.Ting, N.Volkringer, & L.S.Su.

ISHM Advanced Technology Workshop, MCM-D and MCM-L, Invited Paper Presented "IBM ASEM Activity" By H.Clearfield (Ogunquit, Maine, June, 1994)

GOMAC '94 - San Diego: Abstract Submitted: "Electrical Characterization And Design Using IBM's MCM-C Packaging Technology" By N.Volkringer And W.Jennings.

5.1.5 Application Demonstration Conclusions

Significant progress has been made regarding hardware standards and industry awareness of IBM's technology characteristics. Additional applications will benefit from this progress.

5.2 CAD Infrastructure

The major accomplishments have been related to work with the ASEM Alliance toward Foundry Interface Standards and Information modeling of MCM descriptions. The information modeling

activity couples closely with EDIF-PCB extensions that could lead to better MCM electronic data books (EDBs) and Design Kit Standards.

5.2.1 ASEM Alliance Results / Standards

ASEM Alliance meetings initially discussed possible areas for standardization. The primary interface of interest was that of the completed physical design entry into the foundry. There were many foundry unique requirements due to the special processing capabilities at each of the foundries. Despite these differences, a draft of an ASEM Foundry Interface Specification was published. IBM chaired many of the foundry-to-customer working group meetings.

In publishing the interface document, the core reasons for differences came under discussion. It was determined that the information to describe the data, which must be exchanged from MCM foundry to customer, had to be studied. Some of the basis for the information content came from MCC experience with DICE and the ROSE data base activity. With that demonstration base, further discussions were held, which lead to evaluating the EDIF-PCB information model relative to the MCM requirements. Discussions and meetings with the EDIF-PCB working group lead to current activity in EDIF of trying to incorporate ASEM findings into a follow-on EDIF-PCB releases.

Progress towards an EDB standard and a Design Kit Specification has been made with the ASEM Alliance activities relating to the information modeling of MCMs. Additional effort will be needed to follow through with this activity.

5.2.2 Other organization Support

CFI-CIR Meetings: Contributed to Proof of Concept EDB request for technology. Also contributed to terms dictionary and scenarios development.

Logic Modeling Corporation: Hosted meeting at IBM E.Fishkill to review bare die information requirements for ARPA chip library work. Module, Electrical, and Test requirements were discussed. 3/10/93

Participated in many of the review meetings for the Die Information Format and provided an IBM EDB.DTD (Document Type definition) for use in establishing SGML format option.

Continued recommending this format in documentation, papers, and industry discussions.

Tanner Research: GDS2 was provided for a sample MCM along with the design kit specification and the documentation associated with the Cadence MCM-D kit.

Cooper Chyan Technologies: An Allegro .brd file of a sample MCM-C was provided to CCT to allow tool evaluation of channel routing objectives for mesh plane technologies. Technology discussions followed. CCT currently doesn't have controls to force signal routing to align underneath mesh lines. This is considered important for technologies with mesh planes.

University of Tennessee, Knoxville: Hosted meeting at IBM E.Fishkill with Dr. Don Bouldin with regard to semiconductor design using flip chip pad arrays.

Cadence, Mentor Graphics, Intergraph, Harris EDA, and Racal-Redac: Ongoing discussions regarding design kit development activity and other CAD issues.

5.2.3 Industry Conferences and Meetings

Multichip Module Conference: Conference attended, March 15-18th, discussions held with other attendees/ presenters on MCM infrastructure topics. MCM Design kit plans discussed with attendees at the IBM Technology booth.

MCM design kit demonstrations on both the Mentor Graphics and Cadence design tools were shown at the Feb., 94 conference.

IPC Fall meeting: Paper presented entitled "The MCM-L/SCM-L Design Infrastructure: Matching Customers to Foundries" at in October 1993 in Alexandria, VA.

ISHM Conference: Conference attended, April 13-16th, discussions held with other foundries/EDA suppliers on Design Kit support and standardization.

MCM design kit demonstrations on both the Mentor Graphics and Cadence design tools were shown at the April 94 conference.

Workshop on Enabling Technologies U of W. Virginia: Attended CERC meeting and collaborated on a short paper on collocation (multi-location concurrent engineering activity)

ARPA Contractors Conference: Conference attended, Feb. 94, MCM-D kits demonstrated for the first time on both the Mentor Graphics and Cadence tools running concurrently on an RS6000.

PCB Design Conference: Mini-Course presented on "MCM Technology: Design For Optimized Application" March 28-31, 1994, Santa Clara, CA (1)

5.2.4 CAD Infrastructure Conclusions

Relationships have developed between IBM and other MCM companies, consortia, and standards organizations. This has created contacts for discussions of MCM description requirements, MCM design kit requirements, and customer/foundry interfaces. The ASEM Alliance has been an effective forum for improving the consistency of foundry interfaces.

The CIR and Conference attendance has influenced approaches to design kit specifications, content, and future directions as electronic design representation and exchange concepts are discussed in the open forum. Instead of working individually with the CFI/CIR organization, our proposals and efforts for standardization moved to activities within the ASEM alliance. We worked towards MCM (EDB) standards and design kit standards through work with the ASEM Alliance which included reviewing the information model of EDIF PCB for possible extensions to cover MCMs.

We contributed to other industry activities by providing IBM perspectives on the DIE Format being created by Synopsis (Logic Modeling corporation) and work being done by Dr. Bouldin's University of Tennessee activity.

Information has been shared and discussions have been held with Tanner Research and Cooper Chyan Technologies, as well as Cadence, Mentor Graphics, Intergraph, Harris EDA, and Racal Redac.

5.3 Module Test / Known Good Die

The major accomplishments have been in the sharing of experience and recommendations in the areas of MCM Test and Known Good Die (KGD).

5.3.1 MCM Test

Paper presented titled "The Test Challenges for an ASEM Foundry" by T. Story, E. Atwood, C. Lapihuska and L. Su, at the 27th International Symposium on Microelectronics sponsored by the International Society for Hybrid Microelectronics, Boston, MA. Nov. 15-17, 1994.

Paper presented titled "A Test Methodology to Support An ASEM MCM Foundry" by T. Story, E. Atwood, C. Lapihuska and L. Su, at the IEEE International Test Conf., Washington, D.C., Oct. 3-5, 1994.

Paper presented titled "Data Integrity Concerns for Multichip Module Testing", by L. Su and E. Atwood, at the International Electronic Packaging Society Conf., Atlanta, GA. Sept. 25-28, 1994.

Paper presented titled "MCM Test using Boundary-Scan Methods for Internal and Merchant Designs" by E. Atwood, at the MCM Test Workshop, Napa, CA. September 11-14, 1994.

Paper presented titled "1149.1 MCM Interconnect Testing Using Victory ATPG and Scan Chain Serializer" at the Teradyne Users Group Workshop, 4/25-27/94, Santa Clara, Ca.

Paper presented titled "A Test Methodology and It's Implementation to Support an ASEM Foundry" by T. Story, E. Atwood, C. Lapihuska and L. Su, at the ARPA EP&I Meeting, 2/14-17/94, Marina Del Rey, Ca.

Attended IEEE MCM conference, MCMC-93, 3/15-18/93, Santa Cruz, CA

Attended IEEE BIST/DFT Workshop, 3/17-19/93, Charleston, SC

Attended IEEE VLSI test symposium, 4/5-8/93, Atlantic City, NJ

Attended Workshop In Hierarchical Test Generation, 8/9-11/93, Blacksburg, Va.

Attended ITC Conference, 10/17-21/93, Baltimore, MD

Attended IEEE VLSI Test Symposium, 4/26-28/94, Cherry Hill, NJ

5.3.2 Known Good Die

Active participation in Bumped/Tabbed Die Sub-committee KGD task force
(Guideline for Procurement and Use of Known Good Die) 1/20/93, Austin, TX; 3/2/93, Austin, TX; 4/13/93, Denver, CO; 5/13/93, Austin, TX.

Published In MCC's "Consortia For KGD Phase-I" Report WL-TR-94-5008, 2/94

Active participation in MCC/SEMATECH/ARPA project meeting on KGD
(KGD Assurance Technology Assessment Guidelines) 1/21/93, Austin, TX; 3/3/93, Austin, TX; 4/13/93, Denver, CO;

Published In MCC's "Consortia For KGD Phase-I" Report WL-TR-94-5008, 2/94

Assembled a team with members from IBM Packaging Business Unit including Bond, Assembly, and Test personnel to assist MCC in formulating the ARPA Phase II KGD plan.

Presented and discussed the IBM KGD strategy and experience with engineers from RELTECH, Sun, and National Semiconductor.

Attended 1993 Advanced Microelectronics Qualification/Reliability workshop, 8/24-26/93
Denver CO.

5.3.3 Other organization Support

Discussed bare die test information requirements with Logic Modeling Corporation at meeting in IBM E.Fishkill. 3/10/93

Initiated a series of meetings with Mentor Graphics/Teradyne and Cadence in an effort to speed up the development of Test Pattern Generation software.

Continued testing the Victory ATPG Software as a beta site for Teradyne. Surfaced major problems in dealing with Virtual Component Clustering Test (VCCT). Results shared with Teradyne and plans for a solution discussed. Updated Beta software is under test.

5.3.4 Module Test / Known Good Die Conclusions

Attendance in test related conferences and workshops has provided an important influence in the development of a standardized and effective test methodology. Broad industry interactions at such forums is helping to converge the scope and range of OEM test methodologies.

Attendance in the MCC phase I KGD efforts, ARPA sponsored EP&I meetings, and industry forums such as the ISHM Conference/exposition has provided a forum for disseminating IBM knowledge of KGD issues related to manufacturing of MCM's & Die Burn-in, has provided a forum to influence the content of proposed KGD standards, and has influenced IBM's approach and understanding of KGD issues involving wire bond die.

5.4 Interconnection Technology

Major accomplishments have been in leading industry activity and sharing interconnection and material knowledge and experience in the following arenas:

- Presenting results on TSM, thin film and module assembly development at various MCM-related conferences
- Chairing sessions at conferences and workshops
- Serving on organizing committees for MCM related conferences and workshops
- Participating in known good die standardization
- Presenting C4 reliability experience to establish widespread knowledge based on flip chip technology for MCMs
- Providing physical specifications in support of standardization of MCM designs
- Reviewing proposed standards and provide feedback to other members of ASEM team

5.4.1 Industry Conferences and Meetings

M.I.T. Packaging Program Workshop: Paper presented on 'Chemistry and Long Term Durability of Metal Polyimide Interfaces: Processing and T/H Stresses'; review panel

member providing feedback on program's progress as well as setting strategic directions for the program. Jan. 93.

Review panel member and participant in guiding the activities to solve industry MCM processing problems. April 93.

Review panel member as above, November 93.

U. ARIZ./IEEE/CHMT Workshop: Participant in benchmarking industry use of flip chip die attach technology against IBM experience; provided comments and feedback on industry standard die attach techniques. Jan. 93.

CHMT/ISHM Workshop Advanced Materials: Paper presented on 'Chemistry and Long Term Durability of Metal Polyimide Interfaces: Processing and T/H Stresses'; benchmark industry standard substrate technology against IBM experience. Feb. 93.

ARPA/SEMI/EIA MCM Workshop: Participant providing input and comment on industry standard tooling issues in MCM manufacturing. Feb. 93. Internal IBM meetings held to set strategy for EIA participation and work areas to be addressed. April 93.

Adhesion Society Symposium: Session chairman on Metal/Polymer Interfaces; organizing committee providing input for future directions of the symposium. April 93.

Materials Research Society Spring Symposium: Paper presented on 'Ta/Polyimide Interface Durability: Correlation to Chemistry and Water Uptake'; session chaired on Interface Properties and Durability. April 93.

IBM Symposium on Reliability and Statistics: Paper presented on 'Statistics for Crack Initiation and Propagation'. April 93.

ISHM MCM-C Workshop: Participant in benchmarking IBM MCM-C technology, design capability, interconnection and turn-around-time against other MCM vendors; learned about latest materials and processes for high performance modules. August 93

Advanced Microelectronics Qualification/Reliability Workshop: Presented a paper entitled "Interconnection Fatigue Modeling," Denver, CO, August 93

Gordon Research Conference on Adhesion Science: Chairman of conference, which included presentations on low- cost metalization and reliability, New Hampton, NH August 93.

Intl. Symposium on Microelectronics (ISHM 93) : Invited paper presented, entitled "Chemistry and Long-Term Durability of Metal/Polyimide Interfaces: Processing and Temperature/Humidity Stresses." Paper won a "Best of Session" award.

ASEM TDV substrates displayed at the trade show, which generated interest in IBM thin films technology. Dallas, November 93.

Materials Research Society Fall Symposium: Invited paper presented, entitled "Factors Affecting the Long- Term Durability of Metal/Polymer Interfaces in Microelectronics Packaging: Chemistry and Water Uptake." November 93

ARPA EP&I Principal Investigators Meeting: Presented a Paper Entitled "Technology for Mixed Interconnection on Thin Film Multichip Modules" (Marina Del Rey, Ca., February, 1994)

International Conference on Multichip Modules: Presented a paper entitled "Implementation Of Advanced, Micro-Interconnection Techniques on A Thin Film Multichip Module"; Session Chair in "Materials and Processes" (Denver, April, 1994)

International Symposium On Microelectronics (ISHM '94): Session Chair, "MCM Packaging"; paper presented, entitled "A Single Contact Metallurgy for Flip Chip, Wirebond, and TAB Applications on Thin-Film MCM's" (Boston, November, 1994)

International Society For Hybrid Microelectronics: H. Clearfield Selected for the National Technical Program Committee, The Subcommittee on Packaging

The Adhesion Society : H. Clearfield elected vice-president (president-elect)

5.4.2 Other organization Support

RELTECH: Meetings 2/4, 2/26 and 3/11 discussing common test vehicles and reliability experiences

IBM ASEM TDV test plan presented at RELTECH Symposium 4/13/93.

IBM ASEM TDV test plan approved by RELTECH 4/13/93. Hosted a visit to IBM E. Fishkill by RELTECH as part of their survey of all ASEM contractors. Provided information on the TDV processing and test objectives. July 93.

Attended RELTECH Committee Meeting, Denver, CO, August 93 to begin writing "National Specification" document for MCM's.

Attended RELTECH Subcommittee Meeting, New Orleans, LA 11/5/93.

Applications task: Provided ground rules for 50 ohm impedance thin-film (joint with design).

Interconnection standards for MCM-C and MCM-D top surface design have been proposed. Ground rules include:

- C4 pad size and pitch
- Wirebond pad size and pitch
- TAB pad size and pitch
- Edge I/O pad size and pitch
- Minimum allowable clearance between adjacent devices.
- Die attach pad size and design

Don Bouldin (University of Tennessee - Knoxville): Discussed his flip-chip infrastructure activities. Agreed to provide support for MCM activities through our technology offerings.

5.4.3 Interconnection Technology Conclusions

Most conference activity has been related to materials science aspects of MCM technology. By participating in these forums, we have kept abreast of developments that may enable low cost MCM-D in the future and shared knowledge on some of the factors that influence long-term durability and reliability of MCM structures.

Interactions with RELTECH have had an influence on the design of, and the test plan for, the technology demonstration vehicle. We have also convinced RELTECH that electrical and mechanical performance of the C4 interconnections is not a concern under conditions in which IBM products are qualified.

The activities described above have led to participation in national level conference and workshop planning committees that will influence the direction of MCM research and development. Our participation in the university workshop activities has allowed us to influence the direction of research toward solving technological problems relevant to MCM fabrication.

5.5 Infrastructure Conclusions

Significant technical contributions and discussions were held within industry conferences and meetings with other organizations. This helped further advance the MCM infrastructure throughout the industry.

6.0 APPLICATION DEMONSTRATION

The objective of the Applications task was to select MCM applications from OEM customers that would demonstrate the foundries design, build, and test capabilities, and would also provide the customer with a beneficial packaging solution. Substrate Technology from IBM Microelectronics East Fishkill packaging foundry was used as the base to assemble the modules, with die attach, test, and encapsulation being done at the IBM facility in Poughkeepsie, N.Y.. The technology offered was the same as what is currently available to internal IBM customers, and made accessible to the customer by the development of the design kits and test strategies discussed in this report. The applications were staggered in time to allow for the development of the various design kits and to make the most efficient use of the ASEM personnel. After the selection of the applications, the applications tasks were as follows:

- ▶ Work with customer to develop MCM application
- ▶ Import netlist into design tools at IBM (as necessary)
- ▶ Release design into Manufacturing
- ▶ Verify success of substrate build by comparing to customer netlist
- ▶ Prepare die for assembly (Flip Chip)
- ▶ Assemble die to Substrate
- ▶ Demonstrate all interconnects are complete
- ▶ Encapsulate module with appropriate cap/heatsink

In all cases, the functionality of the module was not tested by IBM, and could not be guaranteed due to the absence of Known Good Die.

6.1 CUSTOMER SURVEY

6.1.1 Selection Criteria

The candidates for the Application Demonstration Vehicles (ADV) were screened based on a set of predefined criteria listed in Table 6-1. The criteria were established to guarantee timely demonstration of ASEM program objectives and fit IBM-Microelectronics Division product offerings. The list of application candidates were further screened based on the business case, strategic value, and timeliness. In all cases, the application conditions for the end product, assuming manufacturing volumes were realized, were used to size the manufacturability and reliability of the design. Manufacturing volume pricing was also compared to customer objectives to validate the business case for the product.

6.1.2 Methods of Customer Contact

The companies and individuals contacted, and applications reviewed during the selection process was extensive. Over 25 potential customers were contacted who had potential MCM applications. In addition, a number of potential customers contacted IBM directly, based on referrals or conference contacts. Initial contact was primarily made from IBM to the customer as follows:

- ▶ Call placed to customer/company requesting points of contact for discussion of multichip modules.
- ▶ Prime contact established.
- ▶ Explanation of ASEM contract and criteria for application.
- ▶ Review with ASEM Application team to determine fit to ASEM goals.
- ▶ Customer visit to review details of program and application.

A complete customer list is contained in the "Demonstration Plan" CLIN 0002AS, July 28, 1993.

ATTRIBUTE	CRITERIA
NUMBER OF DEVICES	2 - 16
TYPE OF DEVICES	CMOS
TYPE	DIGITAL
CHIP POWER	10 Watts Max.
PACKAGE TECHNOLOGY	MCM-C, MCM-D
MODULE SIZE	IBM Standard sizes up to 127 mm square
ENCAPSULATION	Hermetic, Non-Hermetic
MODULE POWER	20 Watts Max.
COOLING	Air Cooled
DEVICE ATTACH	Flip Chip, Wire Bond, TAB
MODULE ATTACH	Pin Grid Array - 0.100" Interstitial grid Surface Mount Array - 0.050" grid Edge Connect - 0.5mm pitch Ball Grid Array - 0.050" grid
DESIGN SYSTEM	CADENCE MENTOR
TEST	BIST, Boundary Scan

Table 6-1: Application Selection Criteria

6.2 SELECTED APPLICATIONS OVERVIEW

The candidates selected as Application Demonstration vehicles are SUN MICROSYSTEMS, the AIR LOGISTICS CENTER AT MCCLELLAN AFB, and NATIONAL SEMICONDUCTOR. These three candidates are selected based on a best fit to the selection criteria, the timeliness of the application, and its ability to demonstrate unique aspects of the IBM technology (refer to **Table 6-2**). Detailed descriptions of each application will be described in the following sections.

	SUN MICROSYSTEMS	McCLELLAN AIR FORCE BASE	NATIONAL SEMICONDUCTOR
DESIGN ENTRY	COMPLETED LOGIC	COMPLETED PHYSICAL	COMPLETED LOGIC
DESIGN FORMAT	CADENCE ALLEGRO	CADENCE ALLEGRO	EDIF NETLIST
DIE SUPPLY	CUSTOMER SUPPLIED OEM DIE	THIRD PARTY SUPPLIED OEM DIE	NATIONAL SEMICONDUCTOR DIE
DIE ATTACH METHOD	FLIP CHIP - IBM DESIGN	WIRE BOND	FLIP CHIP - CUSTOMER DESIGN
CARD/BOARD ATTACH	PIN GRID ARRAY	PIN GRID ARRAY	BALL GRID ARRAY
ENCAPSULATION	NON-HERMETIC	HERMETIC	NON-HERMETIC
INTERCONNECT TEST	JTAG 1149.1	NON JTAG	PHYSICAL INSPECTION
KNOWN GOOD DIE	IBM KGD PROCESS	NO	NO
TEST SOCKET	AMP "TAZ" CONNECTOR	AMP "TAZ" CONNECTOR	IBM BGA/CGA TEST SOCKET

Table 6-2: Technology Attributes of the Application Demonstration Vehicles

6.3 SUN MICROSYSTEMS

6.3.1 Product Development

6.3.1.1 Business Development Description

The first of the application demonstration vehicles was designed and built for Sun Microsystems, Inc.. Sun approached the IBM East Fishkill foundry to better understand the foundry's capabilities. IBM proposed building an MCM for Sun, and looked to find a fit for the ASEM project. The 10 chip SPARC MCM was selected.

Sun's objective is to be able to replace an existing single chip module card with a card of the same size containing two multichip modules. Sun had already completed a design for the multichip module, using the Cadence Allegro design system, and die were available in wafer form for use. Since space was one of the key drivers for the MCM, flip chip bumping was the front up approach. In parallel with the Flip Chip sizing, the module was also laid out assuming wire bond for all the die, as well as a layout which assumed wire bond for the SRAM's and Flip Chip for the Cache Controller and Microprocessor. The only design that met the size requirements and could be cooled to the required chip junction temperatures was the all Flip Chip approach.

6.3.1.2 Sun Multichip Module Description

The application is a 50MHz Multichip module, with logic designed by Sun Microsystems, Inc. containing two Texas Instruments Devices, the Viking Microprocessor and Mbus/Xbus Cache Controller, and eight Micron Synchronous 128k x 9 SRAM's. Six 0.1uF decoupling capacitors are also included in the design. The substrate is a ceramic pin grid array, 64mm x 44mm, with a non-hermetic lid and heatsink. The total module power is 20 watts maximum, with the Viking die having a worst case power of 10 watts with a maximum power density of 4 watts/cm². For testing purposes, a Tool Actuated Zero Insertion Force (TAZ) fixture was procured for this application.

The rectangular shape of the substrate provided a very high packaging density, with little wasted space on the device side of the substrate. The flip chip design provided greater than 70% silicon packing efficiency in the active device area of the substrate. A sealing area on the perimeter of the substrate provides the necessary real estate for placing a non-hermetic lid. If required, this area can be metallized to provide a hermetic seal. All wiring is contained within the substrate so that the I/O connections to the board can be made from the MCM, which in this case is provided by a Pin Grid Array (PGA), but could also be by Ball Grid Array (BGA).

The substrate is manufactured as multiple "ups" on the ceramic laminate with no wasted ceramic, thus providing the most cost efficient design. The devices were arranged on the module to provide the shortest path lengths possible between the die. The worst case path length was less than 3cm, with the most critical nets kept as short as possible. The substrate groundrules are designed to provide a 50 ohm impedance match.

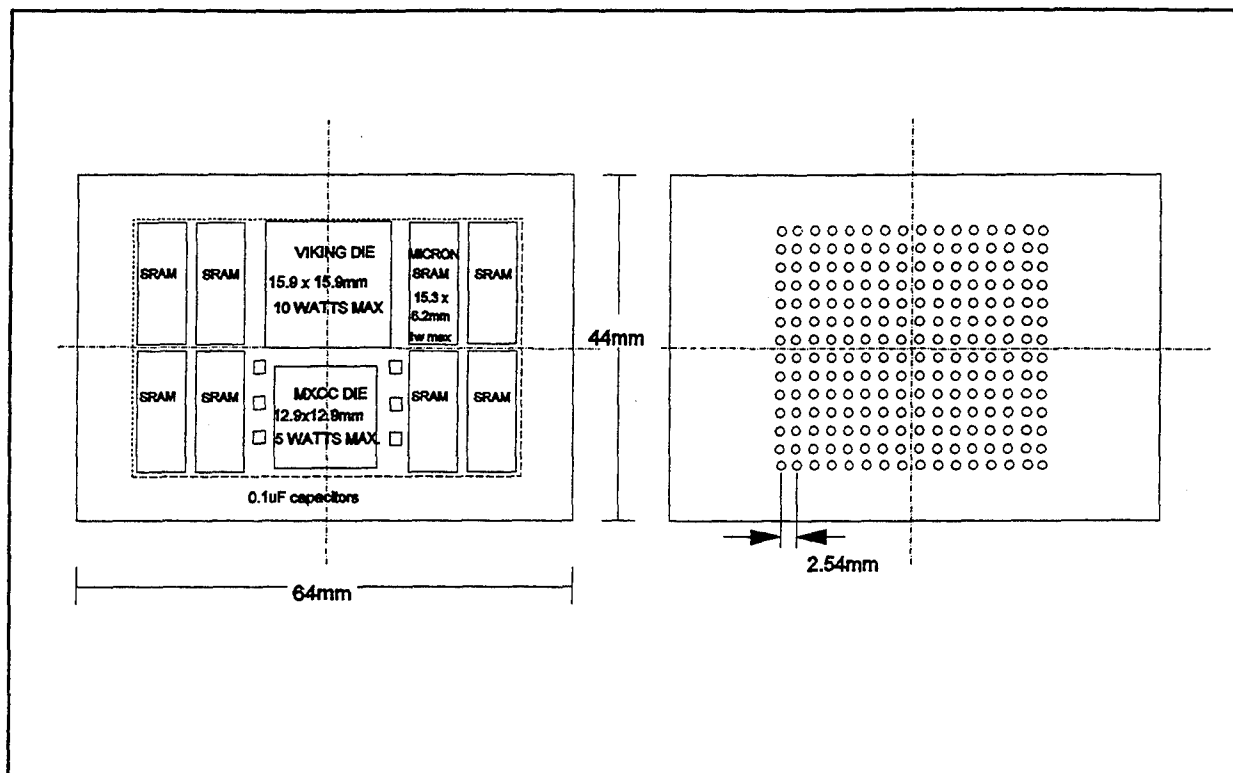


Figure 6-1: Sun Microsystems Multichip Module Top and Bottom Surface Layout

6.3.2 Sector Activity

6.3.2.1 Process Overview

The development of the MCM began with a preliminary hardcopy input from Sun Microsystems, Inc. describing the physical and power attributes of the devices to be packaged. This information, along with a description of the system environment and physical restriction, was used to generate a first pass proposal. Working with Sun, the application was refined to provide the most manufacturable, cost efficient design, while satisfying Sun's requirements. During each step of the process, IBM engineers from development and manufacturing provided input to the technical feasibility and manufacturability of the MCM package. Any changes to the package were reviewed with Sun to insure compatibility.

Upon receipt of the netlist from Sun Microsystems, Inc. the development of the MCM proceeded along five concurrent paths: electrical and physical design of the substrate; thermal analysis and design of encapsulation hardware; Flip Chip wafer bumping; module interconnect test; and module functional test. Each of the five areas proceeded with the concurrent engineering, which crossed company boundaries, such as the inclusion of test pins in the substrate design to facilitate module debug. To simplify module debug, an AMP connector was procured which provided the capability to mount and demount modules into the test board, without having to solder and desolder the modules. The design of the connector and its associated actuation device was generated based on the physical design of the module and test card.

To guarantee manufacturability of the module, a design review meeting is standard practice so that all manufacturing units responsible for the build of the module can review and concur with the design. Included in the design review process are representatives from the substrate build, bond, assemble, and test areas. A design review is also held between the companies at critical stages of the project, to insure the module and the functional test preparation converge.

6.3.2.2 Substrate Design

6.3.2.2.1 Design Support

The Sun Multichip module was designed using the Cadence 7.0 Allegro Design System. The first part of the design process is the creation of the padstacks and symbols for the various components, using their respective editors within the Allegro Design System. The amount of time required to create the padstacks for this substrate was less than 5% of the entire design cycle. The creation of symbols for the Sun module, ASCII files were created to automatically place pins and thus reduce a portion of the cycle time.

6.3.2.2.2 Logic Entry Level

The logic input for this module was supplied as a third party ASCII netlist from Sun Microsystems, Inc. Clean logic input is dependent upon the netlist and the created symbols being consistent. If this isn't the case, then several attempts at leading the logic input must be attempted. If the data is provided in a different input, usually transformation and reformatting is required and this will contribute significantly to the overall design cycle time.

Once the netlist was inputted into the Allegro system, the necessary level-to-level connections are generated. This was minimal in the overall design cycle time. The next portion of the design effort was the placement of the created symbols. A proposed outline of symbol locations was provided to the designer and this outline was to be used as the skeleton for the automatic placement for the symbols. With the symbol outline, the placement of the symbols occurred in minutes.

One part of the designer's responsibility which adds to the cycle time is any manual type of interaction with the design system. On the Sun module, the manual interactions involved redistribution from off-grid to on-grid locations for the MXCC and Viking devices and overflow routing in nets which the automatic router can not complete the connection. These two tasks represent a major percentage to the overall design cycle time (at least 33%). For rapid prototyping where turn around time is of utmost importance, the nets can be connected almost entirely by the router, which was the case in the Sun prototype. The design was routed in three X-Y plane pairs, but was followed up with a two X-Y plane pair design, with hand routing of multiple overflow nets. In volume manufacturing, it is much more cost effective to wire the substrate in as few layers as possible where the material and build cycle time savings can warrant the added design time.

6.3.2.2.3 Release

Once the design was completed, the top and bottom surface design drawings were imported to a CADAM tool where the substrate tolerances were placed on the drawings. A substrate layer drawing was also generated, describing the function of each of the individual substrate layers. The drawings were placed on the IBM part number list, controlled by a Product Engineer, with all changes requiring concurrence by the engineering team responsible for the project (Team consists of Manufacturing, Product, Development, and Applications Engineers). The substrate was not built on the Manufacturing line, but on the prototype line, using an Electron Beam tool (E-BEAM), which produces substrate layers without using metal masks. The design data, normally sent through the standard direct release process, was instead provided to the Engineer

responsible for the Electron Beam (E-BEAM) tool. The engineer converted the data to a tool format, and proceeded with the build of the module.

6.3.2.3 Substrate Prototype Build

The ceramic green sheets used for the multilayer ceramic were personalized using a high power electron beam system, or E-BEAM. This quick turn-around, high precision and high resolution system provides an ideal process for the timely development of specialized ceramic packages in prototype volumes. This is the result of E-BEAM's ability to personalize green sheets using a direct write instead of a glass master and metal mask as the typical personalization methods involving paste screening use. By using the E-beam for prototype build, the NRE savings for the substrate build is approximately 80% and the turn-around time savings is approximately 33% over traditional punch and screening methods.

Once the greensheets were personalized by the Ebeam tool, they were stacked, laminated, and sintered according to conventional ceramic substrate fabrication. The initial substrate lot was tested for capacitance and the 'chip to chip' and 'chip to I/O' connections were tested and compared to the netlist to verify that the substrate hardware completely matched the netlist. The parts were then overplated with nickel and a thin layer of gold to provide a wettable surface for device attach. Thick gold was not required for the module due to the absence of any wire bonded components.

6.3.2.4 Flip Chip Bumping

6.3.2.4.1 Design Considerations

In parallel with the substrate build, the Viking and MXCC wafers provided by Sun Microsystems Inc. were being prepared for Flip Chip (C4) bumping. The periodicity of the Flip Chip bumps is optimized at 0.010" with bump diameters of approximately 0.005". Both the Viking and MXCC die are designed for wire bond, and the pitch for both die was less than what was practical for flip chip bumping. A layer of wiring was added to the die to redistribute the I/O to the 0.010" pitch, with two rows of bumps for the Viking, and three rows for the MXCC. Die designed for flip chip eliminate the need for redistribution and also potentially reduce the amount of silicon required for I/O interconnection. The SRAM's did not require redistribution because the wire bond pad periodicity was within the limits of the bumping process.

6.3.2.4.2 Implementation

A layer of passivation was deposited on all wafers, vias opened to connect to the underlying metallization, and the Flip Chip pad was formed. The Lead/Tin solder ball was then formed on the die, and the die were diced and picked.

In keeping with Sun's objective of having the capacity of placing two multichip modules on the current Mbus card, the flip chip bumping of all the die significantly reduced the required substrate area by eliminating the need for wire bond pads. Flip chip bumping, coupled with the advanced thermal compound between the die and cap, provided a very efficient thermal path without having to reduce substrate wire density, necessary when thermal vias or heat studs are required. The area array capability of the flip chip technology was more than sufficient to handle the I/O of the microprocessor and Cache controller.

6.3.2.5 Module Design

6.3.2.5.1 Cap and Heatsink Development

The MCM substrate design was influenced by the need to cool the MXCC and Viking die to an acceptable temperature which provided both performance and reliability. The devices were placed adjacent to each other to minimize the path lengths between the die. They were oriented on the module to receive parallel airflow so that there would be no air heating effect from one die to the next. As mentioned previously, an advanced thermal compound was used between the chip and cap to provide a very efficient thermal path. With a very low internal thermal resistance from the back of the die to the cap, the bulk of the heat transfer is through the die into the cap, and out the heatsink. The gap between the cap and die is controlled very closely to minimize the internal thermal resistance. The SRAM's and the capacitors do not have thermal grease because the lower power requirements of the SRAM's and capacitors did not create a demand for thermal enhancement.

A unique feature of the design was the requirement to provide a backside electrical contact to the die after assembly of the module. The MXCC and Viking die required a drain for the backside bias, and since the chips were face down, the drain could not be by direct contact between the die and substrate. Two techniques were considered; 1) electrically conductive thermal paste and 2) A spring loaded contact between the cap and die. The thermal paste has been fabricated and tested for other applications, but since the die rework was a requirement for the package, there was concern that the conductive grease could get under the die and cause a potential short between Flip Chip I/O pads. Non-reworkable modules would have an encapsulant below the die, which would prevent the conductive grease from contacting the I/O connections. The spring contact was chosen and prototype caps were built and demonstrated successfully.

The system application conditions are consistent with desktop/deskside environmental conditions. During the thermal modeling and design of the module, system airflow, inlet air temperatures, physical size restrictions, and altitude adjustments had to be considered to predict worst case chip junction temperatures. Based on the above worst case system definitions, an external thermal resistance was calculated that would meet the maximum chip junction temperature limit. Commercially available heatsinks were sought, but none could be found which met the requirements, so a custom heatsink was designed. The heatsink was designed to overhang the module because the demountable connector chosen for prototype evaluation increased the overall height of the assembly by 9 mm, thereby reducing the available height in the system for the module. Once the need for the demountable connector is eliminated, the heatsink will make better use of the Z-axis height in the system.

6.3.2.5.2 Release

The module release process for the Sun MCM was the most complex of the Application Demonstration vehicles. A unique cap and heatsink were designed to fit the 64mm x 44mm size, and CADAM drawings were generated for both. The drawings were used by the vendor to build the hardware, and were also used to develop the overall module assembly drawings. As with the substrate drawings, the module drawings were assigned Part Numbers, which are on record and require the necessary engineering team concurrence prior to change. Documentation was also generated for the test sockets, but Part Numbers were not generated. The Flip Chip pad layouts were also documented with CADAM drawings.

6.3.2.6 Module Assembly

Once both the substrate and bumped die were available for assemble, a Flip Chip furnace profile was established for the module, and the die were reflowed to the substrate. The capacitors were also reflowed to the substrate subsequent to the die to 1) preserve their electrical performance, and 2) be consistent with

temperature hierarchy of the solders used for Flip Chip (97Pb/Sn) and the passives (63Pb/Sn). After the die were bonded to the substrate, the parts were tested to guarantee all the Chip to Substrate I/O were electrically connected. This was to insure that the die bumps, redistribution, and substrate I/O were making the correct contacts. Once tested, the modules were encapsulated with a thermally conductive grease between the die and the module lid, and the heatsink was placed on top of the module.

The connector chosen for the evaluation was an AMP Tool Actuated Zero Insertion Force (TAZ) connector. It was designed to accommodate a 25 x 25 array of pins. A unique actuation tool was designed which provided sufficient clearance for the heatsink during actuation. The connector was solder reflowed to the card similar to a PGA package, and the MCM's were inserted in the connector and actuated. Once testing of the module was complete, the module is removed from the connector, and the process is repeated on the next module.

6.3.2.7 Interconnect Test

The Sun Super Sparc Mbus MCM assembly interconnect test was generated and debugged concurrently with the installation and debug of the Victory software package. This combined process complicated many aspects of the overall process because of uncertainty in the test data input to the system. The initial test development and debug process was done using a circuit card version of the Mbus MCM and was tested solely through the TAP port using the ASSET scan port driver. The Asset tool also includes Victory package as its ATPG resource. The ten chip set used in ADV1 consists of 8 - 9 bit by 256k SRAMS which is organized as a 64 bit plus 9 bit parity memory, a 1149.1 compatible Super Sparc 64 bit RISC processor and an 1149.1 compatible MXCC Mbus Cache controller. The signal architecture of the MCM is illustrated in Figure 6-2 and shows the basic signal topology of the MCM. Physical features added to the MCM for improved testability include an observe point in the 1149.1 scan chain between the RISC and the MXCC, an observe point on one of the SRAM parity lines and module I/O access to the SRAM output enable control signal.

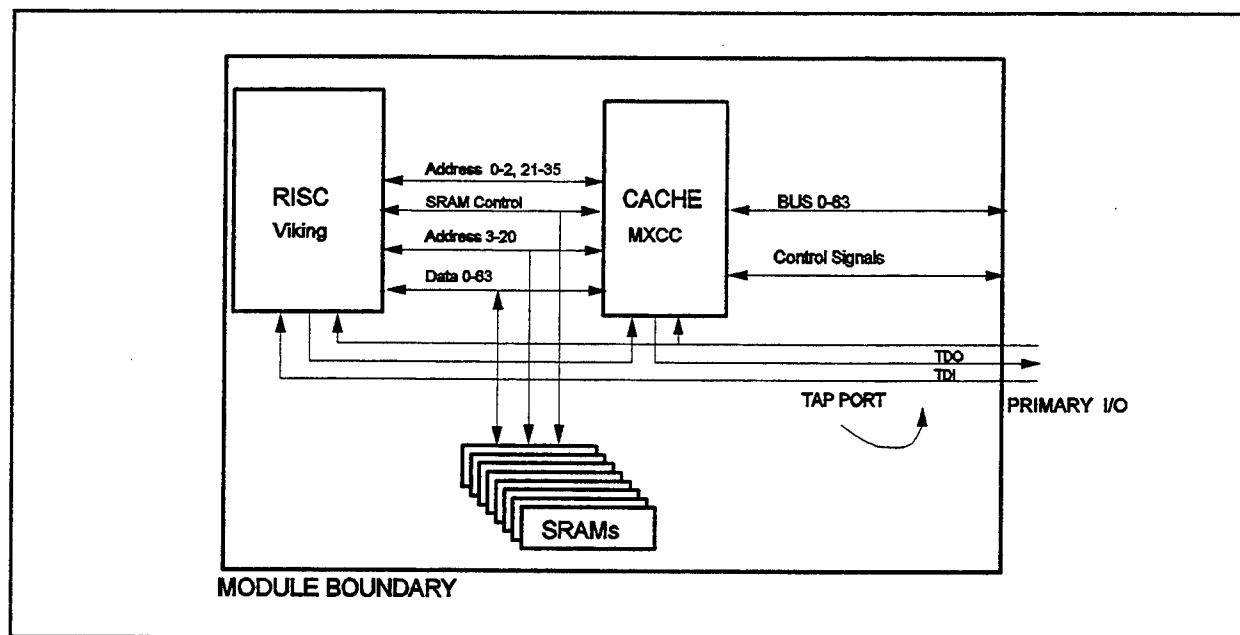


Figure 6-2: ADV1 - Module Signal Architecture

6.3.2.7.1 Test Plan

The test plan for the ADV1 module consists of a parametric test for power ground shorts and an assembly verification interconnect test which assures continuity of all bonds. Test data was supplied by Sun in the form of hard and softcopy documents and included device BSDL and an EDIF netlist. The EDIF netlist was for the MBUS card while the netlist used for the MCM itself would be obtained internally from the Cadence physical design tool. Hardware descriptions for the SRAM devices was obtained from hardware specification sheets published by the die supplier (Micron.) The interconnect test patterns are generated automatically and manually dependent on available 1149.1 test resources. A prototype board, tested through its TAP port using the ASSET tool, was to be used for database verification. The final MCM product is interconnect tested using the flexible hardware fixturing and a DAS9200 based scan tester. Die supplied in wafer form by the customer are not considered KGD. C4 bumped die are to be mounted on temporary chip carrier single chip modules for production of known good die. Functional test of the module is to be performed by the customer using a system level self test after insertion of the module into a system level MBUS card.

6.3.2.7.2 Test Pattern Generation

Victory Automatic Test Pattern Generation was used to provide test coverage for all interconnects between 1149.1 devices on the MCM. Although the reduced pin TAP port was used for test access, a 1149.1 based test fixture was used to observe and stimulate all primary MCM I/O. Access to the MCM primary I/O was enabled by embedding the MCM inside a "ring" of 1149.1 compliant bus transceivers. The test fixture BSDL descriptions and netlist connectivity were combined with the MCM database to enable ATPG interconnect testing of the primary MCM I/O. For this product, ATPG has provided open and short coverage for approximately 60% of the total 267 nets and partial coverage (approximately 66% complete open and shorts) for the remaining nets. Nets not fully covered by Virtual Interconnect Test Generation (VITG) were the SRAM branches of address and data nets and SRAM control signal group nets with only single ended boundary scan cells. Test coverage was extended to the partially covered nets using test patterns generated manually from data sheets and the Victory Virtual Component Cluster Test (VCCT). To minimize any delays, debugging of the Victory test software and the test generation process was accomplished concurrently using a printed circuit board version of the MCM. The card was tested using the ASSET test system from Texas Instruments.

To ensure that the SRAM data bus drivers were not enabled during VITG, a value was forced onto the SRAM(s) Output Enable receiver(s.) The forced signal level was accomplished by altering the BSDL descriptions for both of the 1149.1 devices on the net. One side of the net was changed to hide the driver control from Victory while ensuring the output enable bit was never altered from its disable value. The other side of the net was altered to always drive the correct value onto the net. The result was unique BSDL descriptions for the VITG and VCCT portions of test program.

VITG MBUS Card Test Results

After a great deal of preliminary learning and adaptive efforts, the MBUS card was successfully tested using an "automatically generated" SVF file. The BSDL descriptions included a manually generated BARE_DIE pinmap and were debugged in an iterative process by successively generating the ATPG portion of the card interconnect test, then testing the card and finding the root cause of test failures. Since the card was "known good" most failures could be ascribed to hardware description errors. A summary of the coverage provided by the ATPG portion of the test, valid for both the MBUS card and MCM, is provided in Table 6-3. The time spent on the card was very worthwhile since numerous errors were discovered in the supplied BSDL descriptions and uncovered several undocumented Victory problems. Overall the ATPG and BSDL

environment using Victory has great promise of providing a quick TAT and low cost assembly test process.

As previously stated, VCCT testing was performed individually on all eight SRAMs. The original test plan treated all eight SRAMs as a single cluster, however VCCT testing (per Victory release 2.1) had to be performed on a component-by-component basis. A consequence of this component test methodology was that a unique Victory PFA and ACT file was required for testing each SRAM on the brassboard and MCM.

OPEN / SHORT COVERAGE	VITG	VITG + VCCT
Fully covered	131	242
Partially covered	111*	0
Shorts covered	4	4
Some opens covered	3	3
Not covered	12	12
Covered by TAPIT	6	6
(Number of covered nets / total nets) x 100	81.4%	95.5%
* Derated by approximately one third		
Partially covered nets may have an uncovered branch or may be single ended. A single ended net refers to a net having only one observe/stim point. Partially covered nets are derated by the fraction of branches not covered.		

Table 6-3: ADV(1) Interconnect Test Coverage

Manual Test Pattern Generation

A specific test data file was manually generated from data specification sheets for each SRAM. Unique data was written to the SRAM memory and addresses using walking patterns selected to test each separate address line. The tests check for opens and shorts between every two I/O nodes on the SRAM. Because known good die was assumed, extensive in circuit tests were not conducted to verify internal SRAM integrity. Data read back from the SRAMs is used to determine interconnect integrity. The output enable, write enable lines were set by input vector patterns but because these are synchronous memories a clock also had to be applied to initiate actions and cycle the SRAM functionality. Checking of control signals and clock interconnect continuity is a by product of the correct functioning of the SRAM test data patterns. Parity bits, as defined in the module design, are actually the ninth data bit for these particular memories and were tested accordingly. The SRAM test patterns start by initializing the lowest address to zeros and the highest address to ones. Then unique 9 bit words were written to addresses selected by a walking one. On readback, a short to ground or an open pulled/floating low, in the address bus would be identified by the associated data being written to address zero instead of the planned address. If a short was to the power rail or an open pulled/floating high, the word would be written into where it was expected to go into memory, however the complement pattern set would write the unique word into the all ones address rather than the correct address thus allowing a definitive diagnostic. Referring to data line interconnects, either a short or an open in a data bit would be reflected by incorrect data on readback from either the original or complemented data.

After a significant investment of time, an SVF file was produced which successfully applied a walking ones test to the MBUS card SRAMs. The knowledge, and detailed process required to use the VCCT tool was then applied to the database for the MCM.

6.3.2.7.3 Known Good Die (KGD)

The die used in the ADV1 design are not considered as KGD. For each die type, wafers were received from the silicon fabricators with either a map or dot marked indicator of die passing the wafer level sort test. Since wafer level sort testing is usually not an at-speed test *and* is not exhaustive, the probability of defective die was assumed to be quite high. This assumption needed to be made because the wafer suppliers were either unwilling or unable to supply the expected versus actual yield information needed to plan assembly yields. Also, for the Super Sparc and MXCC die, the manufacturer was unsure if the 1149.1 resources were adequately tested during wafer sort which directly impacted the ability to deliver known good MCM assemblies. Additionally each of the die used in the ADV1 design were C4 bumped and in the case of the Super Sparc and MXCC die, had redistribution metal applied to transform the wirebond footprint to an area array prior to C4 bumping. The added level of complexity and added potential sources of error introduced by bumping, redistribution and lack of expected yield data suggested to us the need for a way to isolate problems which could and did occur.

Because the die were all C4 bumped, an internal(at the time) technology for temporarily attaching the die to single chips modules could be used for testing. Briefly, the temporary chip attach method uses spring force to press the die C4 against a contact pad which has a proprietary plated palladium dendrite structure. The dendrites may be formed on many different material systems but in this case we used our standard ceramic substrate. Thermal control is provided by the spring containment structure which has integral cooling fins extending upwards from the ceramic carrier. An example of the TCA module package is illustrated in Figure 3-10 in Section 3.4, Known Good Die.

For the Super Sparc and MXCC die, the single chip packages currently in use for those products were mimicked, which is a multilayer ceramic PGA having SMT decoupling capacitors. The TCA module used for the SRAMs was a metalized ceramic PGA. The following sections will describe the test methodology used for each of the three different die types. The test methodology focuses primarily on detecting faults associated with our performing the interconnect assembly verification test.

SRAM

The TCA module used for the SRAMs was a 50mm metalized ceramic substrate with a 2.54 mm pin grid array. The testing of the TCA module was performed on an IBM designed ATE, at full MCM system speed of 50MHz. The test patterns were manually generated and were directed at two different fault types. The first fault type are faults that would impact our ability to perform interconnect verification test. These vectors toggled the address lines and memory locations which we would be using to verify assembly interconnects. The second set of patterns was aimed at flushing out the most likely at-speed types of faults. The faults are slow to rise/fall driver/receivers and adjacent pattern sensitive faults. Results for the SRAMs showed all TCA die to function properly for the required functionality needed for the interconnect test and for the base set of sensitivity patterns done at-speed.

Super Sparc and MXCC

The Super Sparc and MXCC TCA modules were fabricated using 50mm multilayer ceramic substrates having 293 and 363 pin grid arrays on 1.27mm centers. The I/O footprint of each of the substrates was laid out to be exactly the same as the commercially available packaged SCM parts. The netlists for the substrates

was supplied by Sun Microsystems. The TCA modules were also used to verify BSDL descriptions and 1149.1 hardware functionality as a screen for interconnect assembly verification test. The TCA modules were tested by socketing them into LIFs which had been hardwired to supply power, ground and lead-to-lead interconnectivity. The lead-to-lead netlist was developed manually and interconnected as many nets as possible in order to test the temporary contacts and the die drive/receive circuitry. The netlist and BSDL data was used with Victory ATPG to generate the test and the TI ASSET tool was used to drive the test. Coverage for these tests included all signal nets with the exception of clocks, Mbus/Xbus select and the reset line.

The TCA modules were also used to establish or screen die parametric parameters. Resistance measurements between the power and ground planes were not possible at the die level because of probing and handling concerns and were not possible at the module level because the power planes are commoned. The results for parametric screening provided determination that the Super Sparc die had a VCCC to GND resistance which was well below the level measured on SCM parts (100 vs. 5000 Ohms.) The specification values we obtained from the SCM packages was confirmed by Sun. Failure analysis on the die, which consisted of resistance measurements taken before and after removal of the IBM applied redistribution, showed the low resistance was integral to the die. There was no observed impact on 1149.1 functionality due to the low resistance plane. Sun was informed of the finding and took it under advisement. The MXCC die were all observed to match the parametric behavior of their corresponding SCM parts.

Results for BSDL description screening uncovered several errors in the BSDL descriptions for the Super Sparc and MXCC die. The errors were similar to others observed during the early ATPG and test vector development but were unresolved because of insufficient diagnostic resolution. The errors in the BSDL were in this case port descriptions which were switched in position. The use of the TCA modules provides unambiguous results for a device as opposed to the results provided by two or more devices on a net. The TCA process also provided the ability to resolve several transcription errors which had occurred earlier in the design phase and had been caught by 1149.1 testing but not yet been assigned to cause.

6.3.2.7.4 MCM Interconnect Test

MCM interconnect test used the process and BSDL developed during the initial debug work and TCA module testing. This information was combined with the MCM netlist to produce automatically generated interconnect test patterns and to format the manually generated memory interconnect test patterns. The SVF output of the Victory tool was translated to our tester format and the product specific socket mounted in the thermal cooling assembly. For this design the cooling assembly was adapted to provide backside grounding of the Super Sparc and MXCC die using a pogo like spring contact.

Test coverage for the MCM is reported in Table 6-3 for both VITG and VITG+VCCT sections of the test. The 1149.1 based test was quickly able to detect and isolate open or shorts in the MCM assembly. Using the test information repair orders were generated and the prototype modules were successfully reworked.

6.3.3 Conclusions

The selection of the Sun MCM as the first demonstration vehicle provided the opportunity to demonstrate the ability to accept a Cadence netlist into the factory. Since the netlist had already been debugged by Sun, incoming design errors were minimized and the substrate physical design proceeded smoothly.

The build of the Sun Microsystems Substrate using the E-BEAM prototyping tool was proven to be successful through testing the substrate per the supplied netlist. After the first build of the Sun substrates, a requirement for a separate power plane for the Viking die was defined. Using the E-BEAM tool, which does not require metal screening masks, provided a very easy path for rebuilding the hardware. Once the new design was completed, the parts were rebuilt without incurring the Non Recurring Expense charges of the masks. The redesign was accomplished without changing the wiring layers or adding additional power layers to the substrate. The new voltage 'layer' was added by partitioning a section of the existing power plane below the Viking die. The design in the 44mm x 64mm format was a new form factor for the foundry. Since then, additional projects have made use of the form factor, using the same tools and fixtures.

The module was successfully interconnect tested using the 1149.1 resources of the Super Sparc and MXCC die as well as manually generated write/read cycles applied to the SRAMS using the available boundary scan resources. A test coverage of 95.5% of all possible nets was realized with 100% coverage of boundary scan accessible nets. The nets not covered consisted primarily of power/ground nets, signal level control nets, clock inputs to the large ASICs and mode select signals. If debug of data integrity problems and Victory software bring-up are neglected, the test generation process was straight forward and met our expectations.

Establishing a known good die methodology for the Sun module was the most critical accomplishment of the project. The use of TCA for the ADV1 MCM provided a useful means of die isolation and access for verification of device BSDL, single chip module netlists and dendrite contact verification. Furthermore the process yielded die which were guaranteed to function properly for assembly verification test. Tested Super Sparc and MXCC die used in the final module assembly verification test allowed elimination of a class of faults which otherwise would have had to be considered and facilitated a reduction in the complexity of MCM diagnostics.

6.4. SACRAMENTO AIR LOGISTICS CENTER (SM-ALC)

6.4.1 Product Development

6.4.1.1 Business Development Description

SM-ALC's objective for the MCM was as replacement hardware for the existing Data Transfer Module. The ADTM is intended to be used for transferring Operation Flight Programs to the F-111 aircraft. Each Operation Flight Program (OFP) is approximately 512K 16 bit words of instruction code where a total of 640K words are actually needed when check-sum and variable initialization requirements are included. Therefore, the ADTM is sized for 640K 16 bit words of program data storage. Current aircraft avionics require the OFP's to be loaded into flight computers using a magnetic tape system that is prone to malfunctions and requires access to aircraft equipment bays. The F-111 also has a cockpit socket which can be used to transfer the OFP into the aircraft flight computers using an existing 32K word DTM. The ADTM design used the cockpit flight computer interface socket to load the entire OFP, eliminating the need for the tape system and replacing the limited capacity 32K DTMs with a single ADTM.

6.4.1.2 Document of Execution

A document of execution was generated describing the responsibilities of both IBM and Sacramento ALC. The document contained descriptions of the module and a schedule of key program activities.

6.4.1.3 Hardware Description

The Advanced Data Transfer Module (ATM) application includes a multichip module (MCM) consisting of ten Atmel AT28C010 EEPROM memory devices, one Xilinx XC4005A Field Programmable Gate Array (FPGA) and six 0.1 μ F decoupling capacitors. The nine layer Alumina hermetic MCM-C module is 44mm x 64mm with wire bond die interconnects and a 95 pin MCM I/O array (Figure 6-3). The MCM is mounted on a single printed circuit board that includes the ADTM connector, a DC to DC converter, I/O driver IC's and a serial PROM for configuring the FPGA.

A rectangular shape for the substrate was used to allow for an optimized manufacturing process. This shape provided the necessary wiring density for the application, while also leaving minimal unused space on the top surface of the MCM. The substrate size and pin array were the same as the Sun Microsystems MCM, and therefore the fixtures developed for the Sun MCM could be used for this application, thus reducing the Non Recurring Expenses (NRE). As mentioned in the Sun Microsystems application demo vehicle (ADV) section, the substrate was manufactured as multiple "ups" (six in this case) on the standard IBM 127mm ceramic laminate. Using six "ups" on the laminate left little unused ceramic and resulted in a very cost efficient design. The path lengths for the devices were optimized with the longest net length being 1.76mm. Also, as with the Sun ADV, the substrate groundrules were designed to provide a 50 ohm impedance match.

6.4.2 Sector Activity

6.4.2.1 Process Overview

The development of the MCM began with a hardcopy proposal from SM-ALC for a solution to their DTM problem. The proposal outlined the physical and electrical attributes of the devices to be packaged on the substrate. This information, along with the system information including environmental, physical and power, allowed the application team to generate a preliminary proposal. Working with SM-ALC, the application

team was able to refine the proposal to provide SM-ALC with a cost effective, efficiently manufacturable MCM which met their overall application requirements for the DTM.

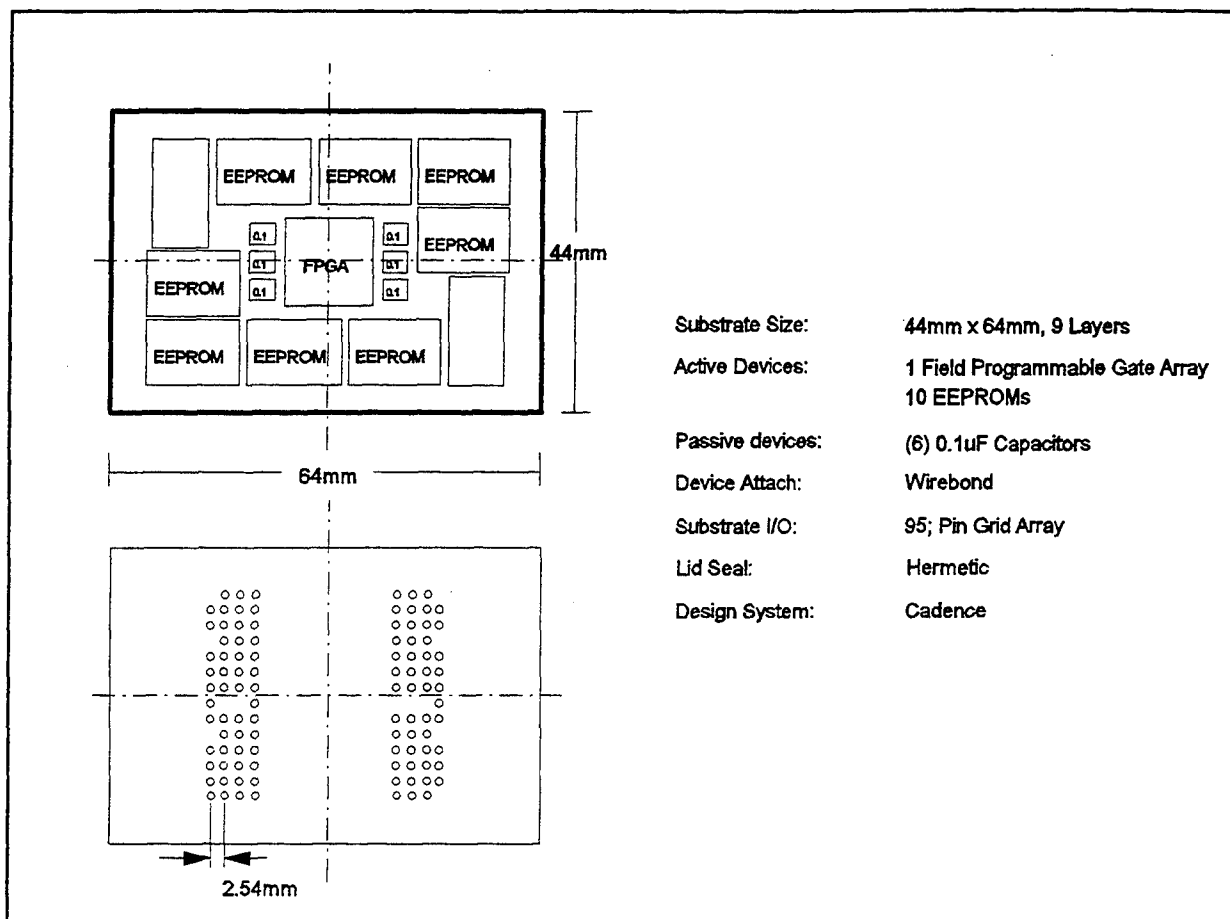


Figure 6-3 : Sacramento ALC MCM

6.4.2.2 Substrate Design

Once the system inputs for the refined MCM application were obtained, the next part of the process was to get SM-ALC set up with the Cadence 8.0 Design System. IBM, Cadence and SM-ALC worked together to get the 8.0 design system software running at the SM-ALC facility so that the logic and physical design could be accomplished. SM-ALC performed both the logic and physical designs using the IBM SCM/MCM Design Kit. The detail of the design process is described within the Sun ADV section of this report. The final physical design was then sent over the Internet by SM-ALC and inputted into the IBM internal design system for design checking.

While the logic and physical design was being performed at SM-ALC, the interconnect test development was being done concurrently within the IBM Poughkeepsie facility. This concurrent engineering activity allowed for a reduced product cycle time as the substrates were ready for testing as soon as die bonding was completed.

6.4.2.3 Substrate Prototype Build

The ceramic green sheets that were used for the MCM substrate were personalized using a mechanical punch tool. Using a mechanical punch system allows for high precision and rapid raw machine time for medium to high volume packages. Once punched, the ceramic green sheets are screened with a molybdenum paste. The remainder of the multi-layered ceramic build for the substrate was the same as the Sun ADV as described in the earlier section, including test, plating and pin braze. The one minor difference was in plating, where a thicker gold was used in order to allow for wire bond device interconnection.

6.4.2.5 Module Assembly

After the substrate was deemed a "known good substrate" (KGS) from open and short continuity testing, the EEPROMs and FPGA were attached and wire bonded to the top surface of the substrate. The capacitors were joined to the surface of the substrate using solder reflow. The modules which passed assembly verification testing were now assembled using a ceramic cap. Solder reflow was also used for prepping the seal band during capacitor attach. With the seal band ready for encapsulation, the ceramic caps were assembled to the MCM and the modules were tested for hermeticity.

6.4.2.6 Test

The signal architecture of the ADV2 MCM is illustrated in Figure 6-4 and shows five banks of 16 bit wide and 64k deep Electrically Erasable Programmable Read Only Memory (EEPROM) memory accessed and controlled by a Field Programmable Gate Array (FPGA). The illustrated 4005 Xilinx FPGA is compliant with the 1149.1 test standard. The connections between the FPGA and the five banks of EEPROMs are buried nets without physical probe access. The remainder of the FPGA leads are brought out to the module I/O for either programming the FPGA, observing the FPGA internal/external states or for use in future reprogrammed MCM configurations. The data is transferred into and out of the module using a serial protocol, while the module itself is brought to the aircraft by sneaker net.

6.4.2.6.1 Test Plan

The test plan for the ADV2 module consists of a parametric test for power ground shorts and an assembly verification interconnect test which assures continuity of all bonds. Test data was supplied by Sacramento in the form of hard and softcopy documents and included device BSDL and Cadence netlist. Hardware descriptions for the EEPROM devices were obtained from hardware specification sheets published by the die supplier. The interconnect test patterns are generated automatically and manually dependent on available 1149.1 test resources. A prototype board, tested through its TAP port using the ASSET tool, was to be used for database verification. The final MCM product would be interconnect tested using the flexible hardware fixturing and a DAS9200 based scan tester. Die supplied by the customer are mature designs and are considered as being close to KGD. Final functional test is performed by the customer using a Genrad tester after insertion of the module into its second level system.

6.4.2.6.2 Automatic Test Pattern Generation (ATPG)

Assembly verification test for ADV2 uses an automatically generated vector set and a manually generated set of vectors. The ATPG portion of the test checks for opens and shorts between the FPGA die and the module I/O. Using the FPGA BSDL description, MCM netlist and EEPROM characteristic files, Victory VITG is used to generate the SVF file containing the ATPG vectors. The BSDL description was received directly from Xilinx using their bulletin board service. Notification was made to Sacramento and Xilinx concerning the alteration made to correct their supplied version of the FPGA BSDL. The customer performed the MCM

physical design using the Allegro layout tool and as such supplied the netlist directly to the foundry. Nomenclature mismatches were not observed when testing this MCM.

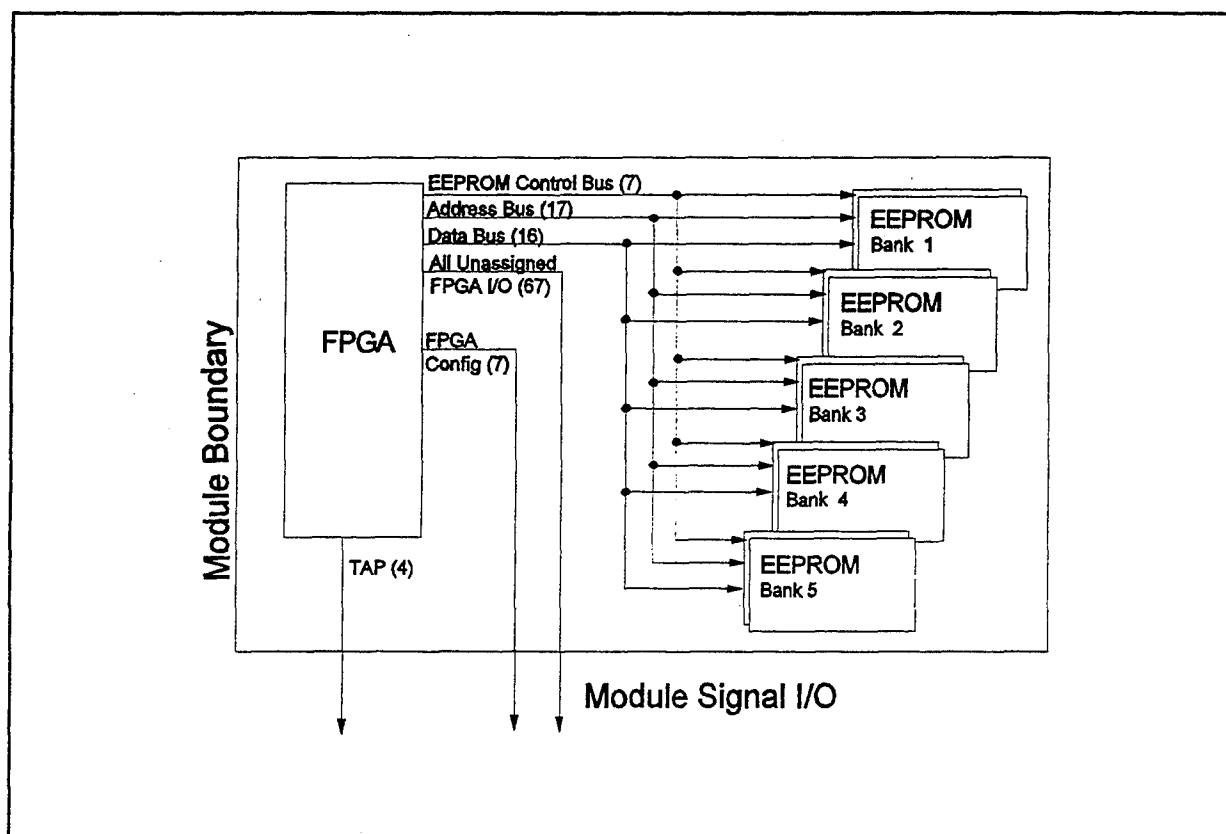


Figure 6-4: ADV2 Module Signal Architecture

6.4.2.6.3 Manual TPG

The vectors required to test the interconnects to the EEPROM devices were manually generated from the device specification sheets and consisted of write/read cycles. Because the EEPROM design read/write vectors had to be written in 128byte blocks and then electrically written into ROM, this process required a pause to be included in the vector application process due to the write operation being a relatively slow operation requiring several milliseconds. The vector set itself is similar to that used for ADV1 with the difference being in the number and organization of the address lines and not requiring a clock strobe.

A prototype board was used for test data verification during MCM build and proved valuable in flushing out problems before they impacted the delivery schedule. The board was used to verify and debug the power on procedures, the FPGA BSDL as well as the exact protocol for EEPROM write/read cycles. The board was also used to develop a test for the few non-1149.1 compliant signal lines on the FPGA. A null (or all zeros) program was loaded, using the serial input and control signals until the 8k FPGA program block was filled. The test observed the program completion signals for activity following the loading of a FPGA program thereby establishing the connectivity of the targeted signal lines.

6.4.2.6.4 MCM Interconnect Test

Interconnect test coverage for the ADV2 module is presented in Table 6-4 and is 98.4% overall and is 100% for all signal lines. The test generation process and integration with the test fixture went very smoothly and resulted in the ADV2 MCM assembly verification testing to be completed on schedule. With regard to the benchmarking data presented in Figure 3-14, Section 3.5, Data Integrity, additional effort was required for debug of the BSDL and test procedures prior to receipt of the MCM, underscoring the need for complete and verified data. One benchmark category, Test Pattern Generation (TFG), was right on the target of approximately eight days. The contributors to the success of this task were a single nomenclature, timely receipt of all required information, access to a prototype board and our increased experience in applying manually generated patterns through Victory and the 1149.1 test architecture.

OPEN / SHORT COVERAGE	VITG	VITG + VCCT
Fully covered	70	113
Partially covered	0	0
Shorts covered	43*	0
Some opens covered	2	2
Not covered	0	2
Covered by TAPIT	5	5
(Number of covered nets/total nets) x 100 *Derated by 100%	64.1%	98.4%
Partially covered nets may have an uncovered branch or may be single ended. A single ended net refers to a net having only one observe/stim point. Partially covered nets are derated by the fraction of branches not covered.		

Table 6-4: ADV2 Interconnect Test Coverage

6.4.3 Conclusion

The Sacramento Air Force Logistics Center MCM application was successfully built and all interconnects were verified using electrical testing. Although a straightforward design, the application provided the opportunity to demonstrate acceptance of a completed physical design into the IBM design system. IBM personnel worked directly with SM-ALC to develop their physical design capabilities on the Cadence system.

The substrate build used conventional alumina thick film materials and was manufactured on the high volume line in the foundry, demonstrating low volume build capability in the line. The module used tooling and fixtures put in place for the Sun ADV form factor, thereby helping to reduce the NRE expenses. The module was fabricated using off the shelf wire bond die, which were known to function as required, reducing the risk of assembling bad die to the MCM.

The customer was able to assemble the completed module to the test board developed for the project and functionally test the module.

6.5 NATIONAL SEMICONDUCTOR

6.5.1 Product Development

6.5.1.1 Business Development Description

The third application demonstration vehicle was designed and built for National Semiconductor, based on a logic design provided by National. The end user for the module is E-SYSTEMS, who will use the module as a Digital Signal Processor for a SATCOM modem. The use of high density flip chip technology provides a conduit for breaking up a very large die into multiple, smaller, higher yielding die which can be fully interconnected without losing any circuit capacity. National Semiconductor required high density I/O on both the chip to substrate and substrate to board connections and both were achievable using Flip Chip and Ball Grid Array. National Semiconductor approached the IBM foundry through the Request for Sizing process, describing the technology requirements of the package. The foundry, through the ASEM team, then worked with National to develop the current design configuration.

6.5.1.2 Document of Execution

The National Semiconductor application was the first of the ADV's to be designed and built under ISO 9000 certification. A Document of Execution is required for all new programs and documents the program plan and module description in detail. No new product can be built without the document in place. Since this is a prototype build only, the appropriate Prototype document format was used. The document was generated and provided to National for review. Upon approval, it was inputted into the foundry, and has been updated according to a predefined schedule. The Program Manager is solely responsible for the updates.

6.5.1.3 Hardware Description

The design consisted of four Custom Logic Array (CLAy) devices on a 32mm square substrate. The four die on the MCM are identical, and are wired in a symmetrical pattern that provided the opportunity to wire the substrate using tighter line widths and spacings than conventional thick film modules. The off module I/O are through a Ball Grid Array, with a pitch of 0.050", providing a total of 625 I/O on the 32mm substrate. The lid design is a standard aluminum non-hermetic cap with no thermal enhancement.

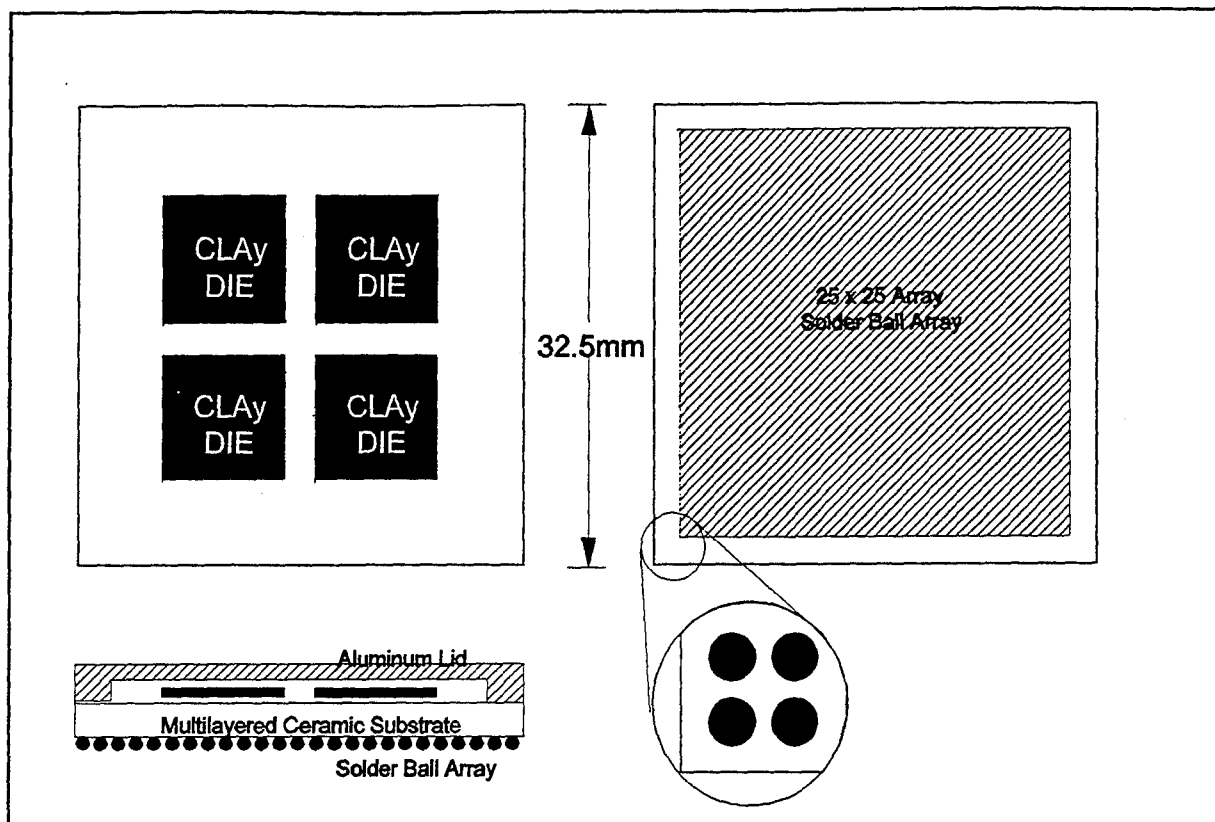


Figure 6-5: National Semiconductor CLAY MCM

6.5.2 Sector Activity

6.5.2.1 Process Overview

National Semiconductor requested proposals for the CLAY MCM through the IBM Request for Sizing process. A number of module options were proposed in both thick film (MCM-C) and thin films (MCM-D).

When the decision was made to use Thick film technology, there was considerable interaction between the electrical analysis group at IBM and National Semiconductor. Through this interaction, the current wiring layout was generated. Once this was completed, the project proceeded along the same path as the Sun Microsystems MCM.

6.5.2.2 Substrate Design

6.5.2.2.1 Design Support

The function of the CLAY MCM made for a very unique substrate design. Since each of the die were identical, and the die to die connections were along parallel paths, the substrate could be wired by straight point to point paths without any X-Y crossovers. Figure 6-6 represents one of the rows of wiring in the module. Conventional thick film screening for wiring layers uses separate wiring planes for X and Y wiring, with a reference plane, either power or ground, between plane pairs. This standard 'triplane' structure was evaluated for this MCM, but resulted in a cross section of 42 layers. By screening X and Y wiring channels on the same layer and stacking three wiring layers together before adding a reference plane, and by reducing

the wiring pitch from 0.020" to 0.010", the cross section was reduced to 20 layers. The screening technology required to achieve this is similar to what is used on redistribution layers, except the redistribution lines are generally much shorter. The concern was whether the longer line lengths would result in a screening problem in manufacturing.

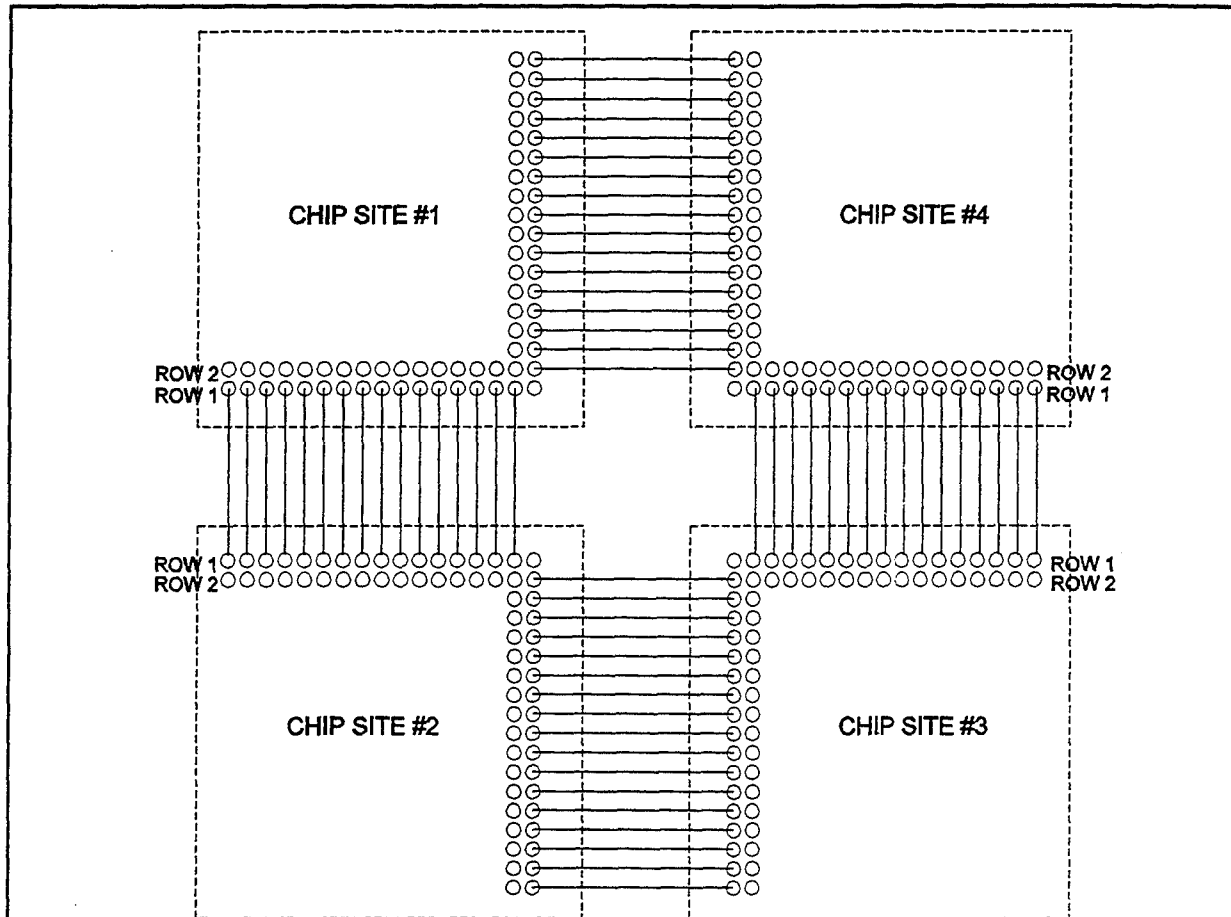


Figure 6-6: CLAy Chip to Chip Wiring Pattern

6.5.2.2.2 Logic Entry Level

The actual substrate design was done on a combination of Cadence Allegro and IBM's IGS-2 design systems. The substrate logic design was completed by National Semiconductor on a Cadence design system, but because of the need to route the I/O's on a straight line and fine pitch grid, the module was 100% manually routed. Design data was sent on a tape in the form of an ASCII netlist.

6.5.2.2.3 Release

The substrate design data proceeded through the standard IBM Direct release procedure, with post processing of the design data into data that was used to generate the Molybdenum masks for feature screening. The design data was also used to generate the punch data. The design data was used to generate the CADAM drawings of the substrate cross section and the top and bottom drawings required by the module assembly area. The drawings were given corporate Part Numbers and are subject to the same change procedures as described in the Sun Microsystems section.

6.5.2.3 Substrate Prototype Build

The CLAY MCM substrate was fabricated in the manufacturing line using conventional punch and screen methods. The complexity of the finer wiring grid, and the inclusion of X and Y wiring patterns on the same layer caused some concern on the ability to yield the substrates to an acceptable level. A "send ahead" lot of substrates was manufactured to determine if the distortion of the substrates met the specification, essential for Flip Chip modules. If there was a distortion problem, the lamination pressure can be adjusted in the following build to compensate for the problem. In this case, the distortion was within spec and the remainder of the parts were released to manufacturing.

After sintering, a sample of 10 parts were submitted for electrical verification and open/shorts testing. The electrical verification compares the customer netlist to the actual hardware build to confirm the design is correct. The CLAY MCM's passed electrical verification. The opens/shorts test did confirm a yield problem with the substrates, consisting of a small number of shorts on approximately 40% of the parts. Diagnostics of the substrates, consisting of sectioning through the substrate layer, showed line bleeding between adjacent lines. This was attributed to the location of 'tabs', which hold the screening mask together on long lines. The 'tabs' were placed adjacent to each other in the mask. Staggering the tabs would eliminate the problem and bring the yield to an acceptable level.

The parts were then submitted to the plating sector where a layer of electroless Nickel (Boron) was plated on the Molybdenum and diffused. This was followed by a thin layer of gold, which was also diffused. The gold thickness is minimized in order to limit the amount of Gold/Tin intermetallics in the flip chip solder joint. The part is now ready for device joining.

6.5.2.4 Flip Chip Bumping

National Semiconductor used the existing wire bond die design and modified it for flip chip pads. The design used an array pattern of pads, with off module signals, power, and ground around the periphery of the array, and chip to chip signals inside. National's design system laid out the flip chip pad design in a periodicity of 226 microns. This is not consistent with the IBM substrate design periodicity of 225 microns, but the cumulative error was not sufficient to cause misalignment of the die to the substrate. National provided softcopy data of the pad layouts, as well as the die layouts on the wafer. Two sets of wafers were prepared by National for bumping:

1. Wafers with capture pads and no passivation
2. Wafers with capture pads and passivation applied by National

The purpose of the two sets of wafers was to evaluate whether the National applied passivation, which could be a potential cost reduction, would perform as well as the IBM applied passivation. The passivation was evaluated based on physical strength and mode of failure after tensile pull of the die off the module. Since there was no IBM redistribution required for the module, electrical analysis of the flip chip bumping was not required.

The process flow for the wafers is as follows:

- Receive wafers from National Semiconductor
- Apply passivation (unpassivated wafers)
- Open passivation and apply Ball Limiting Metallization (BLM)
- Apply Lead/Tin Solder
- Reflow to form Flip Chip ball
- Inspect Solder Balls
- Dice and Pick die

6.5.2.5.1 Cap/Heatsink Development

Due to the low power dissipation (0.5 W/Chip, 2.0W/Module) of the CLAY MCM, the module did not require advanced cooling techniques. After the die were Flip Chip attached to the module, a cap was placed over the die. Thermal grease and a heatsink were not required. The 32mm module design allowed for the use of a standard cap, which has been used on prior MCM and SCM projects. The absence of decoupling capacitors eliminated the need for recesses in the cap (capacitors are higher than the bumped, attached die, and therefore require unique recesses) and the cap could be used 'as procured'. The cap was attached to the module using a Silicone based epoxy. A unique marking pattern was designed for the cap, incorporating the National Semiconductor logo, as well as the ARPA and IBM logo's.

6.5.2.5.2 Release

The drawings of the module were created following the completion of the cross section and delivery of the chip thickness specifications from National Semiconductor. Since the cap was already designed and fabricated, only the substrate thickness and chip thickness had to be defined. The drawings were generated and provided to the module test socket engineering group and the Bond and Assembly group. Control of the document was maintained through IBM's internal part number system. An official change to the module drawing required a design review and awareness of all users of the module assembly drawing.

6.5.2.6 Module Assembly

The assembly of the flip chip bumped die was verified using a sample of mechanically good die from National Semiconductor. The first step in the assembly process was to establish a furnace profile for the specific National substrate. Thickness and metal loading within the substrate can affect the top surface temperature of the module during reflow, so the profile was established using a thermocouple instrumented CLAY substrate. Following the definition of the profile, the mechanically good die were placed on the substrate using flux. The split optics of the place tool confirmed that the Flip Chip pads designed by National Semiconductor matched the pads designed on the substrate. After reflowing the die to the substrate, they were pulled off to check for wettability. Each microsocket (flip chip pad) must be wetted before the Flip chip attach process is confirmed as acceptable. The failure mode and pull strength are also checked against a specification to insure there are no unusual failure mechanisms. In the case of the wafers passivated by National Semiconductor, the pull strengths were well above the minimum pull specification and all the pulls were ductile "taffy" pulls, which is the best condition.

After the electrically good die were assembled to the electrically good substrates, a non hermetic lid was attached to the top of the module to protect the die. The lid was attached with an epoxy. No thermal grease or die underfill was required because of the low power requirements of the module. The lid was then marked with the appropriate design through a stencil.

The last phase of the assembly process was the Ball Grid Array attach. Eutectic Lead Tin solder paste is screened on the pads on the bottom surface of the substrate and the module is placed in the fixture with 90Pb/Sn balls. The assembly is then reflowed through a furnace, and the eutectic forms a fillet around the base of the solder balls. The ball does not reflow during the process, maintaining its shape for assembly to the card. The module is then removed from the fixture and inspected.

The electrically good modules were then shipped to National Semiconductor for test.

6.5.2.7 Test

The National MCM proposal was reviewed for appropriate testability before the final National silicon design was finalized. Recommendations were made concerning known good die, the impact of die yield on MCM prototype yield and MCM diagnostics. Since the customer was adding new devices and wiring to an existing mature FPGA die design, KGD concerns were focused primarily on ensuring complete test coverage of the new die features. The customer took our recommendations under advisement and implemented a die test procedure which enabled complete testing of all new die features. The test procedures which are used to ensure a known good substrate were reviewed with the customer.

6.5.2.6.1 Test Plan

National will produce known good die for the module by performing wafer level test in two stages. The first stage is exactly the same as used for the existing FPGA production part. The second stage of the test uses the new I/O and a subset of the original I/O and performs checks on the operation of the new circuitry and wiring. National will perform all interconnect and functional testing of assembled modules. The testing will consist of two major components:

- Parametric test establishing correct power/ground resistance levels and ESD signal diode continuity.
- Functional Test using a Trillium tester and proprietary FPGA tests.

In lieu of electrical testing at IBM, a sample of mechanically good parts were assembled at IBM, the die were pulled off the substrates, and the flip chip pads were inspected for wettability. The parts built with the Plan of Record assembly process showed 100% wetting of all pads, providing a high confidence that the electrically good parts will also be 100% wetted.

6.5.3. Conclusion

The National Semiconductor CLAY MCM was successfully fabricated using the IBM Microelectronics thick film alumina and Flip Chip Interconnect processes. The Substrate was confirmed as good through electrical testing which compared the fabricated substrate with the National Semiconductor netlist, and also confirmed there were no opens and shorts. The die interconnect to the substrate was not electrically verified by IBM, but Flip Chip wettability inspection on mechanically good samples confirmed that the process yielded 100% wetted pads.

The electrical analysis of the substrate was extensive in order to guarantee that the design would meet the product requirements. The manufacture of the substrate was also complicated by the fine line screening, and yield losses were encountered, but were subsequently understood and will be corrected in future builds. This learning will be applied to future fine line products.

Flip Chip assembly on die designed for area array by National Semiconductor was also successfully demonstrated, including die which were passivated by National. National successfully transferred the flip chip pad location data, which was successfully incorporated into the top surface substrate design and the Flip Chip bumping masks. The die attach process was verified on mechanically good samples, providing a high confidence that the electrically good samples were 100% interconnected. The electrically good samples have been provided to National, and electrical testing is currently in progress.

6.6 APPLICATION TASK CONCLUSIONS

Each of the applications selected demonstrated different levels of complexity in the design, build, and test of a multichip module. All of the module designs successfully passed interconnect testing at the module level.

The Sun application used conventional substrate technology in a standard size, but demonstrated the ability of the Cadence design system to accept Sun's logic design and convert it into a physical design. The application also demonstrated the ability to apply IBM's Flip Chip technology to die designed for wire bond. But perhaps the most significant accomplishment in the Sun application is the demonstration of IBM's Known Good Die process for flip chip bumped die. Using Single Chip Modules (SCM), designed to match the pin pattern of the existing Viking and MXCC SCM's, die were tested and screened for use on the Multichip Module.

The Sacramento AFB application made use of "off the shelf" die technology from OEM suppliers, conventional wire bond technology, and standard foundry substrate technology and sizes. The significant demonstration was the customers ability to use the design kit to do the complete physical design, and to have the IBM tools accept the design and turn it into a fully functional module.

The National Semiconductor CLAY MCM used fine line screening in the substrate and die which were designed for flip chip by National Semiconductor. The design demonstrated a logic entry point into the IBM design system, but required a custom design to route the unusual wiring pattern.

All three substrate designs were validated by comparing the finished substrate to the netlist by electrically testing a sample of substrates. The die attach was confirmed on both the Sun and Sacramento MCM's through interconnect testing. The National design was verified by validating the assembly process through inspection of the solder joints. In each case the requirement to provide a module guaranteed through interconnect testing was successfully accomplished.

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7.0 OVERALL ASEM CONTRACT CONCLUSIONS

All contract tasks were completed successfully, on-time, and to cost. Significant progress was also shown towards achieving the global ARPA objectives for the ASEM program. Detailed conclusions for each technical area are at the end of the respective sections.

The main thrust of additional efforts should be in developing applications that map well to MCMs and provide significant product advantages.

Some MCM support issues, while improving still need attention. To list them:

- Increased availability and quality of Known Good Die
- Increased availability of softcopy descriptions of the die, (in the DIE format)
- Increased focus on data integrity issues of data consistency (e.g. BSDI to netlist nomenclature consistency) and of design data management. This probably involves increased integration of design process activity within fuller function framework environments.
- Continued focus on fabrication, assembly, and test cost reduction
- Continued focus on interface standards (e.g. EDIF-PCB extensions for MCMs)
- Continued focus on standardizing substrate configurations and footprint definitions
- Continued infrastructure support to insure a forum for discussion of critical MCM issues

End of ASEM Final Technical Report

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