MCM-L Technology: A Systems Cost Analysis for a High Volume Automotive Electronics Application

John L. Evans, Larry E. Bosley, Chris S. Romanczuk, and R. Wayne Johnson

Abstract—Cost concerns related to the development and manufacturability of multichip modules have limited the widespread use of MCM’s for high-volume, low-cost applications. This paper discusses the many elements necessary to evaluate fully the financial effects of MCM programs. In particular, this paper evaluates a development program for a multichip module design targeted for high volume automotive electronics control module. Often the added material costs associated with multichip modules prohibit MCM usage for low cost applications. This paper deals with the overall costs and savings associated with MCM development. While each decision to incorporate MCM’s within a product design must be made individually, the analysis detailed below provides considerable insight into the overall systems cost involved with MCM’s.

Index Terms—MCM-L, cost analysis, automotive electronics, electronics packaging, system cost.

I. INTRODUCTION

OVER the past ten years, electronic control modules for automotive applications have evolved from initial electronic ignition systems and crude control modules to complex highly intelligent electronic control systems. As a result of this progression, packaging density, material cost, and product reliability are of increasing importance. Also, the magnitude of electronic control systems in the automobile is compounding problems related to electromagnetic interference. To increase packaging densities, reduce electromagnetic interference, and reduce overall systems cost, multichip semiconductor packages are currently being considered for high volume automotive applications.

Technological progress in advanced electronics packaging have opened new possibilities for electronic product designs. The drive to increase packaging densities has provided new markets for MCM development. MCM technology allows increased feature content within smaller electronic packages. MCM technology also allows greater design flexibility with faster design changes than silicon development. However, many factors related to MCM technology have prevented the widespread use of MCM’s for high volume low cost applications. Issues such as known die quality, product yield, substrate performance, and die availability have limited the market expansion of MCM’s. In addition, concern over the added cost of using MCM’s has prohibited the use of multichip technology. The cost of MCM’s is the primary barrier prohibiting the widespread insertion of MCM technology. As stated in [1], "The performance benefits alone have not provided enough incentive to pull any particular technology out of niche markets and into mainstream of electronics." Unfortunately, the total system savings realized by using MCM’s are not considered in the preliminary decision-making process. The limited focus on electronic module cost savings that can be provided by MCM technology is a critical restriction to future expansion of the multichip module market.

The discussion presented here provides insight into the systems cost comparisons necessary to evaluate fully the cost of using MCM technology. The focus of this paper relates to Chrysler Corporation’s planned use of MCM technology for a high volume engine controller application. The analysis considers the cost associated with the following:

1) purchasing unpackaged semiconductor die,
2) scrap and rework costs related to product yield,
3) savings related to electromagnetic interference improvements,
4) manufacturing process comparisons with and without MCM technology,
5) cost savings realized by product size reductions provided by MCM’s.

Because the engine controller product used for this program is currently in existence, a known cost baseline is in place against which the new design can be measured.

II. EXISTING CONFIGURATION

The electronic module design used for this multichip program is an engine controller. The engine controller module is currently designed with two operating printed circuit boards using surface mount and through hole technology. Power components are placed on an insulated metal substrate in order to optimize heat dissipation [2]. The logic components are placed on a four-layer FR4 printed wiring board. The logic board (Fig. 1) is the focus for this MCM development program. As can be seen, the integrated circuits placed on this module require considerable space for the module assembly. The "bottom" side of this board is heavily populated with various discrete surface mount components. The printed circuit boards are connected via a rigid interconnect and placed in a metal housing. The back side of the insulated metal power board is used as the cover for the module. The assembly is illustrated in Fig. 2. The module is plotted using urethane gel
material to protect the electronics from harsh environmental conditions found in "under-the-hood" automotive applications. The module is designed to meet -40°C to 125°C operating temperatures and must conform to other typical automotive requirements like thermal shock and vibration over a ten plus year product life. Typical environmental requirements are listed in Table I.

III. MCM CONFIGURATION

The challenge of this MCM program is to develop a cost effective multichip module to meet the functional requirements of the logic board's "micro core" area. MCM technology used for the micro core area offers the best possible size reduction, the elimination of the greatest packaging costs, and the greatest improvement in electromagnetic interference (EMI). A functional block diagram of this area is illustrated in Fig. 3. Notice that the MCM integrates three microcontrollers with an ASIC semiconductor device and two flash EPROMs. The technology employed for this program is a laminate-based multichip module (MCM-L) using a standard 32 mm 164-pin QFP package. Laminate substrate material is selected due to the significant cost advantages over ceramic and silicon based designs [3]. The developed MCM package is slightly larger than the largest single microprocessor package on the existing design (28 mm, 132-lead QFP). In implementing this MCM, I/O is reduced from 388 pins to 164, a factor of >2:1.

This MCM will be fully qualified for introduction into the engine controller by application of a test series; the test series includes mechanical tests (marking, lead pull/bend/solderability), functional tests (parametric evaluations), and reliability/durability tests (high temperature operation, temperature cycling, biased humidity, vibration, and resistance to solvents). In addition, the module will be fully evaluated for its EMI/EMC characteristics. It will be tested, in the system, for operating voltage range, ignition off current draw, supply voltage extremes/transients, manual switched logic transients, electrostatic discharge, electromagnetic susceptibility, conducted rf emissions, magnetic field emissions, and conducted transient emissions.

It is anticipated that MCM Technology will reduce the cost of compliance with EMI Specifications. Tests will be performed at the Product Development, Design Verification, and Production Validation stages of this program to insure compliance with all specifications. While the value of improved EMI/EMC performance is often difficult to quantify,

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**Table I**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>-40° to 125°C Under Hood, -40° to 85°C Other Applications</td>
</tr>
<tr>
<td>Humidity</td>
<td>0 to 100% Relative Humidity</td>
</tr>
<tr>
<td>Random Vibration</td>
<td>10 Gms, 10 to 2000 Hz</td>
</tr>
<tr>
<td>Operating Hours</td>
<td>Ignition On: 4000 hours, Time Keeping: 80,000 hours</td>
</tr>
</tbody>
</table>

**Table II**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Time</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESD, Human Body Model</td>
<td>N/A</td>
<td>2000 Volt Minimum</td>
</tr>
<tr>
<td>Temperature</td>
<td>15 sec (0,45)</td>
<td>20 to 260°C</td>
</tr>
<tr>
<td>Solvent</td>
<td>5 min (1, 5)</td>
<td>Chemical blend or analog of isopropanol, methanol, or ethyl alcohol; blends include silane, stannate, stannoxane, water, water, and other similar compounds or blends.</td>
</tr>
</tbody>
</table>

**Auto Insertion/Placement**

Components must be capable of withstanding the mechanical shock and vibration when the item is placed onto a PC board by placement and insertion equipment.
TABLE II  
MCM SUBSTRATE OPTIONS

<table>
<thead>
<tr>
<th>Substrate Size</th>
<th>Layer Count</th>
<th>Feature Size</th>
<th>Relative Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>30mm x 30mm</td>
<td>4 Signal, Pwr, Gnd</td>
<td>0.25mil lines/spaces, 0.25mil drill holes</td>
<td>1.03 – 1.13</td>
</tr>
<tr>
<td>40mm x 40mm</td>
<td>4 Signal, Pwr, Gnd</td>
<td>0.25mil lines/spaces, 0.25mil drill holes</td>
<td>1.00</td>
</tr>
<tr>
<td>50mm x 50mm</td>
<td>2 Signal, Pwr, Gnd</td>
<td>0.25mil lines/spaces, 0.25mil drill holes</td>
<td>1.13 – 1.18</td>
</tr>
</tbody>
</table>

Fig. 4. Top layer MCM layout.

its significance cannot be understated. System design engineers rely on experience and trial-and-error to solve problems associated with EMI/EMC. However, as more complex circuit designs and changing packaging technologies become more prevalent, packaging assistance is needed by the designers. To reduce EMI and crosstalk, designers typically partition various analog and digital sections of the electronic circuit board. As stated in [4], “MCM’s create new hierarchical partitions of the circuit that isolate circuits without using excessive PCB area.” This paper attempts to quantify many of the advantages presented by MCM’s in the design of electronic controllers.

IV. PROTOTYPE MODULE DESIGN

The MCM was designed using the Harris EDA design tool Finesse. A number of options were investigated to study the effect of design choices on substrate cost. The MCM was designed and routed with different substrate sizes, number of layers and feature sizes which are summarized in Table II. To achieve the same routing density in a 40 mm x 40 mm substrate, increasing layer count was less expensive than decreasing feature size. Increasing wiring density by decreasing feature size and substrate area resulted in an intermediate price increase. Based on the additional savings at the next level assembly, the 32 mm x 32 mm substrate was selected. A layout of the MCM top layer is shown in Fig. 4.

The first step in the prototype assembly process is the attachment of the leadframe to the substrate using 96.5 Sn/3.5Ag solder. The leads are on 25 mil centers and are pre-solder coated. After reflow and substrate cleaning, the die are epoxy mounted on the top side of the substrate and electrical connections are made by thermosonic gold wire bonding. For the prototypes, the die are encapsulated with a liquid encapsulant. The encapsulation process uses a two material system: Dexter FP4451, a high viscosity damming material, and Dexter FP4450, a low viscosity encapsulant. Both materials are of the same chemistry. The damming material is first dispensed in a picture frame around the substrate perimeter using an Asymtek 402 system and then the FP4450 is dispensed over the interior area. The substrate is heated to 80°C during the dispensing of both materials. The low viscosity of the FP4450 minimizes void formation under wire bonds. No intermediate curing step is required for the damming material. The encapsulant is cured in a box oven for 1 h at 110°C followed by 4 h at 160°C. In laboratory tests with this encapsulation system and gold wire bonds, over 3500 thermal cycles between -40°C and 125°C have been completed with no wire bond failures. Following encapsulation, the decoupling capacitors are attached to the substrate bottom side using conductive epoxy. The final process step is leadforming to produce gull wing leads.

The above process description explains the process developed for the initial prototypes. Various derivatives of this process may be selected as this program approaches volume production. For example, ball grid array (BGA) technology may be incorporated to improve the MCM interconnect process with the main printed wiring board. The selection of the actual process will depend on the reliability and the cost presented by potential suppliers.

V. SYSTEM COST ANALYSIS

To perform a thorough examination of the costs and savings associated with the multichip module, the entire system cost of the electronics control module must be reviewed. Table III details the cost components which are affected by the MCM insertion for the control module. As can be seen by this cost matrix there are many system cost components which offset the cost of the MCM. First, the number of circuit layers required for an electronic module can greatly influence the financial evaluation of a multichip program. In this case the savings resulting from a two layer circuit reduction in the electronics module is approximately $4. In addition, the development of the MCM allowed the width of the printed circuit board to be reduced by 1/2". This resulted in an additional $1 per module.
savings since more circuits will fit into the standard processing panel size. The 1/2" size reduction allowed a reduction in potting material of 10% by reducing the overall width of the control module. The physical size reduction is illustrated by reviewing the logic board designs; in Fig. 5 the old logic board is on the left, and the new logic board is on the right. This illustration includes all six semiconductor die within a 32 mm × 32 mm package. It should be noted that additional module size reductions could be obtained by using an alternate MCM substrate material (i.e., silicon) or by using a more dense laminate substrate. However, these options adversely affect the overall system cost of the program. In addition, the added size reduction provided by this additional reduction is not significant. A complete module redesign could provide additional product size reductions but would require a large upfront investment of resources and cost.

The material cost reduction of purchasing unpackaged semiconductor die is estimated at $5 per module. This is based on future price projections of semiconductor suppliers involved with the program. This price reduction occurs primarily from the elimination of packaging costs associated with the semiconductor devices. In addition, the design of the multichip module significantly improves the electromagnetic interference (EMI) associated with the control module. This allowed 30 EMI protection capacitors to be removed on the new design resulting in a $1.50 reduction in module cost. Another cost savings which cannot be overlooked is the manufacturing process savings. The reduction from six to one IC package reduces the required number of top side placement machines needed for controller assembly from two to one. This capital investment reduction can be amortized into a module cost savings of approximately $5.50. Also, the potential product rework and scrap involved with IC repair is greatly reduced with the new product design. The MCM has only 164 solder joints versus 388 for the six individual ICs. This is estimated to save $.25 per module.

VI. CONCLUSION

Based on the above cost evaluation for this program, the packaging for the six semiconductor die must be purchased for $8.50 or less to financially justify the program. This would require the MCM to be purchased for $48.50 including silicon. If the MCM allows the “mother” board to be redesigned to a two layer substrate, then the program can sustain a $12.50 packaging cost or an MCM cost of $52.50 and still be cost justifiable. While design options are still being reviewed, the authors feel that this target price range is certainly reasonable and attainable for this program.

In addition to the potential cost benefits of this MCM program, several additional improvements will be realized. First, the module performance will be improved related to electromagnetic interference. Also, the improved packaging density provides a reduction in overall module size and weight. The assembly process is also greatly simplified and potential reliability improvements are possible. Finally, the movement toward MCM technology can be rapidly accelerated by successful implementation of one high volume MCM program. The authors feel that success with this program will foster a wide range of new and innovative MCM programs for the future of automotive electronics.

REFERENCES


John L. Evans received the B.S.E.E. degree from Auburn University in 1984. He received the M.S. degree in engineering management, and the Ph.D. degree manufacturing systems engineering from the University of Alabama in Huntsville, in 1987 and 1991, respectively.

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