STIMULATING THE USE OF MICROELECTRONICS

FUSE

Multi-Chip Module (MCM) technologies

Best Practice

Authors: Nicolás Cordero, NMRC
Björn Ekström, IMC
Stellan Granström, IMC

Table of contents

1. References and Terminology

Issue	Date	Issuer	Comments
1.0	17/May/1999	Stellan Granström	Revision 2.2

1.1 References

Refer to *Bibliography*, and to Appendix A, *MCM Application Experiments*.

1.2 Terminology

AlO	Alumina oxide (ceramic)
BeO	Beryllium oxide (ceramic)
BGA	Ball Grid Array
BP	Best Practice
CoB	Chip On Board
CSP	Chip Scale Package
FC	Flip Chip
FR4	Standard PCB material
FU	First User
HDP	High Density Packaging
HQ	Head Quarter - Manufacturer and Head Office
HTCC	High Temperature Co-fired Ceramic
LTCC	Low Temperature Co-fired Ceramic
MCM	Multi-Chip Module
MCM - C	Multi Chip Module Ceramic Substrate
MCM - D	Multi Chip Module Deposited (metal and dielectric)
MCM - L	Multi Chip Module Laminate Substrate
PCB	Printed Circuit Board
PGA	Pin Grid Array
QFP	Quad Flat Pack
Si	Silicon
SiO_2	Silicon dioxide i.e. quartz
TAB	Tape Automated Bonding
WB	Wire Bond

2. Abstract

This document is an introduction to the Multi-Chip Module (MCM) Technology. Most of the material is based on information collected from FUSE Application Experiments where a MCM technology was used for a first time in a product or process. The objective of this document is to provide Best Practice information for those considering the use of the MCM technology for the first time.

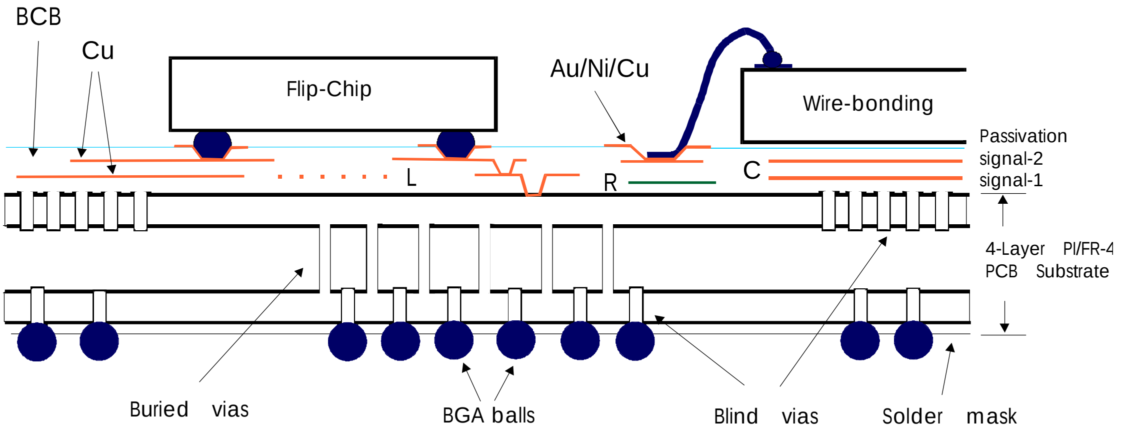
An introduction to the technology, including substrate selection, chip-assembly, packaging and testing is followed by a comparison of MCM with alternative technologies. An analysis of the economic impact derived from the introduction of MCM is followed by two main sections: Workplan construction and Management of subcontractors.

3. Introduction to MCM Technologies

In the commonly used electronic technology, the semiconductor chips (also known as bare-dice) are individually mounted on a package, and wire-bonded to its I/O pins. This package is then mounted on a Printed Circuit Board (PCB).

However, there is an emerging technology where several bare die chips are mounted on a single package. This technology is known as Multi-Chip Module (MCM) technology. It can be used for both standard and ASIC chips. The resulting package can then be soldered on a PCB.

Although different from MCM, Chip-on-Board (CoB) and Flip-Chip technologies are generally considered as related technologies. In CoB technology, a semiconductor chip is placed directly on a PCB, eliminating the packaging step. In the Flip-Chip technology, the chip is mounted upside-down (metal contacts down), providing a direct electrical connection to the I/O pads, eliminating the wire-bonding step.



The following sections provide a closer insight into these technologies.

3.1 General description

A Multi Chip Module (MCM) is an electronic system or subsystem with two or more bare integrated circuits (bare die) or Chip Sized Packages (CSP) assembled on a substrate. The substrate is either a PCB, a thick/thin film ceramic or silicon with an interconnection pattern. The substrate is either an integral part of the package or will be mounted in a package. The package can be a standardised package containing parts of the electronics for assembly on a printed circuit board or a package containing all the electronics. The full module can be assembled directly in the system (PC, instrument or mechanical design, etc.). Multichip Modules introduce a packaging level between ASICs and PCBs and there are many reasons why this might be beneficial. The driving forces to develop an MCM instead of using packaged circuits, assembled on a printed circuit board (PCB) are:

Size: The utilisation of the active silicon area is about 15% for surface mounted circuits on a PCB. In an MCM it can be between 30-60% or even higher.

Technology Integration: In an MCM, digital and analogue functions can be mixed without serious limitations and an ASIC can be mixed with standard processors and memory in one package. For some MCM technologies passive components can be integrated for decoupling, protection and/or high precision passive functions. The next generation of MCMs will be available also with optical I/Os as an option.

Complexity: A large MCM can be divided into several circuits as for some complex processors on the market today. The dimensions on the MCM substrate are close to the I/0 dimensions of the IC, so high complexity circuits can be assembled without large fan out and interconnection can be made with fewer layers in the mother-board substrate.

Data Speed and Signal Integrity: High speed components can be placed closer to each other, the load on the IC output buffers is lower and signal transmission properties are better. The overall capacitive and inductive loads in the system are lower and easier to control compared to a standard PCB. Furthermore, MCMs are in general less susceptible to electromagnetic interference than PCBs.

Reliability/Harsh environments: A small system can be protected from electromagnetic interference, liquids, gases etc. more easily than a larger system.

Cost: Many low cost products are produced in large volumes. Typical examples are Chip on Board, more complex MCMs in watches, calculators and in new products such as video cameras and PCs. Presently, however, for general products the cost is equal or higher for an MCM compared to PCB. The external development cost excluding components may vary between 5 and 50 kECU or higher depending on the complexity of the system and whether standardised packages can be used.

Simplification of motherboard design: Subsystems with high wiring demands can be integrated on an MCM with a limited number of external connections, thereby reducing the number of wiring layers on the motherboard.

Reusability/Standardisation: An MCM can integrate functions required in a family of products, thereby creating a component that can be handled like a single IC. Such functions can be integrated as logical and physical building blocks in new designs.

Development of an MCM is in many respects closer to development of an ASIC than development of a PCB system. The design has to start with a detailed specification including function, environmental and mechanical specification, partitioning of the electric functions into standard circuits or ASICs, and with a test strategy. It is very difficult to estimate the development and production cost of an MCM before the detailed specification and component partitioning is done. Testability considerations have to be taken into account in an early design stage and the test strategies are similar to ASICs as access to internal test points is limited. Functional test can be simplified if internal test (BIST, boundary scan or special internal programs) is used. Based on the detailed specification and partitioning, component purchase and detailed design can start. In the electrical design the netlist of the module is created either from a high level description or in a more traditional way from an informal specification of the module and digital/timing/analogue simulations are performed. In the physical design phase the netlist is transformed into a layout. After manufacturing of the substrate and assembly of components on the substrate, the system can be electrically tested using the internal test. Components that do not function can be replaced before final packaging or package sealing.

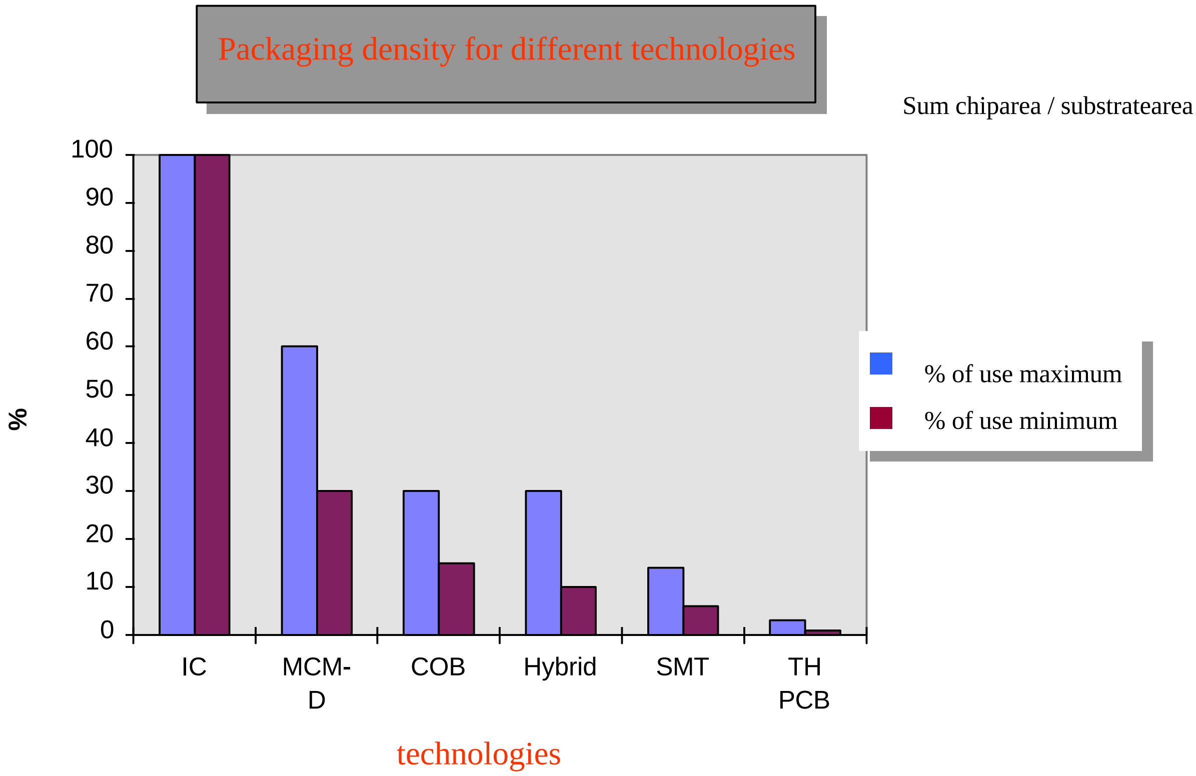


Figure 3.1: Packaging density for different technologies

3.2 Markets for MCM

The are several areas where one or more of the MCM/CoB technologies can offer an advantage over alternative electronic technologies:

- Reduced cost,
- Reduced size and weight,
- Hermeticity (ESD, chemical, thermal, …)
- Smaller number of interconnections to improve performance.

Depending on the application requirements, a different MCM technology can be more advantageous. Therefore, several markets are now open to MCM.

While most MCM technologies have a higher cost than alternative technologies, a related technology, Chip-on-Board (CoB) provides the cheapest form of mounted chip. Therefore, in applications where cost is an important issue, CoB is now generally one of the preferred options. This is the case for consumer electronics, where for example, most hand-held inexpensive calculators are using CoB technology. Furthermore, in many applications even when the individual MCM device is more expensive, the reduction in PCB layout and assembly costs achieved using MCM results in a lower cost for the whole system.

In aerospace and military applications, the reduction on size and weight that can be achieved using MCM can be of great importance. For example, the use of MCM in aircraft electronics is at present common. This is also the case for notebook computer manufacturers, who nowadays are considering the use of MCM-L technology.

Ceramic hybrid technology is generally used in circuits exposed to harsh environmental conditions, such as motor vehicles. These hermetic packages are therefore being used in application where a good insulation from the external environment is required.

Computers are generally made from many parts with high number of I/O pins, which have to be connected with the shortest possible interconnection delay. To pack this high pin count chips in a small space while reducing the interconnection delays, most mid-range computer manufacturers are considering the use of MCMs. High-end computer manufacturers have been using MCM technology, mainly MCM-C, for many years. This is also the case for electronic data processing and networking, high performance telecommunications, and instrumentation equipment, where high speed and high number of connections are generally required.

As performance continues to increase in low-end systems, and especially as multiprocesor applications increase, MCMs will capture a significant fraction of the electronic packaging market. Forecasts give an estimate of between a 4% and a 12% of an $11.5 million unit market of workstations, high end PCs and portable computers using MCM technologies.

Regarding the future trend in the use of MCMs, it is clear that a promising area for commercial MCM in the short term is in those systems where small size is absolutely essential. Markets moving toward smaller portable products such as digital cameras, personal computers and cellular phones are a driving force for package size reduction. The reduced interconnection complexity associated with MCMs is also attractive for these applications.

On the other hand, high performance systems where the overall performance is limited by the number of pins available on a single chip package are a longer term candidate for MCMs. In this systems, a reduction in the number of second level interconnections will also lead to higher reliability.

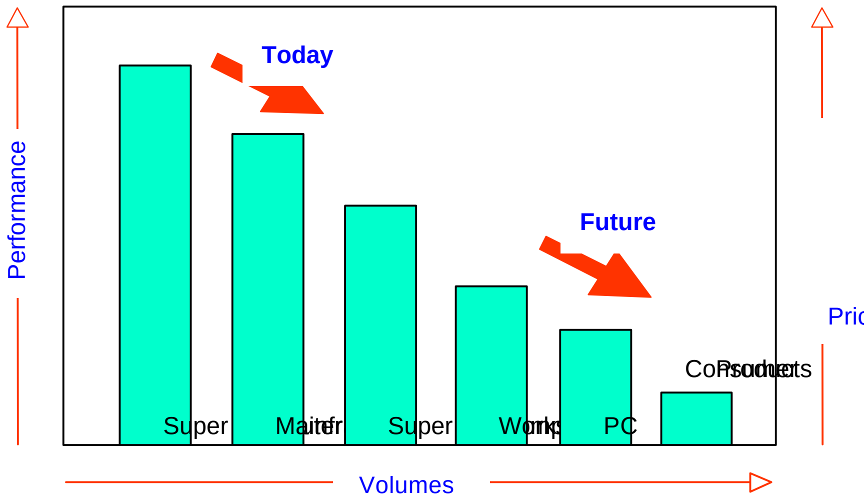


Figure 3.2: Trends on MCMs performance, size and production volumes

However, the implementation and proliferation of MCMs will continue to be constrained by the availability of "know good" die with the necessary cost and performance. MCMs will be driven in the future by size and cost reduction for low end products and size reduction and increased performance for high-end products.

The current European market for MCMs is estimated on $500 millions, mainly on the high performance end of the market. Forecasts for the year 2002 predict a large growth, reaching around $4,000 millions, with a significant increase of applications where reduction of size is important. By the year 2007, the forecast is of a volume of $10,000 millions, moving towards the consumer products market, where a reduction in costs in the main factor.

4. Selection of Technology

4.1 Description of MCM Technologies

The MCM technologies can be divide into the following 3 main areas depending on the type of substrate used:

- *MCM-C*
- *MCM-D*
- *MCM-L*

C, D and L defines the substrate type of the MCM where MCM - L is the Multi Chip Module Laminate Substrate, MCM - C is the Multi Chip Module Ceramic Substrate and MCM - D is the Multi Chip Module Thin Film Substrate

4.2 Substrate Technologies

4.2.1 Laminated Substrates (MCM-L)

MCM-L Technology is essentially a high end or improved PCB Technology, which satisfies the MCM requirements to reach dense packaging. The requirement for high density wireability and the requirement for surface finishes and structures which are suitable for direct chip attach processes like wirebond or flip chip on MCM are the main challenges. Improved or high end PCB Technology for MCM-L Applications comprises:

New or improved PCB base materials	(FR4, FR5, BT etc)
Improved solder mask materials	(PSR 4000, etc)
Surface finish for bondability , flip chip	(Ni/Au, Pd, SnPb etc)
Micro vias	(plasma, optical, or laser vias)
Additional distribution layers	(Polyimide, Epoxy etc)
Smaller mechanical drill sizes or laser drilled	(down to 150 µm vias)
Thin dielectric layers	(down to 50 µm)
Small lines and spaces	(down to 75 µm or lower)

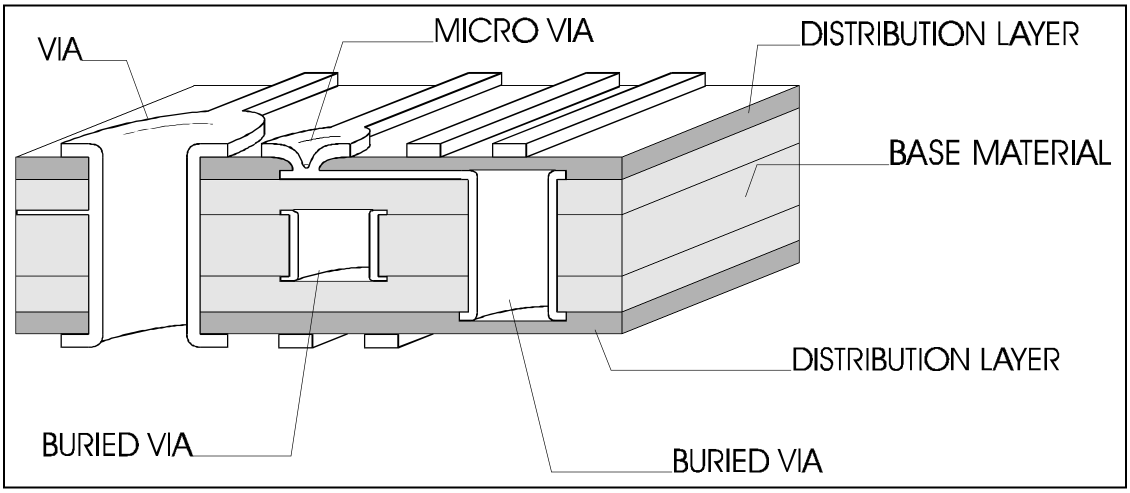


Figure 4.1: Example of a 6 Layer MCM-L with micro vias & distribution layers on top & bottom

The MCM-L technology is not always the best solution for every application. Especially with respect to long term reliability, wide temperature ranges MCM-L technology has a smaller application range than MCM-C and MCM-D technologies. Costwise MCM-L are less expensive than MCM-C and MCM-D.

From AE 22845
"Various MCM technologies have been considered: MCM-D is based on ceramic or silicon substrates and allows for fine structures and a high density of integration, which is, however, not needed in this case and would therefore be too expensive. Further, the ceramic substrate would not guarantee efficient coupling for temperature stabilisation. MCM-C is based on ceramic (Al_2O_3) or Aluminium nitride (AlN) substrates. Since Al_2O_3 is not offering sufficient thermal coupling for the necessary temperature stabilization, AlN would have to be selected, which is expensive. Therefore MCM-L was originally selected, which can be directly laminated onto the surface of the thermoelectric cooler and is thus offering a cost-effective manufacturing technology."

4.2.2 Multilayer Ceramic Technology (MCM-C)

There are two different processes categories in MCM-C technology:

- Several conductive layers deposited on a ceramic substrate and embedded in glass layers,
- Several conductive and ceramic layers cofired at high (HTCC) or low (LTCC) temperature.

The HTCC and the LTCC consist of the state of the art and as such demonstrated by four different processes. Three of those processes are carried out on ceramic substrate and called

- Standard process,
- Fine line,
- Photo-imageable,

The differences between these processes are in the width and the line to line pitch of conductors. They decrease from 254 µm to 75 µm. And a fourth process called

- Low Temperature Cofired Ceramic (LTCC).

Trimmed precision resistors are available for each process (range: 1Ω to 10 MΩ). The standard process is qualified for space environment. All processes are qualified for all other environments (industrial, automotive, military). All processes are used for all applications: analogue, digital, mixed, microwaves (with metallised holes or not).

User guides based on design rules for ceramic and another based on wire bonding, help the customer to choose the right process for his/her application.

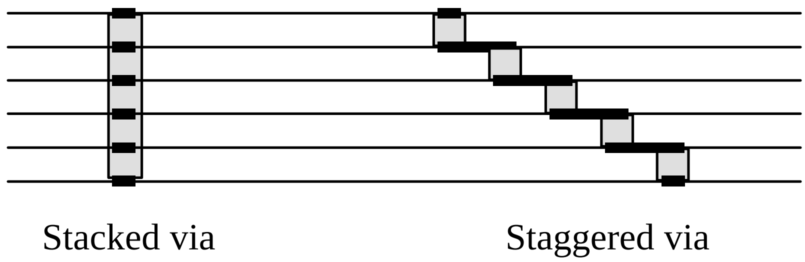
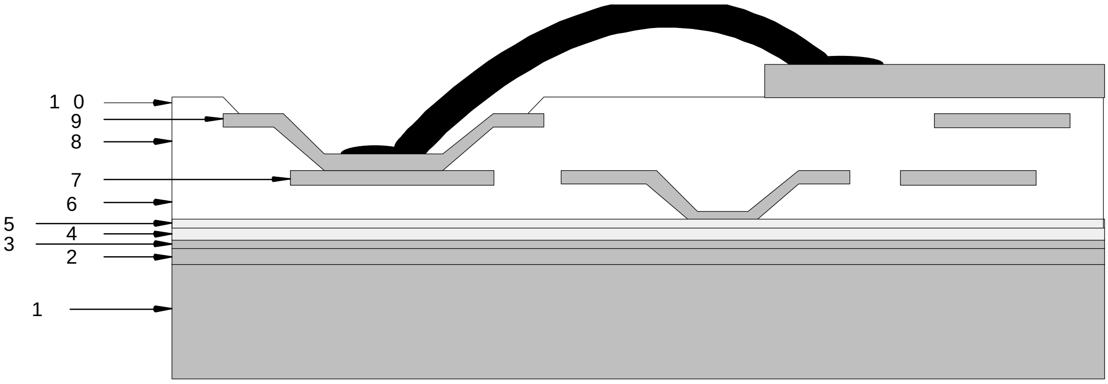


Figure 4.2: Via types in MCM-C technologies

From AE 24760
"The option is to replace the hybrid & metal base by a ceramic chip carrier. Since this housing is hermetic by itself, it no longer requires a crystal that is hermetic but it can do with a quartz blank only (the plate that is actually vibrating within the quartz crystal). The size of the oscillator would be determined by its largest component only, i.e. the quartz blank. All other parts, i.e. the ICs and the capacitor, would fit in the space left between quartz blank and chip carrier. It requires the ability to design the chip carrier, master the component placement techniques, and seal the ceramic carrier."

4.2.3Thin Film Technology (MCM-D)

MCM-Ds are processed by using thin-film materials deposited as dielectric and metallization, formed on dimensionally stable bases such as silicon, aluminium, alumina ceramic or aluminium nitride. The photolithography process used to apply and pattern the dielectric and metallization are the ones commonly used in the semiconductor industry. The metallization layers consisting of power planes, signal layers and die bonding pads are done by conventional sputtering, vacuum evaporation methods or electroplating followed by normal photolithography steps. Aluminium, copper, silver or gold are used for conductor tracks. Typical linewidth for MCM-D is 25 µm with a pitch of 50 µm and the via sizes are between 10 and 50 µm typically. Silicon dioxide or polymers like Polyimide or BCB are normally used as dielectric to separate the metal layers and to provide the low dielectric constant (2.7-3.5) needed to get thin dielectric layers, narrow track widths and still adequate track impedances. Additional layers may be added to include thin-film integrated resistors and thin-film capacitors as an option. A future possibility is to incorporate additional circuitry such as memory, module input/output protection (ESD, EMC) etc. in the bulk substrate if silicon is used for the substrate. This implies a better utilisation of the active silicon area because the I/Os on the chips can be considerably simplified and thereby require less space. The figure below shows a cross-section for a typical MCM-D Substrate.



1	Base	6	Dielectric layer 2
2	Buffer	7	Metal 3
3	Metal 1	8	Dielectric layer 3
4	Dielectric layer 1	9	Metal 4
5	Metal 2	10	Passivation

Figure 4.3: Cross-section of an MCM-D

From AE 415:

"The reasons for choosing this technology were:

- highest integration (we were dealing with a Pentium chip)
- thermal considerations (about 10 W expected)
- thermal stability (important for an industrial environment like we have usually in our applications, typically 50-70° $T_{ambient}$)
- high MTBF (Mean Time Between Failure) values
- excellent technical parameters (crosstalk, reflexions)
- high clock rates (120MHz)."

4.3 Chip Assembly Technologies

Several different technologies are used to connect a bare die chip to the package I/O pads. The most common ones are:

- Wire Bonding
- Tape Automated Bonding
- Flip Chip

4.3.1 Wire Bonding

Wire Bonding is the most common chip connection technology in the microelectronic industry. Wire bonding starts with mounting the chip back side down; the wires are then bonded one at a time to the chip and the substrate by one of the three wire bonding methods which have been developed in the semiconductor industry:

- Thermo-compression
- Ultrasonic
- Thermo-sonic.

Thermo-compression or thermo-sonic techniques can produce either a ball bond or a wedge bond; the ultrasonic technique is associated with wedge bonding.

Several wire materials are available, but the most commonly used are:

- Gold for thermo-compression and thermo-sonic.
- Aluminium for ultrasonic.

The wire diameter is generally between 25 and 30 µm.

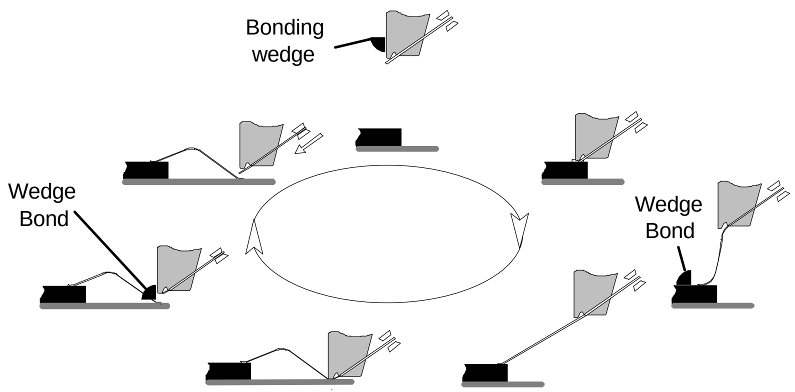


Figure 4.4: Wire Bonding

4.3.2 Tape Automated Bonding

In the Tape Automated Bonding (TAB) technology, the connection between die and package is made by bonding a patterned conductor deposited on a tape to the corresponding I/O pads on the die (Inner Lead Bonding) and on the substrate (Outer Lead Bonding). After Inner Lead Bonding the die can be tested prior to mounting on the MCM.

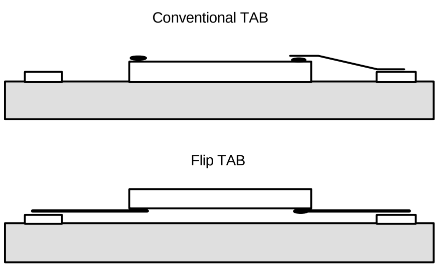


Figure 4.5: Tape Automated Bonding (TAB)

TAB parts can be assembled in conventional TAB: the backside of the die is connected to the substrate, or in flip TAB: the active surface of the die facing the substrate (see figure above). With flip TAB, the leads are shorter than in conventional TAB. TAB is advantageous because it eliminates a level of packaging: the die can be bonded directly on the MCM.

4.3.3 Flip Chip Attachment

The term Flip Chip denotes a chip mounting and contacting technology where the ICs are placed face down on the substrate. To achieve the contact a solderable metal has to be deposited on the chip pads - the bumps. In the assembly process the bumped chips are aligned with the solder lands on the substrate and by a soldering process all bumps are simultaneously connected with the substrate. Different alloys can be used for the formation of the bumps and the solder system. The most attractive systems for MCMs are those that are SMT compatible, i.e. where the soldering of the flip chip contacts and passive components on the MCM can be done in one process. For these systems the bumps consist either of lead rich tin/lead alloy (e.g.Pb95Sn5) or of eutectic solder (Pb37Sn63). The gap between the chip and the substrate is underfilled with an epoxy material taking up the stress from thermal cycling and increasing the reliability of Flip Chip contacts by several orders of magnitude. A cross section of a Flip Chip is shown below.

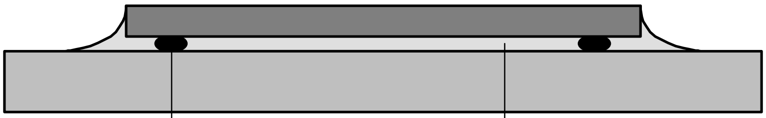


Figure 4.6: Typical Flip Chip Assembly

Flip Chip technology is characterised by the following features:

- It allows the highest packaging density among all the assembly technologies.
- The conductor lines on the substrate must have the same pitch as the chip pads (typically 150 µm - 200 µm) and require a planarity within a few microns over the size of a chip to achieve high yields in the assembly process.
- The low inductance of Flip Chip Joints results in excellent electrical properties and makes Flip Chip suitable for high frequency applications and sub-micron CMOS technologies with high transient currents in the power/ground system.

Special care must be taken for ICs with higher power dissipation. The usual thermal path is through the bumps into the substrate. To lower the thermal resistance additional “thermal“ bumps can be placed. Furthermore an additional heat sink can be mounted on the backside of the chip.

4.4 Packaging

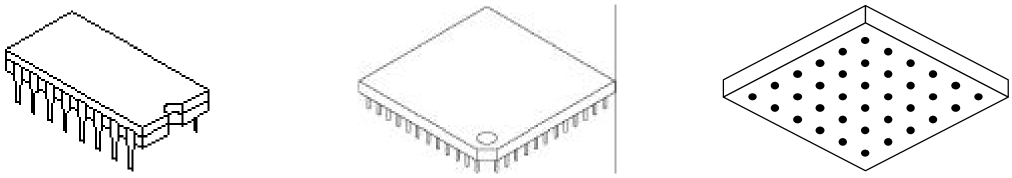
One of the decisions to be made when designing an MCM is to find the package that better satisfies the needs of a particular electronic system. There is a large number of packaging alternatives available to the design engineer. The main issues that drive engineering decisions are cost, performance and reliability. Packaging affects all three, limiting performance, reducing reliability and increasing the cost. While MCMs represent significant improvements in system performance and reliability compared with conventional packages, they are also more expensive, therefore all tradeoffs must be taken into account before making a final decision.

A wide range of packages are available for MCM. The can be classified depending on:

- Material: Plastic, ceramic, or metal.
- Environmental performance: Non-hermetic, high-reliable hermetic and fully hermetic
- Configuration: Peripheral leads, pin array, pad array, bumps array, etc.

It is important to select the packaging material carefully, since MCMs are used in a great variety of applications. While plastic packages offer a low cost option, they present significant problems above or below certain operation temperatures. Furthermore, the environmental conditions can include a wide range of hazards for the components like changes in temperature and air pressure, high humidity and airborne contamination. Therefore the selection of material and environmental performance are closely related.

Peripheral leads packages are the most commonly used single chip package connection arrangement. Most MCM designs resemble these single chip packages. This has the advantage of requiring little or no modification to the PCB tooling machines for assembly and testing. The final user of the MCM does not know whether the package contains multiple chips or a single one. These packages can be used with all the different types of MCM substrates (laminated, ceramic, thin film, etc.), however they are most prevalent in MCM-L. The package is connected to the PCB using either leads or by direct soldering. Direct soldering is preferred for high frequency applications, where the leads inductance is a limiting factor.



a) DIL b) PGA c) PAC (BGA)

Figure 4.7: Typical MCM packages

Pin grid arrays (PGAs) can be utilised as a solution to overcome the geometrical constrains imposed by the peripherally terminated modules. By distributing the leads on the full area of the underside of the package, the module is more efficiently used. Package pin counts from several hundred to over 1000 have been fabricated. Generally, the pins are press fit and soldered onto the MCM. The PGAs can be through-hole mounted, placed into sockets or surface mounted and soldered directly to the PCB.

Pad array carriers (PACs), also known as surface-mount arrays. They are similar to PGAs with the exception that metalised pads replace the pins. This package offers all the benefits of the PGA without the negative effects associated with lead inductance. Furthermore, cost are typically less that PGAs since no leads are required. Attachment to the mother board is through a socket or by direct soldering.
The packages used more often in the MCM industry are:

- **Premolded Plastic:** Low cost and easy to assemble.
- **Postmolded Plastic:** Well suited for high-volume applications.
- **Encapsulated Chip-on-Board:** Combination of bare die and surface mount components.
- **Metal Hermetic:** Rugged and reliable. Expensive.
- **Ceramic Hermetic:** High performance applications.

From AE 415
“The metal housing has different advantages : it is robust, it is a good heat conductor and it gives an excellent EMI shielding.”

4.5 Testing

It is widely accepted that the cost of testing can be as high as a third of the total cost of an MCM (the other two thirds being device and packaging costs), therefore it is important to considering testing carefully while/before making design decisions. While a new design will require more extensive testing than a mature design, MCMs must be designed with good testability in mind.

MCMs present new and unique problems to test engineers. The features that make MCM technology attractive represent the biggest challenges to testing. The complexity of MCMs is greater than that from a single integrated circuit, what makes difficult to adapt established IC test methods and equipment to MCMs.

There are three basic processes in the manufacturing of an MCM: die fabrication, substrate fabrication and module assembly. Two levels of testing are performed: process-specific and functional. A process-specific test detects specific faults that can be introduced by that process. The test procedures for dice, substrates and MCM assemblies are radically different. The final functional test verifies the overall performance of the completed MCM, and also detects any faults that escaped detection in the individual processes.

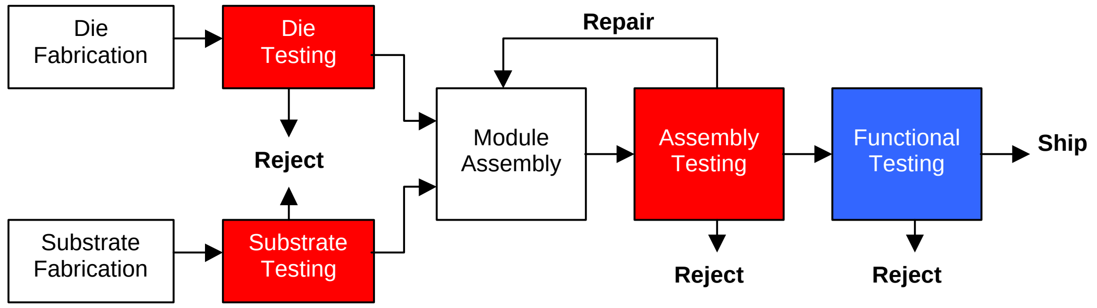


Figure 4.8: MCM Fabrication flow showing the different process-specific tests

Testing of bare dice is much more difficult than that of single-chip packages. Therefore, they have normally being supplied with only limited probe testing. However, some manufacturers are starting to offer "known good die" (KGD), or known with high (such as 0.999) confidence that the ICs are free of any defects and will remain defect-free through assembly, burn-in and environmental stress. The usage of KGD dramatically improves the MCM yields. This is especially important for MCMs with a large number of ICs.

The testing of MCM assemblies generally involves the testing of each individual die to check that if was not damaged during the assembly process and of the interconnection between dice. The assembly testing is therefore a very complicated operation, especially for certain types of packages such as grid arrays. If a die or substrate is found defective during their specific testing, it is discarded. However, an assembly fault can sometimes be repaired: e.g. a defective chip can be replaced for a good one. However, when the fault cannot be repaired the whole assembly is discarded, with all the non-defective chips and the substrate wasted.

Functional testing is generally very dependant on the particular device and application. It can involve very different types of test, from digital test vectors to environmental testing or from high frequency to high power. Therefore functional testing is system related more than MCM technology related. If an MCM is designed to replace a group of single chip packages in an existing design, the functional tests will remain the same.

From AE 1505

"Thus , we looked at FPGA, ASIC , Hybrid thick , Hybrid thin and the MCM technology. Lower costs , quicker time to market and flexibility for future changes were the important criterion for our decision to use MCM. The big advantage of using MCM is that standard dies can be used from the best manufacturers and they can be bonded together. The prototypes can also be done relatively quickly."

From AE 23091

"This choice was motivated by

- thermal calculations and experiments with different designs and materials
- the extension of capabilities, because $AI_2 0_3$ - and AIN- hybrid- circuits without die- and wire-bonding are manufactured in house of TQG since the past year, therefore die-and wire-bonding-technology especially on AIN-substrates will be an important extension of the existing capabilities
- well known and reliable technologies, because compared with the also considered flip-chip-bonding-technology conventional die- and wire bonding and the corresponding test-methods are well known reliable technologies
- the demanded reduction of time- to- market for the demanded smaller products with increased functionality

- the technical requirements and necessary tests reasoned by the most severe requirements of our demanding customers and the general high reliability requirements in telecommunication-applications
- economic calculation which showed a cost- reduction against the old product of about 60 %."

5. Economic impact

5.1 Direct economic impact

The MCM technology is in most cases not used for direct economic impact reasons. It can though be shown that money can be saved by reducing size, improving security and through other general enhancements.

The direct economic impacts through lower manufacturing price can be classified on

- Module level
- Module system level,
- Product level
- Product system level

The impact effect can be calculated through an Economic Product Evaluation shown on next page. The manufacturing price (Section:Price Item:5) is decreased the first 3 years but the number of units sold (Section:Sales Volume Item:6) are constant.

The effect of the direct economic impact viewed as a graph shows that break-even can be reached 3 years after development. The accumulated profit reaches nearly 1000 Euro after 5 years.

From AE 24760
Cost benefits
"By the technology chosen the general production cost is reduced partly by the lower direct cost of the ceramic carrier (hybrid now ECU 2, ceramic carrier after the experiment ECU 0.50). The remaining can be reached by size and handling efficiency in larger quantities. For the PLL-XO in particular, additional savings come from the use of a less expensive crystal blank and the option of automated blank placement.

The specific cost reduction of the ceramic carrier (at a lower cost of ECU 1.50) would be 150 kECU in the first year of producing 100k units and 300 kECU in the second year, followed by 525 kECU in the third year. Since the depreciation of the equipment is already included in the cost price, only the development and engineering costs have to be taken into account. Therefore the payback period will be less than 18 months."

From AE 23091
"But there is a *technology- factor* which implements an increasing prices- reduction of the product by new technologies to reduce the size and the production- costs."

5.1.1 Economic Product Evaluation

The excel sheet calculates the planned investment and return based on a very detailed item level. The time frame is in this case covered from year 1998 to 2002. The total profit per year and total is based on the sections Price, Sales volume and Investment & return. The price section covers the price levels, production cost and discounts from the manufacturers (headquarters) perspective. In the investment and return section the gross margins and sales costs for the dealer and the manufacturer (HQ) are covered. In this section are also the costs for development, documentation and maintenance covered. Part from the profit section table at the end there is also a graph showing the same result and when the ROI can be reached. In this graph also the Gross Margin and the project/maintenance costs are shown.

Economic Product Evaluation Version: 1

(Basic. No inflation adjustments)

	Year	19 98 1 Plan	19 99 2 Plan	20 00 3 Plan	20 01 4 Plan	20 02 5 Plan	20 03 6 Plan	20 04 7 Plan	20 05 8 Plan	TOTAL
Price										
1	street price (average)	1,000	1,000	1,100	1,150	1,200	1,250	1,300	1,350	
2	baseprice HQ	800	800	800	800	800	800			
3	average discount (%of BP)	35	35	35	35	35	0	0	0	
4	transfer price HQ	520	520	520	520	520		0	0	
5	cost of goods/factory price	350	330	320	300	300				
Sales volume	EURO									
6	total units sales	500	500	500	500	500	500	0	0	3000
7	sales volume street price	500.0	500.0	550.0	575.0	600.0	625.0	0.0	0.0	3,350.0
8	sales volume transfer price	260.0	260.0	260.0	260.0	260.0	0.0	0.0	0.0	1,300.0
9	cost of goods volume	175.0	165.0	160.0	150.0	150.0	0.0	0.0	0.0	800.0
Investment & Return	EURO									
10	gross margin Dealer	240.0	240.0	290.0	315.0	340.0	625.0	0.0	0.0	2,050.0
	(%)of sales vol street pr.	48	48	48	48	48	48	48	48	
11	gross margin HQ	85.0	95.0	100.0	110.0	110.0	0.0	0.0	0.0	500.0
	(%)of sales vol transf. pr.	33	37	38	42	42	#DIV/0!	#DIV/0!	#DIV/0!	
12	gross margin world 1	325.0	335.0	390.0	425.0	450.0	625.0	0.0	0.0	2,550.0
	% sales cost Dealer (of vol st.pr)	5	5	5	5	5	5	5	5	
13	Sales cost Dealer	25.0	25.0	27.5	28.8	30.0	31.3	0.0	0.0	167.5
	% sales cost HQ (of vol tr.pr)	3	3	3	3	3	3	3	3	
14	sales cost HQ	7.8	7.8	7.8	7.8	7.8	0.0	0.0	0.0	39.0
15	gross margin world 2	292.2	302.2	354.7	388.5	412.2	593.8	0.0	0.0	2,343.5
16	project development	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,000.0
	maintenance & documents	200.0	50.0	40.0	30.0	30.0	30.0	30.0	30.0	440.0
World profit	per ye	-907.8	252.2	314.7	358.5	382.2	563.8	-30.0	-30.0	903.5
	accumulated	-907.8	-655.6	-340.9	17.6	399.8	963.5	933.5	903.5	
				0.0						

Summary:

Year	19 98	19 99	20 00	20 01	20 02	20 03	20 04	20 05
Street price (average)	1000	1000	1100	1150	1200	1250	1300	1350
Base price Hq	800	800	800	800	800	800	0	0
Factory cost	350	330	320	300	300	0	0	0
Unit sales	500	500	500	500	500	500	0	0
GM before sales cost	325	335	390	425	450	625	0	0
GM after sales cost	292	302	355	388	412	594	0	0
Profit/year	-908	252	315	358	382	564	-30	-30
Profit accumulated	-908	-656	-341	18	400	964	934	903.5

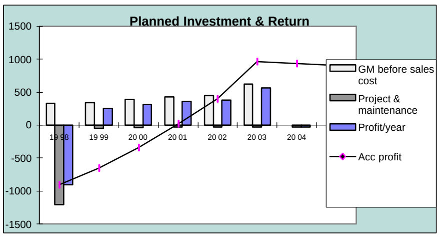
For diagrams only:

Planned:	19 98	19 99	20 00	20 01	20 02	20 03	20 04	20 05
GM before sales cost	325	335	390	425	450	625	0	0
Project & maintenance	-1200	-50	-40	-30	-30	-30	-30	-30
Profit/year	-908	252	315	358	382	564	-30	-30
Acc profit	**-908**	**-656**	**-341**	**18**	**400**	**964**	**933.5**	**903.5**

Specification

including main product: NPV planned (10%) 390.57

options/accessories:



Project / Product: MCM Based Unit

5.2 Indirect economic impact

The market perspective in terms of the total market size and the possibility to increase the actual products market share is normally the most important economic impact parameter. By viewing the current product from a market/customer perspective i.e. the user functionality or other demands and expectations the enhancement might be carried out by using the MCM technology. The sales result in terms of number of units is normally increased when such a product improvement is carried out and will end up in a economic impact.

The impact effect can be calculated through an Economic Product Evaluation shown on next page. The manufacturing price (Section:Price Item:5) is in this case constant through the entire product cycle. The number of units sold (Section:Sales Volume Item:6) are though increasing due to the overall product enhancements. The effect of the indirect economic impact viewed as a graph shows that the break-even can be reached 2 years after development. The accumulated gross profit reaches approximately 3,700 Euro after 5 years.

From AE 22845
"The products of the company will thus become less price sensitive since the company is delivering more added value to its customers."

From AE 1505
"Company markets

Germany	40 % of the Market
Europe	15 % of the Market

Americas 5 % of the Market
Asia Pacific 10 % of the Market
Africa 5 % of the Market

Please note that there are 70 companies in the world who make similar machines . The total volume of production is about 1 billion DM. So although we have a good share in some markets, looking from a global point of view, we have about 5 % of world market share. This shows how much we can do better!"

Economic Product Evaluation Version: 1

(Basic. No inflation adjustments)

	Year	19 98 1 Plan	19 99 2 Plan	20 00 3 Plan	20 01 4 Plan	20 02 5 Plan	20 03 6 Plan	20 04 7 Plan	20 05 8 Plan	TOTAL
	Price									
1	street price (average)	1,000	1,000	1,100	1,150	1,200	1,250	1,300	1,350	
2	baseprice HQ	800	800	800	800	800	800			
3	average discount (%of BP)	35	35	35	35	35	0	0	0	
4	transfer price HQ	520	520	520	520	520		0	0	
5	cost of goods/factory price	300	300	300	300	300				
	Sales volume (EURO)									
6	total units sales	500	700	900	1100	1300	1500	0	0	6000
7	sales volume street price	500.0	700.0	990.0	1,265.0	1,560.0	1,875.0	0.0	0.0	6,890.0
8	sales volume transfer price	260.0	364.0	468.0	572.0	676.0	0.0	0.0	0.0	2,340.0
9	cost of goods volume	150.0	210.0	270.0	330.0	390.0	0.0	0.0	0.0	1,350.0
	Investment & Return (EURO)									
10	gross margin Dealer	240.0	336.0	522.0	693.0	884.0	1875.0	0.0	0.0	4,550.0
	(%)of sales vol street pr.	48	48	48	48	48	48	48	48	
11	gross margin HQ	110.0	154.0	198.0	242.0	286.0	0.0	0.0	0.0	990.0
	(%)of sales vol transf. pr.	42	42	42	42	42	#DIV/0!	#DIV/0!	#DIV/0!	
12	gross margin world 1	350.0	490.0	720.0	935.0	1170.0	1875.0	0.0	0.0	5,540.0
	% sales cost Dealer (of vol st.pr)	5	5	5	5	5	5	5	5	
13	Sales cost Dealer	25.0	35.0	49.5	63.3	78.0	93.8	0.0	0.0	344.5
	% sales cost HQ (of vol tr.pr)	3	3	3	3	3	3	3	3	
14	sales cost HQ	7.8	10.9	14.0	17.2	20.3	0.0	0.0	0.0	70.2
15	gross margin world 2	317.2	444.1	656.5	854.6	1071.7	1781.3	0.0	0.0	5,125.3
16	project development	1000.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1,000.0
	maintenance & documents	200.0	50.0	40.0	30.0	30.0	30.0	30.0	30.0	440.0
	World profit per ye	-882.8	394.1	616.5	824.6	1041.7	1751.3	-30.0	-30.0	3,685.3
	accumulated	-882.8	-488.7	127.7	952.3	1994.1	3745.3	3715.3	3685.3	
					0.0					

Summary:

Year	19 98	19 99	20 00	20 01	20 02	20 03	20 04	20 05
Street price (average)	1000	1000	1100	1150	1200	1250	1300	1350
Base price Hq	800	800	800	800	800	800	0	0
Factory cost	300	300	300	300	300	0	0	0
Unit sales	500	700	900	1100	1300	1500	0	0
GM before sales cost	350	490	720	935	1170	1875	0	0
GM after sales cost	317	444	656	855	1072	1781	0	0
Profit/year	-883	394	616	825	1042	1751	-30	-30
Profit accumulated	-883	-489	128	952	1994	3745	3715	3685.3

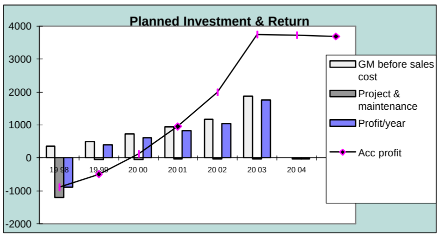
For diagrams only:

Planned:	19 98	19 99	20 00	20 01	20 02	20 03	20 04	20 05
GM before sales cost	350	490	720	935	1170	1875	0	0
Project & maintenance	-1200	-50	-40	-30	-30	-30	-30	-30
Profit/year	-883	394	616	825	1042	1751	-30	-30
Acc profit	**-883**	**-489**	**128**	**952**	**1994**	**3745**	**3715.3**	**3685.3**

Specification

including main product: NPV planned (10%) 2155.47

options/accessories:



Project / Product: **MCM Based Unit**

5.3 Economic Impact: the FUSE experience

While the number of FUSE projects using MCMs is too small to extract general conclusions, they provide very valuable information on the economic impact achieved with the introduction of MCM technologies. To assess the economic impact of introducing MCM technologies, we should distinguish between those MCM technologies like Chip-on-Board and Flip-Chip which provide direct economic impact (reduction in cost) and those which provide indirect economic impact (improved characteristics).

The following tables shows the payback period (time in which the initial investment is returned by profits) and the return on investment (ROI) for some FUSE Application Experiments:

	AE 24801	**AE 24586**	**AE 1603**	**AE 1505**	**AE 22845**	**AE 23047**	**AE 23591**	**AE 26589**	**AE 26725**
Technology (*)	CoB	CoB	FC	L	L	L	L	L	L
Initial Investment (k)	30	90	100	135	80	91	100	94	70
Payback (months)	10	19	12			24	18		15
Lifetime (years)	5	5				2	5		5
ROI (% initial invest.)	>700	1000	500			200	1000		500

	AE 418	**AE 2217**	**AE 23091**	**AE 24760**	**AE 415**
Technology (*)	C	C	C	C	D
Initial Investment (k)	104	98	175	143	120
Payback (months)	36	30		18	
Lifetime (years)	6				
ROI (% initial invest.)	250				

Table 5.1 Return on investment and payback period for FUSE MCM Projects

(*) **FC**: Flip-chip, **CoB**: Chip-on-Board, **L**: MCM-L, **C**: MCM-C, **D**: MCM-D

Using CoB and flip-chip, the cost of the component as well as that of the whole system can be greatly reduced (up to 50%). The initial investment required to introduce the new technology is generally small (between 30 and 100 KECU), and due to the reduction in cost of the final product, short payback periods of less than 12 months can be achieved. Furthermore, the return on investment (cumulative profits over the lifetime of the product) is generally quite high, in some cases more than a ten times the initial investment.

When MCM technology is used to improve the functionality and/or reliability of the product, by reducing the number of inter-connections, the situation is quite different. In this case, the cost of the final product is generally higher than the original, and an increase in sales has to be achieved offering a better product than the competitors. Therefore, a good marketing strategy is required to achieve increased sales. The initial investment for these technologies is normally higher (more than 100 kECU), therefore the payback period is in the order of 3 years. The return on investment is harder to forecast because it is very dependant on the market situation, however a ROI over twice the initial investment is a reasonable expectation.

Finally in those cases where a reduction in size is the main rationale for choosing MCM technology, both a reduction of cost of the final product and an increase in functionality and flexibility can generally be achieved. In these cases, the situation is between the two extreme cases mentioned above.

6. Construction of Workplan

Before starting to work on a project involving the introduction of a new technology, a company must dedicate enough time to prepare a sound workplan[1]. Planning is even more crucial for very complex technologies like MCM. It is important to involve the subcontractors in the definition of the project workplan. This will reduce delays and will help to achieve the required objectives, both on time and on budget[2]. The workplan should be regularly updated during the course of the project. It is very important to include meaningful milestones and contingency plans in order to be prepared for the unexpected problems, both external and internal[3].

In the planning phase of an MCM technology project, decisions on the appropriate MCM technology have to be taken and strategies for the fabrication and test of the MCM must be developed. These decisions depend on a number of factors, which are discussed in more detail below:

The main phases of a project for first use of MCM technology are shown in this flow-chart and will be briefly described in the following paragraphs.

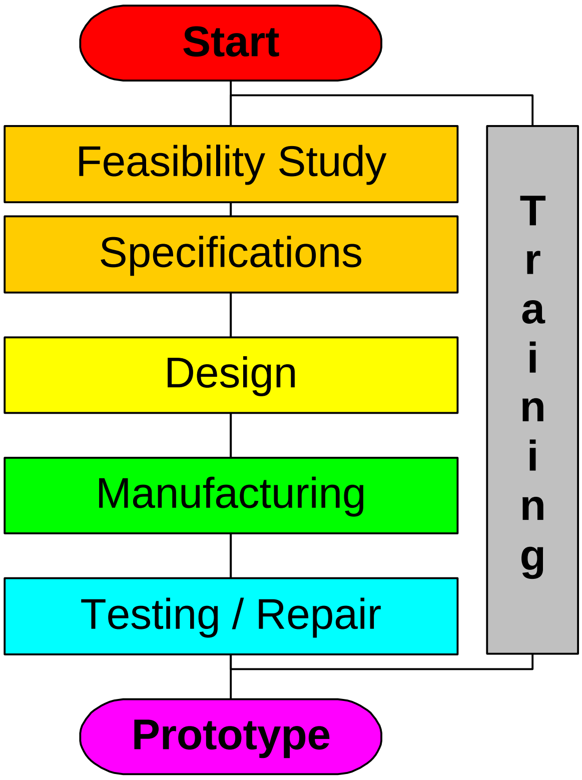


Figure 6.1: Basic flow chart of an MCM prototype project

[1].**AE 22845:** "More time and effort should have been devoted to an appropriate planning … *(The importance of planning)* increases over-proportionally with the complexity of the project."

[2] **AE 1603:** "Planning and complete control of the project, based on the recommendation of the subcontractor, assured success."
AE 23091: "All tasks were planned together with the subcontractor to assure an optimum harmonisation of the development …"

[3] **AE 2217:** "Contingency plans should be made in order to avoid problems. Time reserves should be included."

6.1 Feasibility study and Specifications

One very important step is to perform a thorough feasibility study of the project. In this phase, issues such as economic aspects (investment, costs, profits, etc.), die procurement and the technical feasibility have to be investigated[4]. If some of these questions come out with a negative answer it is important to stop the project at an early stage, before to much work has been put into it. This is described in the flow chart below.

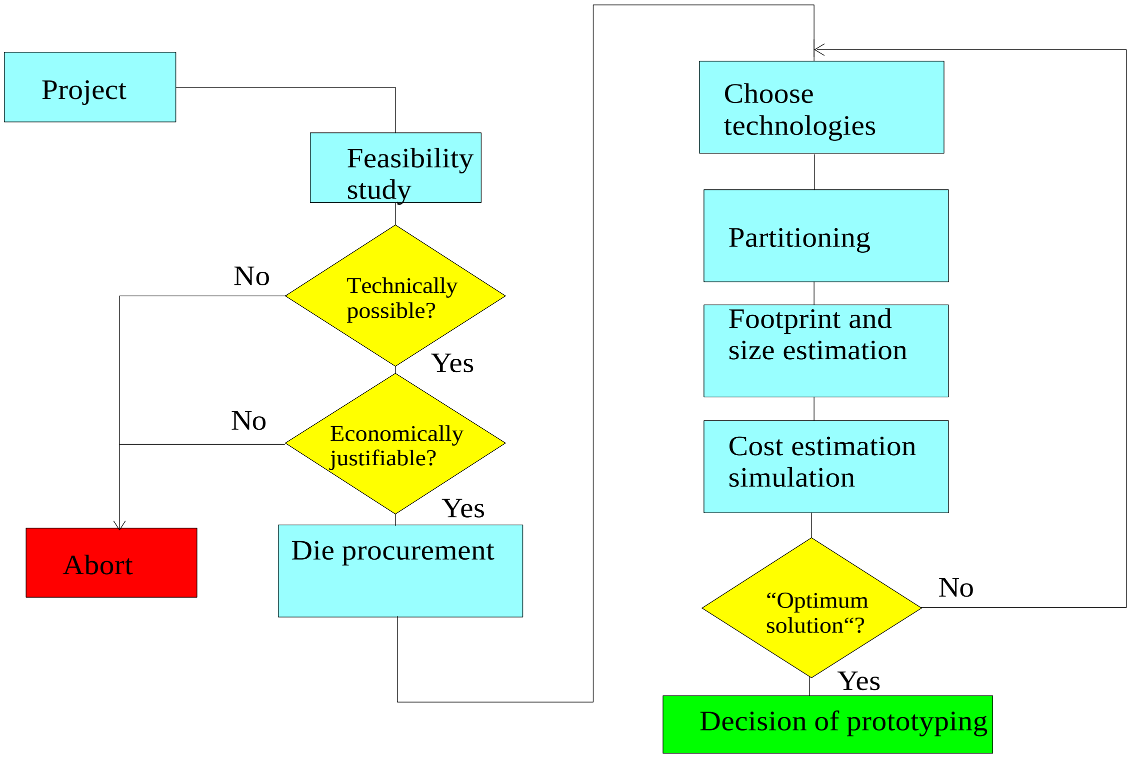


Figure 6.2: Flow chart of a typical feasibility study for an MCM project

At this stage, first users must remember how important is to dedicate enough time to guarantee the availability and cost of bare dice[5]. This will reduce delays at later stages in the project due to the lack of die.

If the project is economically and technically sound, and it is possible to get the dice of interest, the next step in the feasibility study is to choose the most appropriate technology and do the partitioning of the system. From the partitioning it is then time to do a footprint and size and cost estimations. The result of these estimates together with basic simulations of critical electrical parameters, such as cross-talk, high frequency behaviour, timing in critical nets, power consumption and dissipation, is the basis for a trade off analysis. The simulations performed during the feasibility study are done only for parts of the system identified as critical. This trade off analysis has to be iterated in order to find the best solution from both technical and economical aspects.

It is recommended that the feasibility study is performed jointly between the company and a subcontractor with deep knowledge of MCMs and a thorough experience of the market for bare dice.

[4] **AE 1505:** "We did two feasibility reports before deciding the technology and subcontractors."

[5] **AE 1505:** "An important lesson learnt is that we should have spent more time knowing what dice were available before starting the schematics and development."
AE 23153: "Dice were extremely difficult to get. We had to import them from the USA, at a higher cost."
AE 23591: "The bare die was not available in small quantities. We had to buy more than required."

This subcontractor does not necessary have to be a subcontractor for design or manufacturing later in the project. Furthermore, the involvement of current or potential customers can also be helpful[6].

For the feasibility phase to be successful, the company should have found answers to the following questions:

- Are all required ICs available as bare die or is it necessary to mix bare dice and SMT components with small footprints?
- What are the electrical requirements of the interconnections and chip contacts? Is impedance controlled design necessary? Is the MCM a mixed signal system which needs special design rules of the analog and digital parts?
- How much heat is dissipated in the module? Are thermal vias required to increase heat transfer rates in the module? Is it necessary to attach a heat sink to the MCM?
- What is the yield to be expected for the completed module as a function of component yield, substrate yield, and quality of manufacturing processes? Will it be necessary to consider repair of ICs after assembly?
- Which test strategy is required? How will components, substrate and the completed module be tested? Is it necessary to provide tests with error localisation for repair? Which measures are necessary to enhance the testability of the module?
- What will be the cost of design, prototyping and test (for which quantities)?

Once the feasibility study is finalised with a positive outcome, the specifications for the MCM have to be finalised in close co-operation with the subcontractor or subcontractors for manufacturing, assembly and packaging.

At this stage, it is necessary to carry out a market analysis[7]. This should take into consideration both current trends and future prospects.

6.2 Design

When the best solution is found, the next step is the design phase. This may need a number of iterations for all parts to be correctly specified. In the flow chart, a number of design reviews (DR) have to take place in order to see that the subcontractors have made the designs and simulations in a correct way. The details of this part of the project are very dependent of the chosen technology and of the application, i.e. frequency, analog/digital/mixed, power consumption, EMC etc. An example for a high frequency project with power consuming components, manufactured in MCM-D technology, is shown in the flow chart below. In this case a complete thermal analysis has to be undertaken and detailed analysis and simulations of the electrical performance must be carried out.

[6] **AE 24760:** “Without customer involvement, the internal company dynamics bear the risk of being too much determined by technical opportunities.”

[7] **AE 2217:** “In order to justify such a development effort, a market analysis should be made together with the feasibility study.”

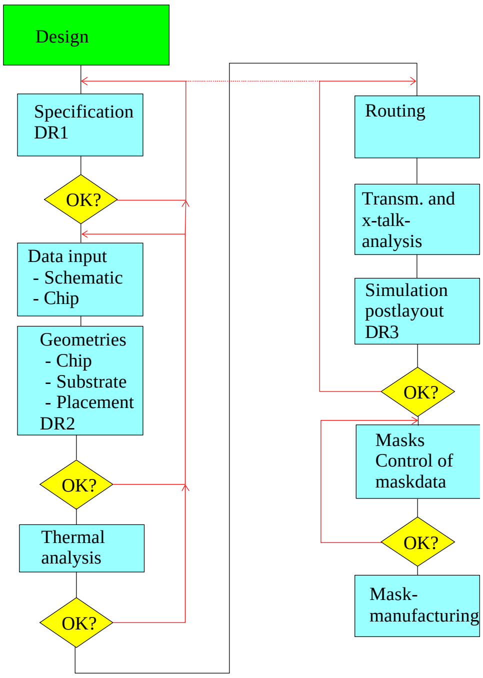


Figure 6.3: The flow of the design phase.

Some, or most, of the work in the design process can be performed in-house, depending on experience/know-how on electronic design and availability of design and simulation tools for MCMs. It is very important to have a good communication with the different subcontractors during this phase, regardless of if the work is done in-house or by subcontractors. A direct transfer of an existing design in PCB/SMT to MCM technology is generally not possible[8], this should be taken into account when planning the design phase.

6.3 Substrate manufacturing and module assembly

In first use of MCM technology, the substrate manufacturing, assembly and assembly test is normally carried out by a subcontractor or by different subcontractors. The supplier of the assembly can perform some functional test but the final test, functional and parametric, has to be performed by the customer for verification and approval of the module.

6.4 Testing, characterisation and repair

This phase includes:

- Test design and setup
- Functional testing
- Prototype testing
- Field testing

If an MCM fails the test phase, a further investigation should be carried out to locate the cause of the failure. In certain circumstances (missing or open tracks, failure of an individual die, etc.) it is possible to repair the module[9].

For more information on Testing, see the "Introduction to MCM technology" section of this document.

[8] **AE 23047:** "The existing circuit could not be transferred 1:1 on the MCM. New partial components had to be designed and tested."

[9] **AE 415:** "We detected a design fault, … our manufacturing subcontractor evaluated a repair solution … which was successful."

6.5 Training and knowledge transfer

In order to successfully developed an MCM it is necessary to have some basic knowledge for the whole cycle of the MCM technology. This training in normally provided by the project subcontractors[10], however external MCM experts can also be used. It is most relevant that the company using the technology for the first time has a good knowledge about the cost driving factors, the limiting factors of the technology and how to prepare the project in order to avoid problems as far as possible[11]. Below are some points where training and/or knowledge transfer from experts may be needed.

During feasibility study:

- ✓ Prototyping costs
- ✓ Manufacturing NRE
- ✓ Module cost in production
- ✓ Module size
- ✓ Savings in a design when MCMs are introduced
- ✓ Savings on a system level when MCMs are introduced
- ✓ Die procurement: How to buy bare dice, will the dice be possible to buy in the future, prices of bare dice
- ✓ Technology possibilities and limitations for different MCM technologies: electrical, thermal and size parameters
- ✓ How to partition a design
- ✓ How to find the best technology and application solution

During design:

- ✓ How is the substrate built up
- ✓ What are the design restrictions
- ✓ What design rules are relevant for the chosen technology
- ✓ What design rules are relevant for the chosen manufacturer
- ✓ What design tools are possible to use
- ✓ What file formats can the manufacturer handle
- ✓ What parameters need to be simulated
- ✓ What tools are available for simulation
- ✓ How will the module be tested
- ✓ How will the module be packaged

During manufacturing, assembly and test:

- ✓ Production batch sizes
- ✓ Delivery batch sizes
- ✓ Module yield during production
- ✓ Test and rework capabilities

During the start and during the project:

- ✓ Management of a new technology development

Training can be carried out at the beginning of the project, in the form of courses and/or seminars[12] or as a continuous technology transfer from the subcontractors to the user for the whole duration of the project[13].

---

[10] **AE 418:** “Training was realised by active co-operation with the subcontractor throughout the design, manufacturing and testing of the MCM.”
AE 1505: “Education has been a key point of this project. … engineers were sent to workshops and had training from our subcontractors.”

[11] **AE 23091:** “Training on design and processing was planned as early as possible because this knowledge was necessary for the specification phase.”

[12] **AE 415:** “We attended an MCM seminar.”
AE 1505: “Participated on training courses … ”

6.6 Risk assessment

Risk can be defined as a function of the severity of a problem and its probability of occurrence. When preparing a workplan it is crucial to identify the risk factors. If the decision after the feasibility phase is to go ahead with the project, contingency plans for the major risk factors must be included in the project workplan.

Typically, various types of analyses will produce hundreds of hazards in a project involving first use of complex technologies like MCM. To determine which hazards should receive priority, a system of making decisions should be established. Standard guidelines, like those from Mil-Std-882, based on combinations of severity and frequency can be applied in order to carry out such an establishment.

General risk assessment such as technological and financial risks must also be carried out. These risks are very dependent on the rapid costs and technology evolution.

6.7 Project duration, delays and effort: FUSE Examples

It is difficult to estimate the duration of each one of the phases described above, as it is very dependent on the particular characteristics of the project. The following table shows the actual duration of each phase for several FUSE Application Experiments (all figures in months).

	AE 415	AE 418	AE 1505	AE 1603	AE 2217	AE 22845
Feasibility / Specificat.	2	1	2	1	3	1
Training	1	12	3	9	1	10
Design	5	4	3	3	6	5
Manufact. & Assembly	11	9	5	7	2	4
Testing (and repair)	4	5	5	5	4	4
Actual Duration	**14**	**12**	**9**	**12**	**11**	**10**
Deviation from plan	**+7**	**+1**	**-**	**-**	**+1**	**-**

	AE 23091	AE 23591	AE 24760	AE 24586	AE 24801	AE 26589	AE 26725
Feasibility / Specificat.	2	1	1	1	1	1	2
Training	5	17	1	1	8	4	2
Design	5	8	2	4	2	1	7
Manufact. & Assembly	5	6	10	3	1	2	4
Testing (and repair)	2	5	4	4.5	6	2	3
Actual Duration	**14**	**18**	**13**	**10**	**11**	**8**	**10**
Deviation from plan	**+2**	**+3**	**+3**	**-**	**+3**	**-**	**-**

Table 6.1 Duration of the different phases of an MCM project

When comparing the planned and actual duration for these projects, it was found that unpredictable delays tend to appear mainly in the Design and Manufacturing phases. These delays are caused by mistakes, errors or faults which require more than one design or manufacturing loops. These are some examples from the FUSE portfolio:

- AE 415: One month delay during design due to a fault. Five months delay in production due to several problems. One month delay to repair a fault detected during test. These delays accumulated to a total of seven months delay at the end of the project

[13] **AE 418:** “The know-how transfer and training were realised by active co-operation with the subcontractor throughout the full *(project)* cycle.”
AE 24760: “The technical training and learning extended throughout all phases …”

- AE 23091: Five months delay in design phase. As enough time had been allocated for contingencies, this delay was reduced to 2 months at the end of the project.
- AE 23591: Three months delay. Mainly during the design phase. The microcontroller had to be changed as the selected one was not available as bare die. Further delay caused by manufacturing subcontractor not delivering on time.
- AE 24760: After the first prototypes were fabricated and tested, a re-design was required, what resulted in a 3 months overall delay.
- AE 24801: Three months slippage in the test phase. Mainly due to samples being shipped between company and subcontractor frequently. Also due to non availability of test equipment at subcontractor.

Another important conclusion from this table is the fact that the duration of Testing is generally quite large for these technologies (and in particular for CoB), sometimes longer that the Design and Manufacturing phases together.

The following table shows the effort in person/day for the company (subcontractor effort not included) for the some FUSE Application Experiments:

	AE 418	**AE 1505**	**AE 1603**	**AE 2217**	**AE 23591**	**AE 24586**	**AE 24801**	**AE 26725**
Feasibility / Specifications	10	20	40	80	-	45.5	2.5	20
Training	25	12	20	25	48	8	21	19
Design	40	20	60	110	75	54	25	68
Testing (and repair)	40	48	60	120	40	89	21	25
Project management, etc.	35	16	15	35	88	46.5	-	36
TOTAL	**150**	**116**	**195**	**370**	**251**	**243**	**69.5**	**168**

Table 6.2 Effort at the First User for each phase of an MCM project

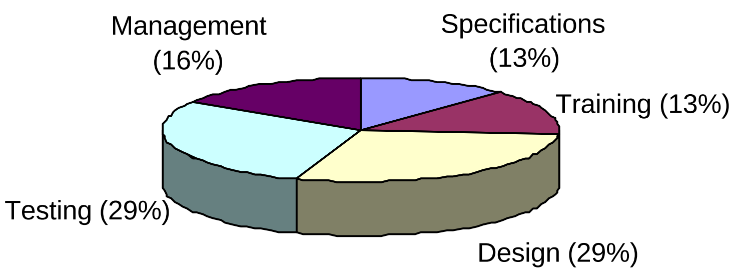


Figure 6.4: Average effort at First user for each phase of an MCM project.

7. Management of Subcontractors

This section looks into issues specific to the MCM technology. For general information on dealing with subcontractors please refer to the document: "FUSE Best Practice: Managing design subcontractors in first time use of microelectronics".

When producing an MCM for a first time, it is good practice to get external assistance[14]. Due to the multidisciplinary nature of the MCM design and manufacturing, this external assistance is/can be required in any of the project phases (see Workplan section for details):

- Feasibility
- Training
- Dice supply
- MCM design
- MCM assembly and packaging (Module manufacturing)
- Testing

An MCM is very dependent on the dice used. Therefore it is important to guarantee availability of all dice involved for the expected lifetime of the product[15]. If the supply of a particular die is stopped, or its specifications changed, the module would have to be re-designed, increasing costs and delaying production. This situation should be consulted with the manufacturer and contingency plans prepared. Alternative or second sourcing should be considered, but it is generally not possible[16].

Bare die suppliers are generally big, market driven, multinational corporations, and it is generally difficult to obtain a written commitment on availability of a specific bare chip. Sometimes, die manufacturers can even require a large order before guaranteeing availability. This could be a problem when only a small number of pieces is necessary[17]. Therefore it is important to establish a good relation with the supplier before the MCM design starts. Furthermore, a good relation can provide very valuable information on MCM technology and manufacturing, due to the extensive experience of suppliers[18]. The

[14] **AE 1603:** "Working (*with the subcontractors)* was very pleasant and will be continued in the future. This collaboration has strengthened our technological ability."
AE 2217: "The assistance of a experienced subcontractor was therefore necessary."
AE 23091: "The subcontractor helped to overcome the barriers because it offered the necessary know-how, equipment and personnel to solve the knowledge and technical problems."
AE 24586: "The right choice of subcontractor is the most important step of the project."

[15] **AE 415:** "We had problems with dice availability from Intel."
AE 418: "Ask for a guaranteed supply for the next 5 years."
AE 1505: "Be aware which dies are available and then do your schematics."
AE 22845: "Due to limited availability of components we had to change from MCM-L to SMT."
AE 23153: "Dice are extremely difficult to get. Many FPGAs are not available as die."
AE 23591: "The chosen microprocessor was not available as bare die for small volumes."
AE 26725: "The MCM was delayed in manufacture due to problems with the supply of die."

[16] **AE 415:** "… no compatibility between dice of different manufacturers …"
AE 23591: "… plan backup solution verifying availability of similar dice …"

[17] **AE 2217:** "*(First User)* ignored by the die supplier if an order of 50,000 dice was not placed immediately."
AE 23153: "A minimum amount of dice had to be ordered."
AE 23591: "Silicon vendors have a minimum threshold to justify an economical lot."

[18] **AE 23591:** "*(The die supplier)* trained us on MCM technology: substrate and packaging characteristics, die attach, wire bonding, plastic encapsulations, etc."
AE 24760: "The suppliers of parts and equipment know (or are willing to give away) more *(information)* than the modules manufacturers."

availability of mechanical samples for assembly tests should also be considered when choosing a die supplier.

Bare die manufacturers frequently reduce the size of their technology for improved performance. While this technological advance can pass unnoticed for a designer using single chip packages, the situation is very different for an MCM, which would require some modifications to adapt for a smaller chip[19].

While most suppliers offer untested bare dice, some suppliers have started to provide fully tested units known as "known good die" or KGD. This can reduce dramatically the cost of the final product by greatly increasing the module yield[20].

The design of an MCM is almost completely independent of the chosen manufacturer. The circuit design can be carried out by anyone with experience on PCB/hybrids design, using similar tools. To design the layout and interconnections of the MCM, input from the manufacturer is required. If for any reason an alternative manufacturer must be used the design can generally be easily adapted, as this would normally represent only a few weeks delay. The customer must be the sole owner of the design[21] in order to have the freedom to change subcontractors if necessary.

MCM is a relatively new technology therefore some manufacturing is still carried out by Research Centres. However, more and more MCM foundries, both large and small, are appearing. When choosing who is going to assemble the module, Research Centres can offer extensive know-how of technology, with a wide range of technologies available (from simple MCM-L to very advanced technologies like MCM-V or MCM-O). They are also advantageous to train on the usage of the technology[22]. However, it is always important to remember that they are not commercial companies[23].

Large manufacturers have the advantage of experienced personnel and state-of-the-art equipment. However, sometimes it is hard for a small customer to interact with a large corporation[24]. Another disadvantage can be the lack of long term commitment to a particular technology. Small manufacturers have advantages such as better accessibility (both physical, due to geographical closeness, and mental, same thinking) improving the customer-subcontractor interaction[25]. However, when choosing a small manufacturer of MCMs, always check that they have the required resources (both personnel and equipment) and experience to carry out the project successfully[26].

---

[19] **AE 415:** "A reduction of dice size (shrink) may require a redesign of the MCM."
AE 1505: "As the die shrinks occurs you will have to redesign at least once a year."

[20] **AE 415:** "We used KGD … *(so)* only fully functional components are included in the module."
AE 23591: "The availability of KGD was one of the most important requirements."
AE 24586: "Difficult to persuade suppliers to provide bare dice since they want to avoid new internal test procedure of the bare dice."

[21] **AE 418:** "… all resulting designs are exclusive property of the company … to hand over the design to another design partner if desired."

[22] **AE23047:** "The Technical University was a very competent subcontractor in all matters of electronic development."
AE 23091: "The subcontractor is a scientific institute, … has the specific know-how, … owns production machinery in laboratory scale, … offers training, …"

[23] **AE 23047:** "A superior knowledge is not enough for a successful project, it must be combined with an understanding of the demands of industry." "… inflexible to react to changes in workplan."

[24] **AE 23591:** "The interaction between the First User and the *(large)* manufacturer was poor. … They did not have sufficient incentive with the relatively small business we offered."

[25] **AE 2217:** "The subcontractor, a SME, was very flexible. Co-operation was very dynamic."
AE 26589: "Locality was seen as the most important subcontractor selection criterion."

[26] **AE 415:** "Our manufacturing subcontractor had not as much experience as he had claimed." "Small companies try to run more projects that they can manage."

When the company has no experience on MCM design and no knowledge on how to select a die supplier, it is recommended to choose of subcontractor with both design and manufacturing capabilities. An experienced MCM manufacturer can be of great help in the selection of and interaction with the die supplier[27].

Regular progress meetings with the subcontractors have shown to be very useful to achieve the required objectives[28]

As mentioned above, referring to die suppliers, it is important to guarantee the availability of the technology for the lifetime of the MCM. Due to the transportability of MCM designs, it is always recommended to consider at least one alternative manufacturer. If things go wrong (delays, high costs, low quality, bad performance, etc.) with the main manufacturer, the second one can replace or support them. Before choosing a manufacturer, it is important to talk to former/current customers and to look for advice of experts in the area.

The assembly testing will generally be carried out by the module manufacturer, however functional testing of the modules can involve a wide variety of testing procedures (analogue, digital, mixed signal, power, high frequency, thermal, environmental, etc.) therefore is generally carried out by someone else. A contractor with the required expertise and resources should be selected.

The success of a development project depends largely on the precise definition of duties and time frame for each part involved. Responsibilities in case of delays or higher costs should be clearly defined in the subcontracting contract[29]. Contractual safeguards, including penalty clauses, can reduce these risks. When dealing with any type of subcontractors or suppliers, it is always important to have a contingency plan just in case they do not perform as planned. Furthermore, sometimes it helps to put some pressure on the subcontractors to achieve the required results[30].

AE 24760: "Their engineering staff had limited capacity, causing long throughput times."

[27] **AE 2217:** "The manufacturer organised the interaction with the die supplier where their know-how and expertise were of great benefit."
AE 24586: "Leave the responsibility for procuring tested bare dies to the manufacturer."
AE 26595: "In co-operation with the subcontractor we found which bare dice were available."

[28] **AE 1505:** "Technical reviews and regular meetings were important points for the project success."

[29] **AE 418:** "The party responsible for redesign -and therefore its associated costs- in case of problems, must be clearly defined."

[30] **AE 23591:** "We established a close control of the subcontractor's activities to manage them properly."
AE 24760: "We learned not to be shy to exercise pressure on the subcontractors."

8. Quality Assurance

To reach a certain level of quality assurance some additional actions have to be planned into the development project.

The initial document is the quality assurance plan which includes hazard analysis, risk assessment and a list of required specifications and test procedures. This plan controls the entire quality structure of the project including all documents required.

In order to fulfil the control activities the specifications and the test procedures must match each other. Every specified item in the technical specifications must have a corresponding test item in the system test document. The specified item in the functional specification must also in a similar way have a corresponding test item in the functional test document.

At the end of the project a document concluding all specifications and tests should be written in order to give a total overview of the quality level.

Recommended Bibliography

1. Members of the Europractice MCM service, *EP-MCM Design Handbook*, Edition 2.
2. J.J. Licari, *Multichip Module Design, Fabrication & Testing*, McGraw-Hill, 1995.
3. G. Messner et al, *Thin Film Multichip Modules*, International Society for Hybrid Microelectronics, 1992.
4. *Savansys Users Guide*, Savantage, Draft, February 1996.
5. P.A. Sandborn, H. Moreno, *Conceptual Design of Multichip Modules and Systems*, Kluwer Academic Publishers, 1994.
6. D.A. Doane, P.D Franzon (ed.), *Multichip Module Technologies and Alternatives: The Basics*, Van Nostrand Reinhold, New York, 1993.
7. P.E. Garrou, I. Turlik, *Multichip Module Technology Handbook*, McGraw Hill, New York, 1998.
8. D. G. Raheja, *Assurance Technologies,* McGraw-Hill, 1991.

MCM Application Experiments

The experiences from the following FUSE Application Experiments have been used to prepare this document. The following abstracts are a brief introduction to each one of them to put them in context. For more detailed information about any of these AEs, please consult the corresponding Demonstrator Document.

AE415: Kontron (Germany)

Technology: MCM-D
Application: Single board computer
Rationale: Reduced size and improved performance

Abstract:

Kontron Elektronik GmbH develops and manufactures computer products for the industrial market. The product portfolio includes portable computers, rack mount computers (19") and single board computers (= SBCs). Most of these products, especially the single board computers, are totally developed and manufactured by Kontron. Kontron has a long tradition in manufacturing SBCs, starting in the eighties with Z80-based products up to 486- and Pentium-based boards today. The functionality on a SBC has increased dramatically in the last years. Kontron was one of the first companies to include a video display controller on a EURO-sized (160x100mm) SBC.

The existing product Kontron wanted to improve, using the MCM-technology, was the EURO-486 SBC. The reason for considering a new technology becomes quite obvious if one looks at the existing board: The board has a very dense population with SMT (surface mount technology) devices on both sides and is therefore not easy to manufacture. It was a very hard job to integrate the 486 into the EURO format and it was only possible using a new PCB routing tool, a 10-layer PCB and a very small line width. Kontron wanted to improve the EURO-486 regarding performance (Pentium, Cache, Memory), but did not want to reduce functionality. So Kontron considered MCMs and the FUSE project gave the final kick to risk the step into this (for Kontron) new and very interesting technology. The company defined an MCM containing the Pentium CPU (120/133 MHz), the second level cache (256KB) and the system controller (= part of the chipset). This resulted in a board which has now much more performance, more functionality and consumes less space (especially in height) than the EURO-486.

Kontron learnt about the MCM design flow, how to specify an MCM, to consider the die availability, to choose which components should be integrated and which not, and about test and verification tools and strategies. Today, after the project, Kontron are able to manage an MCM project by ourselves. But we also had some negative experiences which should not be hidden. We had severe problems with our time schedule, mainly caused by our subcontractor having a delay of 5 months for the MCM-prototypes. The projected duration was 7 months (actual duration 14) and the cost 120 kECU (10% more than originally planned).

AE418: Minimax (Germany)

Technology: MCM-C
Application: Flame detector - Sensors
Rationale: Size and cost reduction

Abstract:

The company MINIMAX GmbH, with 2678 employees, 27 of them are involved in electronic development, manufactured a flame detector employing multi-chip-module (MCM) technology. MINIMAX belongs to the small circle of international fire protection companies able to supply complete fire protection systems. The activities of Minimax GmbH are subdivided into the sectors Fixed Fire Protection, Mobile Fire Protection and Foreign Group Companies.

The MCM-technology allows the design of an infrared multi-spectral sensor/signal unit with 4 integrated infrared (IR) sensors, optical IR-filters and signal pre-processing. The flame detector can be used not only for fire detection but also for the immediate start of extinguishing systems. The existing technology using single sensors and SMD technology on PCBs was replaced by an MCM module with unhoused sensors and bare dice on hybrids.

This advanced integration technology results in space and cost reduction and higher reliability due to improved EMC (electromagnetic compatibility) behaviour. During the application experiment, the technology of applying bare dice (hybrid and MCM technology) is transferred from an experienced industrially oriented institute to the First User. This gain of know-how and experience will enable the First User to access and use this new technology in their future product development. The Application Experiment took 12 months. The development costs ran to 100 KECU. The payback period including the industrialisation will be about 36 months and the lifetime of the product is expected to be about six years. This will enable a Return-on-Investment of about 250%.

This project is of interest to companies working in the area of security systems or in the area of advanced sensor systems.

AE1505: THEN Maschinen und Apparatebau GmgH (Germany)

Technology: MCM-L
Application: Intelligent temperature sensor
Rationale: Size reduction and thermal ruggedness

Abstract:

THEN GmbH is a SME, manufacturing machinery and process control systems for the Dying and Finishing Industry in Textiles. THEN has realised that the Electrical and Electronics parts of the machine with the software have become a key factor in the competitiveness of the businesses. The fact that the electrical, electronic and software parts of the machine have risen from 10 % to 22 % in the last 8 years shows that a lot of functions of the machines that were performed mechanically are now done using electronics and Software.

The existing Control Systems are based on PLCs (Programmable Logic Controllers) and dumb sensors and Actuators. The software is written in ladder logic and is not platform independent. A base line project was started to develop a new type of Control system based on Decentralised Distributed systems. This meant that the Sensors and Actuators needed more electronics and intelligence directly within the components. Hence the need came to build a robust microprocessor sensor for this new generation of sensors and actuators.

This First User Experiment helped us to design, manufacture and test a Multi Chip Module based Temperature Sensor for the base line project. It is important to note that the AE is only a small part of the base line project. The AE by itself does not benefit THEN. The combination of the AE in the complete project has brought THEN a lot of benefits. The main benefits are that the complete machine costs have been reduced by 10%. The savings are largely due to simple installation and the reusability of hard and software.

The lesson learnt in this project is that you have to spend more time knowing which dies are available before you start with the schematics and development. A vary large part of the time was spent negotiating with the die suppliers. The project has been successful as these sensors are being used in the machines THEN is selling now. The total cost of the Application Experiment was 135 KECU and was completed in 9 months.

AE1603: PAV Card Gmbh (Germany)

Technology: Flip-chip
Application: Smart cards
Rationale: Size reduction

Abstract:

A prototype transponder chip card employing a bare die technology (flip-chip) was realised by PAV CARD GmbH, Germany, in 12 month with a budget of 100.000 ECU. PAV CARD GmbH, a former printing company, has about 75 employees with three involved in electronic development. PAV CARD produces a wide range of ID cards like service and guarantee cards, club and credit cards, insurance IDs with and without magnetic strips. They also produce chip cards for policy holders and contactless transponder cards for ticketing and payment. The products are sold to a world-wide market.

The present chip card technology using prefabricated electronic modules with contact areas has been replaced by a custom made telemetric unit with a smart chip and an antenna foil carrying an etched inductivity. This advanced integration technology results in an ultra thin electronic assembly that can be laminated in a conventional plastic chip card and reduces costs and improves the reliability of the cards.

The market for the contactless chip card is now not only limited to health insurance and bank cards as in the past, but now also includes ticket cards for public traffic, access and time control and security systems. The pay-back period has been only some month due to a first big business in the far east in the area of subway automatic access control and payment systems.

The overall time to market was slightly over one year. The pay back period is about 12 months. The return on investment more than 500%, since the basic investments may directly be used for further products.

AE2217: Symacon Electronics and Automation GmbH (Germany)

Technology: MCM-C
Application: Monitoring and control
Rationale: Reusability, smaller size, lower cost

Abstract:

Symacon is an SME with 7 employees with a turnover of 500 kEuros. The company develops and manufactures process control and measurement systems. These are used in a wide range of applications including the monitoring and control of machines and equipment. The company also programmes and tests software components related to these products.

The objective of the AE was to improve the functional features and the competitiveness of one of the company's main products, the heating control system, which contributes 20% of the company's turnover.

The existing technology level within the company, which included knowledge in the design and manufacture of PCB's using SMD technology, and microcontroller applications was not sufficient to remain competitive. In this AE, MCM technology was introduced into the company.

The AE ran for 11 months, one month longer than planned. The total costs were 98 kEuros and a Payback Period of 30 months is expected.

AE22845: Luxcom AG (Switzerland)

Technology: MCM-L - SMD
Application: Fibre optic sensors
Rationale: Lower cost and thermal properties

Abstract:

Luxcom AG is an innovative manufacturer of passive optical fibre components, used primarily in the areas of telecommunication, instrumentation, industrial data-networks and on mobile platforms. In the industrial markets, fibre optic sensors are gaining an increasing interest. The company has thus taken over the temperature sensor products from a company which discontinued its business. This product is used for the temperature surveillance of large industrial transformers, and is currently manufactured by Luxcom as a discrete assembly of its own passive components and transmitter/receivers originally developed for data- and telecommunication.

Although the product was well received by the market, it has been found that fibre optic sensors are often loosing against conventional solutions, despite their potentially large benefits (e.g.: EMC, safety in explosive environments, temperature stability, potential free measurements). The reasons are usually an insufficient maturity of the systems, which are mostly made for laboratory use, lack of reliability and high costs due to a limited potential for mass production. All this can be traced back to the lack of transmitter-/receiver modules optimised for sensor applications, which replace the complicated assemblies of discrete components, commonly used in today's designs.

The prototype of such a transmitter/receiver module has been realised as a printed circuit board in surface mount technology and integrated into the above mentioned fibre optic temperature system. The technology developed, allows to realise a very cost effective and reliable solution such that the company has now an almost exclusive access to this market of approximately 500 temperature sensor systems per year, resulting in a total annual business of almost 1 MECU.

Further, the company acquired a basic understanding of opto-electronic technology and fibre optic sensors, which will be used to develop sensor solutions for other industrial markets resulting in additional business with the company's existing and new OEM-customers. The costs of this AE were 80 kECU. The duration was 10 months.

AE23047: CE-SYS GmbH (Germany)

Technology: MCM-L
Application: Power supply monitoring
Rationale: Improved functionality

Abstract:

The company CE-SYS was founded in 1990 by two engineers and started as a seller of PC. The company now has a staff of 15 employees and develops, manufacturers and sells EMC-testing equipment and communication technology. The AE has improved the “Electric Power Quality Analyser (EPQA)” which is provided by the CE-SYS GmbH based on a discrete controller board realised in PCB technology. The EPQA serves for supervision and recording of the power quality of electric networks. The system measures a wide range of quantities of power supplies (e.g. voltage, harmonics, frequency, etc.). The main application field is the use in PC-networks due to its construction.

The objective of the experiment was an extension of functionality and application field, an improvement of accuracy, a cost reduction and an increase of market share with the existing product. The development should be realised in a Multichip-Module solution which will be able to implement the customer demands and provide the following improvements. Main advantages are the minimisation of the device, the simplification of its handling and the improved functionality. Also the reduction in manufacturing and testing costs and the reduction in power consumption are big improvements to gain a higher market share with this product.

The Application Experiment duration was 10 months. The costs were 91 kECU. The payback period can be estimated of about 24 months.

AE23091: TELE Quartz GmbH (Germany)

Technology: MCM-C
Application: Quartz-crystal oscillator
Rationale: Size and cost reduction

Abstract:

TELE QUARZ GmbH, a mid-sized company with 675 employees in Germany. The activities of the company include design, manufacturing, marketing and sales of quartz crystal units. The quartz-crystal- units are sold as components or are part of quartz- crystal- oscillators, which are also produced by TELE QUARZ. The main business is the supply of the telecommunication industry.

Thermal calculations with different designs and materials were carried out from which the technical solution was derived. Economic calculation showed a cost- reduction against the old product of about 60%. Consideration of the existing capabilities in manufacturing special hybrid-circuits delivered an important extension of the existing capabilities and new technologies like flip-chip mounting of bare- dice were also considered and showed the appropriate technologies.

The existing Product is an oven controlled crystal oscillator (OCXO). Technologically it consists of two interconnected circuit boards, an AlN - oscillator-circuit with a SC-quartz crystal unit and a FR4 board with the supply and regulation circuits. For these devices only packaged semiconductors and SMDs are used. The enclosure is a solder-sealed metal package with lead wires for through-hole mounting.

In the new product all functions of the OCXO are integrated in one AlN - hybrid circuit. The main functions and the correspondent devices are integrated in an ASIC which is die and wire-bonded directly to the AlN substrate. Devices such as a bare die ASIC, thick- film resistors, and SMDs are used. The new smaller package consists of a folded metal lid and an FR4 base-plate with J-leads for SMD- mounting.

The benefits and the increments in capability are that the First User is now able to repeat the design and manufacturing of crystal oscillators of smaller size and with lower costs on AlN-ceramic substrates by using ASICs in the form of bare dice and to use this technique for developing and manufacturing future products. The first user is now more familiar with new technologies like ASICs. The production costs were reduced and through the new technology a new product with higher reliability, lower price, and smaller dimensions to enforce the competitive position was created.

The total costs at the end of the experiment were 175 kECU. The duration was twelve months.

AE23153: Göpel Electronic GmbH (Germany)

Technology: Chip-on-Board
Application: Boundary-scan controller (PCMCIA card)
Rationale: Size reduction

Abstract:

Göpel Electronic (39 employees) designs, produces and sells professional Boundary Scan test equipment, as well as image processing systems and customized functional test systems. Objective of the Application Experiment (AE) was the introduction of Chip On Board technology (CoB) together with VHDL as design language and approach for a highly complex FPGA into GÖPEL electronics business. Within the scope of the experiment the existing Boundary Scan controller on PC/AT basis was transformed into a PCMCIA based product. The existing Boundary Scan controller was developed using packaged chips and a FPGA designed by a design company. Due to board dimensions and maximum component height it was not possible to use this product in portable personal computers such as notebooks and laptops. The new technology (COB) in connection with smallest possible structures on PCBs allowed the reduction of the size of both components and board by about 80% compared to the former product. Thus, the new product was produced as a PCMCIA Card.

During the AE, GÖPEL introduced CoB, a difficult and previously unknown technology to them, into their business. Furthermore, the FPGA designers learnt the description and simulation of a given digital circuit using VHDL, the implementation of this into a highly complex FPGA (25,000 gates) and the possible interface for later migration to an ASIC.

During this AE unforeseen problems had to be solved which resulted in many lessons being learnt. These lessons were mainly related to problems with the dies e.g. delivery times, availability, amount, prices, manufacturing and implementation.

The planned duration of the AE was 12 months as planned. However, due to the problems that occurred during the AE the real costs exceeded planned costs of 130.000 ECU by 10%. The payback period will be approximately 18 months and, assuming a 3 year product life, the ROI will be around 400%.

AE23591: Magneti Marelli SpA (Italy)

Technology: MCM-L
Application: Automotive electronics
Rationale: Lower cost, reusability

Abstract:

Magnetti Marelli Electronic Division (MMDE) is an internal Company Unit of Magnetti Marelli SpA, which designs and produces automotive equipment. MMDE carries out design and assembly of automotive electronics. Its more important products are instrumentation (700/1,000 dashboard per day) and engine control units (3,000 units per day). MMDE employs 5,500 people world-wide out of a total of 24,300 for the whole company.

The company is interested on improving its products using new electronic technologies in order to increase their quality and to reduce their costs to maintain competitiveness on the related market. An engine electronic control unit has been selected and modified in order to manufacture the logic section as an MCM-L, using a PCB laminate as its base substrate, in a Ball Grid Array package.

The duration of this AE was 20 months and its cost was 100 kEuros. The expected Payback Period is 18 months, with a Return on Investment of 1000% of the initial investment for a product lifetime of 5 years.

AE24586: IDM S.r.l. (Italy)

Technology: Chip-on-Board
Application: Automotive electronics
Rationale: Lower cost, size reduction

Abstract:

The company IDM S.r.l. (Italy), with 45 persons of which 3 are electronic engineers, is specialised in the designing, manufacturing and selling of electronic ignition systems for a wide range of endothermic engines like those used for motorcycles, stationary machines, gardening and agriculture

vehicles. IDM S.r.l. also manufactures several kinds of voltage regulators mainly for the motorcycles market. These kind of regulators are used to provide a constant voltage on the AC loads of the motorcycles, e.g. head, meter and tail lamps and, at the same time, to charge correctly their battery, assuring it conditions for a long operation life. The regulator we are currently manufacturing for scooters uses a traditional PCB substrate where two SCRs (Silicon Controlled Rectifier) in the TO220 case and several through-hole components are mounted. In particular the two SCRs preclude us from reducing the size of the regulator and further on they are the critical elements of the product because during their working life, due to thermal shocks, they may de-solder and fail. In this AE the new component is an high dissipation CoB where bare SCR dice are assembled onto a DCB (Direct Copper Bonded) ceramic substrate through a soft solder process of die attach. This will assure a very high thermal conductivity with a very low TCE (Thermal Coefficient of Expansion).

The main benefits of the new product are reduced production costs (about 28%), reduced component dimensions (overall volume is the 25% in less as regards the old product and the weight is 45% respect the old product) and increased reliability. Thanks to this AE, IDM invested heavily to have internal assembly DCB and will allow us to introduce this new technology in several products of ours decreasing the payback period and increasing our global market share

The estimated ROI is 1000% over a 5 year period and will paid back in 19 months. The total cost of the application experiment was planned in 90.5 kECU. The duration was 10 months.

AE24612: Technosystem S.p.A. (Italy)

Technology: MCM-C
Application: Video distribution systems
Rationale: Improved performance

Abstract:

Technosystem S.p.A. (60 employees, 50% involved in electronic design) operates in the area of design and manufacturing of equipment and systems for radio and television broadcasting.

This experiment, during 18 months, with an investment of 164 kECU, is devoted to improve the traditional stand-alone VHF and UHF distribution systems. The new system will replace the single channel broadcasting with a millimetre-wave wideband up-converter to allow the distribution of a multi-channel wideband signal, carrying a combination of both analog and digital video channels. The new system manufactured by Technosystem has been implemented using a MCM technology in hybrid form, to achieve the following objectives: increased system capability (multi-channel broadcasting), investigation of new processing technologies (mm-wave MCM, mm-wave testing, device integration and assembly), extend Technosystem hybrid design, integration level and production capabilities.

The expected Payback Period is 24 months.

AE24760: SaRonix B.V. (The Netherlands)

Technology: MCM-C
Application: Quartz crystal oscillator
Rationale: Size reduction, hermetic

Abstract:

SaRonix B.V. is a medium-sized Dutch company manufacturing quartz crystals and oscillators for the general & industrial market.

The objective of the AE is to reduce the size of the quartz oscillator to an absolute minimum by incorporating the quartz blank and an oscillator IC die into a common, hermetic encapsulation in which the interconnection is integrated, i.e. a ceramic chip carrier with sealed lid.

The existing oscillators of SaRonix are built on PCB-type or hybrid carriers. They are large because of their through-hole leaded metal package, in connection with the hermetic- sealing requirement of the quartz. They are expected to lose market share because most new applications capitalise on the concept of miniaturisation, e.g. mobile telephony, PCMCIA cards. With the new adapted technology the through-hole version changes into true SMD; the SMD connections are integrated into the carrier; the carrier can be sealed hermetically without the need to seal the quartz in its own, separate housing. The size of the resulting product is only determined by the quartz itself. In addition, the cost price is reduced considerably because of fewer materials.

The economic benefits of this AE are a strong increase of sales quantity and profits. The capability of SaRonix increases with the design knowledge in a new, MCM technology and the option to apply this in manufacturing.

SaRonix learned the design rules for ceramic chip carriers; how to implement a sensitive quartz crystal into this carrier; critical design parameters for the interaction of IC and quartz in an integrated small housing; critical process parameters for maintaining product quality.

This AE started at 1 November 1996 and lasted until 30 November 1997. The whole project, including the investment in production machinery, costed approx. 1250 kECU, of which 143 kECU was related directly to this AE. The payback period of the whole project is expected to be less then 18 months.

AE24801: CorkOpt (Ireland)

Technology: Chip on Board
Application: LED array for motor vehicle wheel alignment
Rationale: Manufacturing cost reduction

Abstract:

CorkOpt Ltd. established in 1994 is a rapidly growing small company (9 people) in Cork, Ireland. The company designs, manufactures, and markets optoelectronic components for the European, USA and other markets including LED and laser emitters and photodiode receivers. In this eight-month project, the company introduced chip-on-board packaging technology for the first time. The component realised during the experiment is a low cost chip on board LED array with protective transparent epoxy encapsulant. The component will be used in automotive wheel alignment, sensing and positioning instrumentation equipment.

The driving force for this project, transferring to chip-on-board technology, was manufacturing cost. Chip-on-board technology reduces the total direct costs per unit (on LED arrays, which are presently the biggest volume component) from 21.5 ECU to 17.1 ECU (approx. 20%). The second driving force behind the project was to improve the flexibility of production, allowing modifications to suit specific customer needs. The new technology allows the integration of miniaturised optics into the encapsulant. Additionally, CorkOpt gained improved design flexibility due to product miniaturisation for new designs of both LED arrays and Laser Diode Arrays.

The total project cost was 30 KECU, with an expected payback period of 8 to 12 months. The expected return on investment -for a product lifetime of 5 years- is ten times the initial investment.

AE26589: Digital-Logic AG (Switzerland)

Technology: MCM-L
Application: Microprocessor
Rationale: Size reduction

Abstract:

DIGITAL-LOGIC AG was founded in 1991 and is specialised in developing and manufacturing embedded PC-systems. The company’s staff of 40 employees is composed of competent specialists in various fields.

The products are miniaturised PCs for different applications in different fields (industry, telecommunication, mobile market etc.). The products are produced in SMT with up to 14 layer fine pitch (120μm) multilayer prints. The integration in the current products was at its limit. This could only be increased with a fully new technology, where the chips are smaller (without casing) and the connecting pitches are below 80μm.

This application experiment opened a new technology to DIGITAL-LOGIC AG and improved our products significantly. With the advantage of the new technology, our products could be launched on new markets, such as car navigation. During this experiment, our management and our engineers were trained in new processes and development tools, in order to reduce the integration. Especially the design of the MCM-substrate was a totally new task. With this new product generation, an increasing business activity is expected. The close co-operation with the EUROPRACTICE MCM Design Centre at ETH Zurich ensured the transfer of the specific know-ledge to our engineers. The project duration was 8 months and the total costs were 94,000 ECU.

AE26595: Zimo Elektronik (Austria)

Technology: MCM-L
Application: Model train control
Rationale: Size reduction

Abstract:

The company Zimo develops and manufactures digital control systems for model trains. The company is situated in Vienna, and has 5 employees of which 2 are involved in electronic development. Before this AE the company already had experience with digital ASICs.

In the application experiment, a hybrid module will be developed, which will be installed in a locomotive decoder. The locomotive decoder is an electronic module built into the actual locomotive. It receives and evaluates the digital commands, which are transmitted through the railway tracks from the base unit to the system.

The main objective and big advantage of the new technology is the reduction of the size of the current product to approximately a third, so that it can be installed in small locomotives. Thus, a new type of users can move to a digital command control. The design of the prorotype took 6 months with a budget of 29 kECU.

AE26725: Freeman Hospital (United Kingdom)

Technology: MCM-L
Application: Human body activity data-logger
Rationale: Size reduction, improved reliability

Abstract:

The Musculo-Skeletal Unit (MSU) is a clinical and academic unit within the Freeman Hospital. The NUMACT physical activity data-logger based on a Psion 3 was developed to record a person's activity for a period of 24 hours. It was piloted in rheumatology and since used in other medical areas. The re-development in this AE was a micro-controller based MCM data-logger. This enabled a reduction in the size of the unit, improved reliability, increased recording period, better resistance to damage in cheaper device with fewer components and reduced maintenance costs.

Re-development took place in two stages: 1)Incorporation of micro-controller technology into a dedicated device, which has been fully achieved and evaluated; and 2)Development of an MCM with RF communication, a limited memory capacity and the micro-controller in a single package. The MCM manufacturing was delayed due to problems with the supply of bare dice.

The MSU has a considerable market lead with NUMACT in health and medical research. The duration of the project was 10 months on a budget of 70 kEuros. The payback period is expected to be 14-16 months with a return on investment exceeding 500% of the initial investment in 5 years.