CHEAP MULTICHIP MODULES

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This paper was presented at the IMAPS-UK EC-MCM 99 Conference in London on 1-2 February 1999 and published in Microelectronics International, Vol.16, No.2, 1999, pp14 - 19

Keywords: MCM, MultiChip Modules, MCM technology, cheap modules, MCM-L, MultiChip Modules Laminates, MCM-C, MultiChip Modules Ceramics, cost reduction, RTD, Research and Technology Development

Abstract: The opportunity for mutual benefit across Europe to develop low-cost MCM technologies arose from recognition of the scientific skills and design and prototyping capabilities in organic and inorganic circuits in countries of Central Europe. As a results, the leading research institutions and small/medium-size enterprises of Hungary, Romania and Slovenia together with relevant institutions of the United Kingdom and Belgium proposed and received approval for an European Union INCO-COPERNICUS project (IC15-CT96-0743) "Establishment of Fast Prototyping Low Cost Multichip Module Technology Facilities in Eastern Europe for the Benefit of European Industry" (Cheap MultiChip Modules) to establish fast prototyping low cost multichip module (MCM) technology facilities. The project commenced in May 1997.

MCM Technologies include the design, manufacturing, assembling and testing phases. The tasks of the Project are divided among the participants in accordance with these technological phases and conforming to their interest and capability in the field.

Design is the task of the Rumanian Partners. They have installed CAD systems and developed circuit designs and simulations to determine the design rules and preferences for MCMs. Manufacturing is the task of the Hungarian and Slovenian Partners. They are focusing their laminate and ceramics capabilities towards MCM-L and MCM-C manufacturing and upgrading test technologies up to a level to fulfill the low cost, fast prototyping requirements of the participating Central European Countries (and later Europe-wide). The Hungarian Partner is also establishing mounting and bonding facilities for assembling MCMs in collaboration with the UK and Belgian Partners, exploiting their high level experience in the fields of microjoining and test technologies. The final test of demonstration modules is also the task of the Belgian Partner. The evaluation of the results in accordance with the manufacturing, application and economic aspects will be the task of all Partners with the leadership of the Hungarian Partner.

The Project is carried out in close co-operation of all Partners. In order to disseminate information for and about the Project, the Partnership participates in conferences, organizes seminars and training courses for themselves and for small and medium size enterprises who show interest in the prototyping technology of MCMs.

Considerable progress has been made in the design facilities by the Rumanian Partner, and in the refinement of the printed circuit board (PCB) technology at Budapest, including laser patterning of MCM-Ls. Diffusion patterning and ceramics technology skills in Slovenia are enabling MCM-C prototyping to be demonstrated and further developed.

Poceni multichip moduli

Ključne besede: MCM moduli multichip, MCM tehnologija modulov multichip, moduli ceneni, MCM-L moduli multichip laminati, MCM-C moduli multichip keramika, zmanjšanje stroškov, RTD razvoj raziskovanja in tehnologije

Povzetek: Vodilni raziskovalni inštituti in majhna oziroma srednje velika podjetja Madžarske, Romunije in Slovenije so hkrati z ustreznimi inštitucijami Velike Britanije in Belgije predlagali Evropski uniji INCO-COPERNICUS projekt »Poceni Multichip moduli«. Namen projekta, ki je bil sprejet in je začel teči maja 1997, je omogočiti hitro izdelavo prototipov poceni multichip modulov (MCM).

MCM tehnologije obsegajo design, izdelavo, sestavljanje in testiranje prototipov. Naloge projekta so razdeljene med partnerje glede na njihovo tehnološko usposobljenost. Design je naloga romunskih partnerjev. Instalirali so CAD sistem in bodo s pomočjo testnih vezij in simulacij določili pravila načrtovanja. Izdelava prototipov je naloga madžarskih in slovenskih partnerjev. Madžarski partnerji se bodo koncentrirali na MCM-L (tehnologija tiskanih vezij), slovenski pa na MCM-C (Keramični MCM, v tem primeru večplastna debeloplastna vezja). Madžarski partner bo hkrati z angleškim in belgijskim odgovoren tudi za bondiranje golih silicijevih tabletk in sestavljanje oziroma montažo prototipov MCM. Končno testiranje demonstracijskih vezij je naloga belgijskega partnerja. Evaluacija rezultatov je naloga vseh partnerjev pod vodstvom madžarskega partnerja, ki je tudi koordinator projekta.

V projektu vsi partnerji tesno sodelujejo. Da bi razširili znanja tako o projektu kot o tehnologijah in možnostih načrtovanja, partnerji sodelujejo na konferencah, objavljajo v odprti literaturi in sodelujejo pri organizaciji seminarjev in tečajev za mala in srednje velika podjetja, ki se zanimajo za poceni prototipe MCM ali za izdelavo MCM v tehnologiji tiskanih vezij ali večplastnih debeloplastnih vezij.

Opazen napredek je bil dosežen s strani romunskega partnerja na področju designa, s strani madžarskega partnerja na področju tiskanih vezij in laserskega oblikovanja ter slovenskega partnerja na področju tehnologije difuzijskega oblikovanjanja večplastnih debeloplastnih vezij.

V prispevku je opisana struktura projekta in podana tista bibligrafija sodelavcev, ki se nanaša na projekt.

INTRODUCTION

The success of most electronic instruments and systems, regarding both their performance and marketing issues, depends to a great extent on the ability to use the most advanced technology that is cost-effectively possible. However, the performance of today's electronics is primarily limited by the interconnections between components and subsystems, and not by the high-speed, very large scale integrated (VLSI) circuits from which the systems are built up. Thus, to achieve high performance and high reliability at a reasonably low cost, it is imperative to use the most appropriate interconnection and packaging technology accompanied by advanced design, manufacturing, assembly, and testing expertise.

Regarding the interrelationships between the various products of electronics and between the interconnection and packaging system-technologies used for them, three levels of the products can be distinguished: components (or basic products), circuit modules (or assemblies) and equipment (or electronic systems). The usual physical construction of a personal computer (PC) is a good illustration of the hierarchy of electronics products (Figure 1). This construction points out the importance of interconnection and packaging technologies, mainly realized by the different types of circuit modules. Moreover it presents a characteristic example for the use of interconnection technology, that is to create connections and communication routes between the signal processing chips and large systems, as well as, human beings.

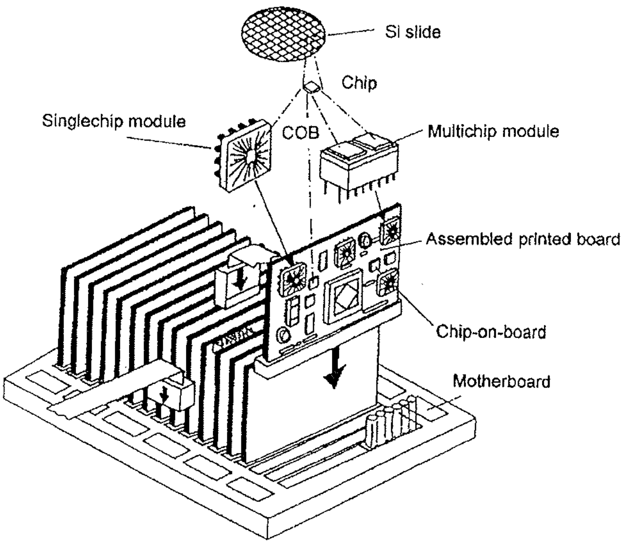

Fig. 1. The hierarchy of electronics products and packaging technologies

Electronic Packaging Driving Forces toward Multichip Modules

In the design and manufacturing of each level of interconnection of any electronic system, the driving forces are to lower cost and to improve performance /1,2/. From these points of view the followings are of great importance:

- **The decrease of the distance between chips** in order to achieve faster operation. This requirement can be fulfilled by increasing the functional density and integration level of the applied very large scale integrated (VLSI) circuits and/or increasing the density of the interconnection system.

- **The reduction of the cost per connection** in order to reduce cost. The most cost-effective solution can be achieved by increasing the integration levels of both the chips and the interconnection systems, thus making more connections simultaneously, reducing the use of materials and processing, which results in the reduction of the cost per connection. From this a general rule can be formulated, that the cost per connection is the higher the farther the connection from the center of the chip is.

- **The use of catalogue devices**. The customization on the chip level is very expensive unless large quantities are to be used. The use of less application specific integrated circuits together with custom designed interconnection system can minimize the duration of the design-manufacturing-test cycle, and can result in a cost-effective complex solution.

- **The optimum partitioning of the circuitry** in order to improve thermal performance by using materials with high thermal conductivity, instead of using more complicated and expensive heat-transfer mechanisms.

- **The exploitation of the existing design, manufacturing, assembly, and testing technology** in the field of interconnection and packaging.

At present time, the multichip module (MCM) approach is considered the most advanced circuit module technology. MCM technology is an advanced extension of bare-chip hybrid technology, offering at least an order-of-magnitude improvement over earlier packaging approaches regarding electric performance, packaging density and reliability as well. Among the criteria beyond which a circuit is considered to be a multichip module there are the followings:

- the application of bare-chips or chip-size packages, and compatible chip attachment and bonding technologies, in the majority of cases,
- the application of multilayer and high-density interconnect substrate, and
- the advanced thermal design of the complete package.

Objectives of the Cheap MultiChip Modules Project

The title of the Project that was proposed and received approval for support from the European Commission in the frame of INCO-COPERNICUS Programme is "Establishment of Fast Prototyping Low Cost Multichip Module Technology Facilities in Eastern Europe for the Benefit of European Industry". The short form of the title is "Cheap MultiChip Modules" or CM^2. The project commenced in May 1997, and now it is over its half-time period. The project is the cooperation of nine Partners given by the institutions of the co-authors of the present paper.

On the basis of the trends in electronics discussed in the Introduction, and taking into account the forces which drive electronic packaging technology toward multichip modules, the Project was initiated with the following important research and development objectives:

- improvement of the technological facilities of the Rumanian, Hungarian and Slovenian Partners in order to be capable for
- prototyping low cost, high performance electronic circuit modules by increasing functional and interconnection density with the
- application of integrated interconnection substrates instead of the extremely expensive on-chip customization.

Multichip module technology, utilizing and/or uniting the advantages of ceramic (C) and laminating (L) techniques, is a promising solution of the requirements. The results are higher reliability, increased yield, reduced use of materials and processing, faster prototyping and shorter production period.

In addition, the RTD Project is intended to

- strengthen the relationship between research institutions of Central-Eastern Europe and their EU Partners in order to enhance research and technological capacities in some Countries of Central Europe,
- establish links with the small and medium-size enterprises responsible for product development and distribution, and
- safeguard and stabilize the research and technology development (RTD) potential of Central-Eastern European Countries by means of training and seminars for researchers working on the Project.

Technology of multichip modules includes the design (1), substrate manufacturing (2), assembling (3) and testing (4) phases. The tasks of the Project were divided among the participants in accordance with these technological phases and conformable to their interest and previous activity in the field. The distribution of the tasks can be summarized as follows:

1. The Rumanian Partners select a suitable CAD system, install it for the use of themselves and for the other Partners, and organize training courses.
2. Manufacturing MCM-L and MCM-C substrates is the task of the Hungarian and the Slovenian Partners, respectively. They have to improve their facilities, manufacturing and test technologies up to a level to fulfill the low cost, fast prototyping requirements. Quantitatively, the aim is to realize 300 μm diameter plated-through holes/vias with 125 μm wide lines and spacings, for laminated and ceramic based MCM technologies.
3. The Hungarian Partners' task is the establishment of mounting and bonding facility for the assembling of MCMs with the promotion of the English and Belgian Partners, exploiting their high level experience in the fields of microjoining and test technology. The aim is to handle 150 μm pitch medium size VLSI chips.
4. The material test and performance evaluation of the test patterns and demonstration modules is the task of all Rumanian, Hungarian and Slovenian Partners directed and controlled by the Belgian Partner.

The evaluation of the results in accordance with the manufacturing, application and economic aspects is the task of all Partners with the leadership of the Hungarian Partner.

The Project is carried out in close co-operation of all Partners. In order to gather and to disseminate information for and about the Project, they participate in conferences, organize seminars and training courses for themselves, for small/medium-size enterprises and research institutions in the Central-Eastern European Countries, who show interest in the application of the established low cost fast prototyping MCM technology.

Contributions of Partners to Project 'Cheap MultiChip Modules'

Considerable progress has been made in the first part of the Project. The present state of the work packages, the activity of the Partners and the most important results are characterized shortly in the followings.

In WP1:T1 University POLITEHNICA Bucharest and Ramelectro Ltd., Romania (UPB.RO and SCR.RO) collected requirements for the design of PCBs and MCM-Ls to help the selection of the CAD System. As the most suitable software, the CADSTAR for Windows made by Zuken Redac, with an additional module dedicated to EMC analysis, was selected. UPB.RO's experience using previous DOS and Windows CADSTAR versions has proved that this is a suitable software tool, which is oriented towards both electrical and technological aspects and contains many options like virtual costs estimation, powerful editing of routes, EMC-analyzer, field solver, thick- and thin-film design, various post-processing tools etc. Another reason for choosing CADSTAR system was that dedicated MCM programs were very expensive in comparison with the budget of the Project and could be run on very expensive workstations only. In WP1:T2 UPB.RO obtained the specified CADSTAR system and installed it into three PCs. SCR.RO has also obtained and installed a version of CADSTAR with the purpose to accommodate with it.

The Rumanian and Hungarian Partners carried out very fruitful discussions on what kind of MCM-L structure and technology, and what circuit should be chosen for demonstration of the use of the CADSTAR system and the manufacturing facilities, respectively. On the basis of consultations with TWI.GB and the other Partners, having also analyzed the different solutions published in the literature (e.g. in /3/, see Figure 2), a combined MCM/BGA structure (Figure 3) was pointed out for a simple transmitter circuit as a pilot demonstration (Figure 4). More details of the analyses of the structure and resulting design considerations are presented by the Rumanian Partners /22/, and the technological aspects of the problem are given later in this paper where the Hungarian Partners' activity is presented.

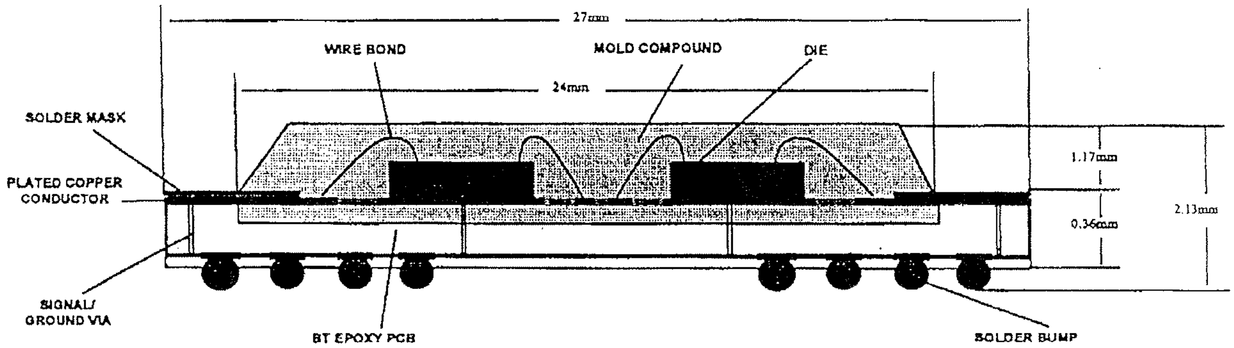

Fig. 2 A typical MCM-L structure combined with PBGA package /3/

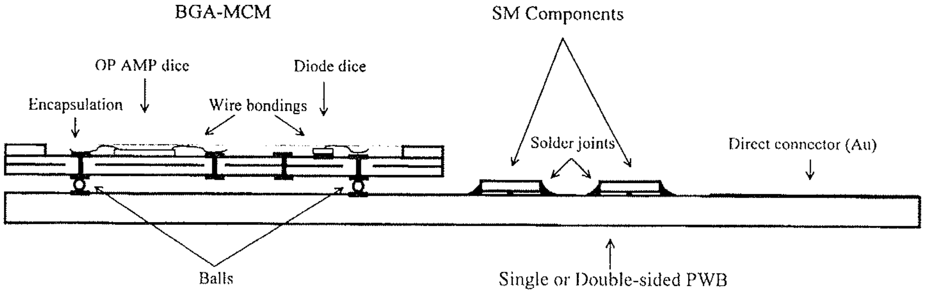

Fig. 3 Principle of the MCM/SMT modul

Technical University of Budapest and Elektroprint Ltd., Hungary (TUB.HU & EP.HU) in WP1:T1 and WP1:T2 collected requirements for the manufacturing facilities of MCM-Ls and selected suitable equipment to improve the resolution of the laminates and to decrease the turn-around time. For this purpose a drilling and direct patterning laser system was specified. TUB.HU had a unique opportunity to apply for a support from the Hungarian Research Ministry (OMFB) to purchase a "large research equipment". At last a support of ca ECU 63.000 was allotted, which sum together with ECU 10.000 from the INCO Project and ECU 23.000 from other incomes of the Hungarian Partners was spent to buy the specified Direct Exposure Laser System for MCM-Ls. In this way the investment for this purpose was about ten times higher than it had been originally planned in the INCO Proposal. The system was installed and is applied for drilling and image transfer /55/. With the professional and financial support of the EP.HU a more advanced etching system and a more suitable grinding machine were also installed.

In WP2:T3 TUB.HU upgrades processing technology of MCM-Ls. Pilot investigations have been carried out for this purpose to combine the laser imaging and wet chemical etching/electroplating processes in order to improve the resolution of the laminates. By the installation of the direct exposure laser system the possibility of the development of this new image transfer technology has been improved /26,38,45,51,53,55/. In addition, the application of the newest Shipley chemical products and the installation of the more advanced equipment provide possibilities for the processing technology upgrading. For this activity suitable test patterns and sample circuits are designed and used.

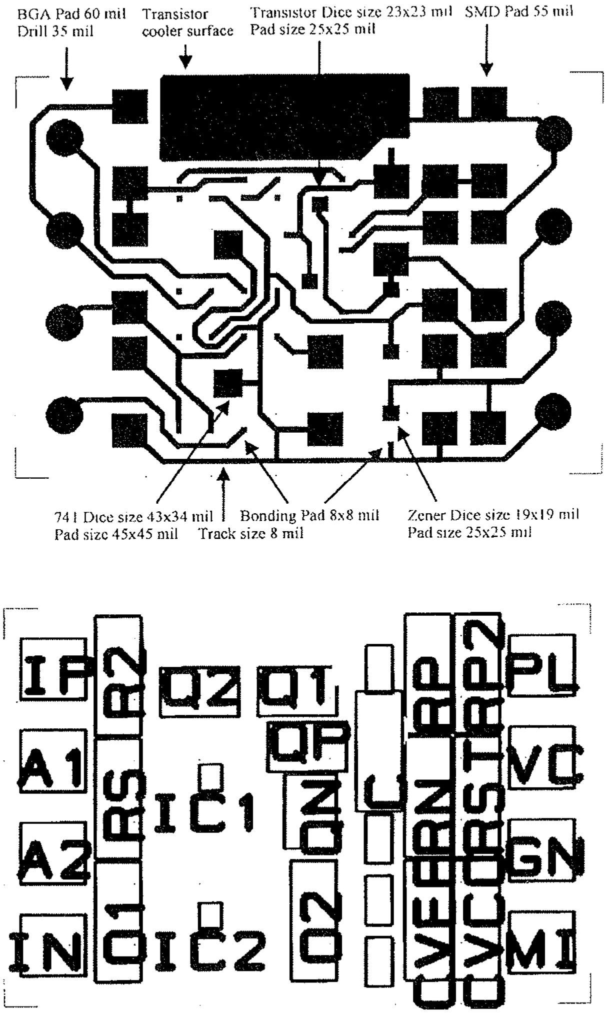

Fig. 4 Layouts of a transmitter for combined MCM-SMT-BGA realization

In WP4:T1 TUB.HU collected requirements for the assembling facility of MCMs. The main question was to decide what type of chip assembling technology, i.e. chip-and-wire, flip chip or TAB, would be used. With the help of the expertise of TWI.GB and IMEC.BE, it was decided that TUB would upgrade the chip-and-wire facility, and later would obtain and install flip-chip assembly equipment. The specification was discussed with JSI.SI at the 1st Project Meeting, and with IMEC.BE, WD.GB and TWI.GB during a visit paid to Gent and Abington, respectively.

In WP4:T2 TUB.HU installed an ultrasonic bonder to study the possibilities of chip-and-wire technology. A new handling table was designed and implemented to the ultrasonic bonder. Applying this bonder the bonding parameters were optimized for different type of substrates, such as thick- and thin-film structures as well as PWB laminates. To check the bonding parameters a new digital pull-up tester was developed. In order to obtain expertise for flip-chips, ball-grid-arrays were studied: a new type of BGA package was developed based on PWB laminates. This BGA version enables higher pitch density using specially positioned balls and filled vias. The new BGA version requires the application of DuPont ink materials. The requirements of ISO 9001 were studied concerning the MCM-L technology (partly as a preparation for WP5). Concerning the reliability and quality questions of the assembling technology a short visit was paid to the TWI.GB.

In WP3:T1 Josef Stefan Institute and HIPOT Hybrid Ltd., Slovenia (JSI.SI & HIPOT.SI) had to upgrade the analyzing and test facilities of integrated substrates for MCM-Cs. Equipment for Complex Impedance Analysis was selected and ordered. The price of the equipment with software was around ECU 38.000. Only a part of this (ECU 8.650) was covered from this INCO Project. The equipment was installed at Josef Stefan Institute in the summer of 1998.

In order to upgrade processing technology for MCM-Cs in WP3:T3, JSI.SI and HIPOT.SI decided to use thick-film multilayer technology to obtain the required MCM-C devices. A relatively novel technique for producing more dense thick film multilayer structures, i.e. the Diffusion Patterning (Diffusion Patterning™ is a trademark of DuPont) is used. Unlike standard via construction with screen-printing, Diffusion Pattering vias do not use any extra substrate space. Typical vias dimensions, obtainable in production, are around 400μm for screen-printing and 200μm for diffusion patterning. The dimensions of diffusion patterned vias are therefore similar to the width of conductor. It is estimated that complex hybrids can be build on 20% to 40% smaller substrates, and hence more complex and cost effective solutions are possible.

On this topic JSI.SI and HIPOT.SI paid a visit in Du Pont facilities in Bristol, England. The aim of the visit was to get acquainted with diffusion patterning technology and processing. Materials and processing equipment needed for the successful application of this technology for multilayer thick-film hybrids production was discussed. In the DuPont laboratory practical demonstration of technology was presented. To apply the above-defined technology, the necessary materials were specified and ordered. More details of the results are given in /61/.

The technical activities of IMEC, Belgium (IMEC.BE) are in connection with WP3, WP4 and WP5, and also IMEC.BE is the financial coordinator of the Project. First of all, IMEC.BE set up an automatic measurement system for measurements on substrates with test structures. The system consists of a switching matrix, 3 source-measurement units (SMUs), and an RLC impedance measurement unit. The devices under test are contacted using needle probes, or by insertion of the substrate in a special socket with 84 contact points. With the system measurements can be performed on passive test structures delivered by the Partners. In this way, the developed technologies can be validated.

For example, three identical test substrates were sent for measurements from TUB.HU. These substrates are square 50 mm x 50 mm FR4 boards, fitting into the test insertion socket. They carry a double-sided Cu metallization with Au finish. Tracks on front and backside of the substrate are connected by plated-through holes. On each substrate two test structures are present, namely daisy chains, consisting of a series interconnection of 200 plated-through holes. In one structure, small holes ($A = 250\mu$m), on the other, large size holes ($A = 350\mu$m) are used. The yield and resistance of the whole structure and parts of the structure were measured using a 4-point method. The results of the measurements on these interconnection substrates are used for the design and realization of test modules at UPB.RO and TUB.HU, and the test structures on these modules will then be measured at IMEC.BE.

The Welding Institute, United Kingdom (TWI.GB) is not Responsible Partner in any Work Packages, however, the contribution of TWI.GB and the activity of Prof. Nihal Sinnadurai as a consultant are very important to the success of the Project. During the first half of the Project TWI.GB

- attended inaugural meeting in Bled Slovenia, and helped set the direction for the project;
- hosted advisory meeting with WD.GB and provided guidance on scope for William Dennehy's activities;
- provided advice on MCM technologies;
- hosted meeting and discussion with TUB.HU on technology evaluation activities to be undertaken in the project;
- provided guidance to project consortium members on suitable equipment acquisition;
- hosted visit by TUB.HU to provide advice on reliability evaluation and training on wire bonding equipment;
- provided ongoing advice to WD.GB on MCM publications;
- provided on-line interactive advice and comments to UPB.RO on the choice of prototype designs and design approach for MCM-L;
- contributed in the work of Project Meetings and gave papers in the joint seminars /63-65/;
- last but not least, encouraged all Partners to participate in this European Conference on Multichip Modules /22,54,55,61/.

The general objective of William Dennehy Ltd., United Kingdom (WD.GB) in the first part of the Project has been to travel a steep learning curve in this subject area in order to apply its technical and statistical expertise in the improvement of the quality of processes used to produce fast prototyping low-cost MCM technology facilities in Eastern Europe for the benefit of European industry. Some success has been achieved in this objective with the significant assistance of Prof. Nihal Sinnadurai of TWI.GB and Prof. Zsolt Illyefalvi-Vitéz, and their teams. He presented a joint paper entitled "Analysis of a Multi-Stage Double-Sided Printed Circuit Board Production" written by L. Várnai of TUB.HU /67/. WD.GB also intends to analyze the design facilities in Romania and the ceramics and thick-film facilities in Slovenia.

Conclusions

Considerable progress has been made in the Project during its first half-time period. New software and equipment were installed and process technologies were upgraded to improve the design facilities at the Rumanian Partner, the printed circuit board (PCB) technology for MCM-Ls at Budapest, and ceramics technology skills for MCM-C in Slovenia. All Partners took part in seminars, conferences, exhibitions and published papers to obtain and disseminate information and knowledge about MCMs and other microelectronics technologies /4-67/. This also helps to safeguard and stabilize intellectual RTD potential of RO, HU and SI.

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Prispelo (Arrived): 9.2.99 *Sprejeto (Accepted): 28.4.99*