FUSE
MST Training Material

MSTTRG1

Co-ordinating TTN: University of Hertfordshire

Version: 2.0, March 1999

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1. Foreword (not part of the final material)

Objectives of the Material

- To produce training material aimed at introducing a potential First-User product manager to best practice in MST-based development project management.

- To make use of the MST-based Demonstrators (and other AE's) from the FUSE portfolio to provide solid examples and case studies of best practice. This should make a significant contribution to the MST field where a lot of secrecy often prevents dissemination of best practice, especially in the direction of SME's.

- To especially emphasise the particular project management issues specific to MST, but for completeness to deal with generic issues as well.

- To give reasonable review and definition of the technology. This is particularly appropriate because:

  - MST is very new as opposed to SMT, MCU, ASIC etc. (especially to SME's). It is also very diverse – really a set of technologies, rather than just one

  - Even the term "Microsystems" is often misunderstood to refer to microprocessor systems

  - There is very little general background material available and only 2-3 widely accepted textbooks on the subject

Status of Material

A first version of the document, based on a few initially available Demonstrators was produced in December 1998. This is the second draft of the material. It is initially in the form of a booklet, but a corresponding PowerPoint presentation is also in preparation. The final version, adding the experiences coming from newly documented Application Experiments, as well as incorporating feedback received, will be produced in mid-June 1999.

Review and Feedback Process

Apart from the FUSE Management Board, the draft training material is being delivered to all FUSE TTNs and some First Users in order to obtain feedback. The TTNs can ensure that best practice from their AE's has been captured. First Users can help ensure that the material is understandable by the target audience.

At the CEC's suggestion, six selected TTN's will be requested to give priority help with the review of the material. However, feedback from any others is most welcome. In particular feedback regarding anything to cut out, anything missing or on overall length is welcomed: we have not been given a specific target length.

Basis of Best Practice Extraction

As far as is possible, this material makes use of all FUSE MST AE's in the portfolio. The selection of suitable examples is based on the reading of TTN reports and selected subcontract agreements, as well as of Demonstrator Documents. (It is important to gain the “inside view” of the AE since the Demonstrator Documents, being public, are sometimes restricted in what they say).

Finding out the status of AE’s is not that easy, particularly as many records in Lotus Notes are not kept up to date. Overleaf is a table of the status of the FUSE AE portfolio for calls 1-12 as far as can be seen on 12/3/99.

With respect to the best practive MST AE’s identified by the TTN’s (shown highlighted in the table below), only 7 TTN’s had responded at the time of writing. Of these AE’s five (23722, 27321, 25137, 545, 26816) are still active and no dissemination material seems to be available. AE 27565 is really microstrip, and does not seem to correspond to the definition of MST. AE’s 22824, 24575 and 26170 have been quoted in the material, along with several others (shown by a “yes” in the BP column in the table).

Some use has been made of negative experiences, but these are not associated with named TTNs, AEs or companies. Some quotes have been edited for reasons of space or English style, but hopefully the sense of the original author has been preserved.

MST AE Portfolio				Yes/No?				
TTN Name	**AE No.**	**LNS**	**Technology Description**	**Demo**	**DD**	**TTN**	**RR**	**BP**
CESVIT	22824*	R	LIGA Infrared Spectrometer analyser Microsystem	Yes	Yes	Yes	No	Yes
Syntens	529	R	A Micro Filtration Analysis System	?	Yes	Yes	No	Yes
SYNTENS	22857	R	Self Regulating Airflow Controller	?	Yes	No	No	No
COREP	24575*	R	Optoelectronic Microsystem for Encoders	Yes	?	No	No	?
DELTA	23595	R	Smart Sensor IC for Angular Position Detector	?	Yes	No	No	No
EPFL	22869	R	Torque Measurement Microsystem	?	Yes	No	No	Yes
ETH Zurich	23617	R	Integrated Optical Chip for Torque Measuring Sensors	Yes	Yes	No	No	Yes
ETH Zurich	25923	R	2.45GHz SAW Microsystem for Identification Tag	?	Yes	No	No	Yes
FhG-IIS	513	R	Microsystem for Prompt Blood Pressure & Pulse-Rate Diagnostics	No	Yes	No	No	No
FhG-IIS	532	R	Micromachined Hydrostatic level Sensor	No	Yes	No	No	Yes
Gemac	412	R	Absolute Coder Length Measurement System with High Resolution	Yes	Yes	No	No	No
Glam	23569	R	Insect Trap Microsystem	?	Yes	No	No	Yes
Herts	2198	R	Construction of a Photomultiplier Microsystem	No	Yes	Yes	Yes	Yes
IAM	1805	R	Combined Thin Film Data Reading for Safe Credit Card Reader Systems	No	Yes	No	No	No
IMC	24557	R	Microsystem X-ray Detector	Yes	Yes	No	No	No
LETI	410	R	Angular Position Sensor Integrated in a Bearing	Yes	Yes	No	No	No
LETI	22894	R	Integration of a Miniaturised Pressure Sensor in a Ventricular Shunt	?	Yes	No	No	No
NMRC	26147	R	Electronic servocontroller for Vibration Feeders	?	Yes	No	No	No
ETH Zurich	25802	C	Micro-Spectrometer for WDM Network Analyzer	?	Yes	No	No	No
IAM	1401	C	Two Axial Force Measuring System	?	?	No	No	?
Bolton	23722*	A	Electrodless Liquid Conductivity Sensor System	?	?			?
Bolton	25916	A	Intelligent Adhesive Dispenser & Controller	?	?			?
CESVIT	27436	A	Brahms-Bar-Code reader	?	Yes			Yes
Syntens	26662	A	Micro Liquid Handling System	?	No			?
COTEC	25858	A	Load Cell with Microsystem	?	Yes			Yes
ETH Zurich	25970	A	A Magneto Resistive Sensor for Encoder Applications	?	Yes			No
Fincitec	27321*	A	Micromechanical Integration of Silicon-Based Scintillation Crystal Sensor	?	Yes			Yes
Gemac	545*	A	New Generation of Electromechanical Aneroid Sphygmomanometer	?	Yes			No

MST AE Portfolio cont'd				Yes/No?				
TTN	**AE No.**	**LNS**	**Technology Description**	**Demo**	**DD**	**TTN**	**RR**	**BP**
Gemac	25137*	A	Thermal Insulation Measurement for Building Materials	?	Yes			No
Glam	22843	A	Switch Output Temperature Sensor	?	Yes			Yes
Glam	23649	A	Demand Ventilation Microsystem	?	Yes			No
Glam	25844	A	Integration of a Mixed Signal ASIC into a Microcontrolled Valve	?	Yes			No
Glam	25879	A	Development of a Microsystem Based Presence Detector	?	Yes			No
Herts	26170	A	Microsystem for Signal Monitoring of Strain	?	Yes			Yes
Herts	26816	A	An Integrated Microsystem for the Extraction of Nucleic Acids	?	Yes			No
IMEC	25777	A	Integration of Electroluminescent Foils in Membrane Switches	?	Yes			No
RIIC Linz	2156	A	Inductive Length Measuring Microsystem	?	Yes			No
Aramis	29418	Co	Smart Trigger for a Superposed Shotgun					
Glam	26793	Co	Microsystem for use in Asthma Management					
Glam	29852	Co	The use of MST in Water Purity Measurement					
Gemac	29738	Co	Microsystem Technology for decentralised Glucose Analysis					
IDF-PIC	29405	Co	Micro Pollution Assessment Device					
Herts	29896	T	The Development of an Angular Rate MST Sensor for Oilfield Application					
IAM	1401	T	LIGA Technology for Producing Orifices for High-Speed Inkjet					

Notes:

*: - Listed on Best Practice list
LNS: - Lotus Notes Status (A = active, C = completed, Co = considered, R = reviewed, T = terminated)
Demo: - Is the AE a Demonstrator?
DD: - Do we have the latest Demo Doc?
TTN: - Do we have the TTN report for the AE?
RR: - Do we have the Reviewers Report for the AE?
BP Used: - Is Best Practice evident in the AE or can it be deduced from AE?

2. Introduction to Microsystem Technology

The Esprit Programme in the EU’s 4th Framework states that:

> “A Microsystem is defined as an intelligent miniaturised system comprising sensing, processing and / or actuating functions. These would normally combine two or more of the following: electrical, mechanical, optical, chemical, biological magnetic or other properties integrated onto a single chip or a multichip hybrid.”

The evolution towards miniaturisation of complete systems derives from the progress of research in the field of integrated circuit manufacturing. Microsystems Technology - MST (also sometimes known as Micro-Electro-Mechanical Systems - MEMS) is the next logical step in the silicon revolution.

Although silicon is the base material of many microsystems, it can be combined with many other materials (glass, pyroelectric layer, biosensitive layer, piezoelectric layer…). Silicon has exceptional physical properties – apart from semiconductivity – regarding piezoresistivity, as well as specific optical features.

Silicon is a substrate that has many advantages: it is well-known through its use in electronics, and it can be micromachined with technologies that are compatible with those used for integrated circuits, enabling therefore the integration of various features on the same substrate. This is the case for numerous production-intensive applications. In many other instances, the microsystem is hybrid, i.e. it includes various modules that are made on different substrates and assembled in the same packaging.

The main benefits of miniaturisation are simple. The first one is economic: semiconductor technologies enable the manufacturing of large numbers of identical and perfectly reproducible devices. The success of the microelectronics industry over the last 20 years owes a lot to this batch-manufacturing concept. Another benefit is the access to new applications for which miniaturisation is essential. Biomedical devices that interact with the human body are a striking example.

The following diagram could illustrate a microsystem.

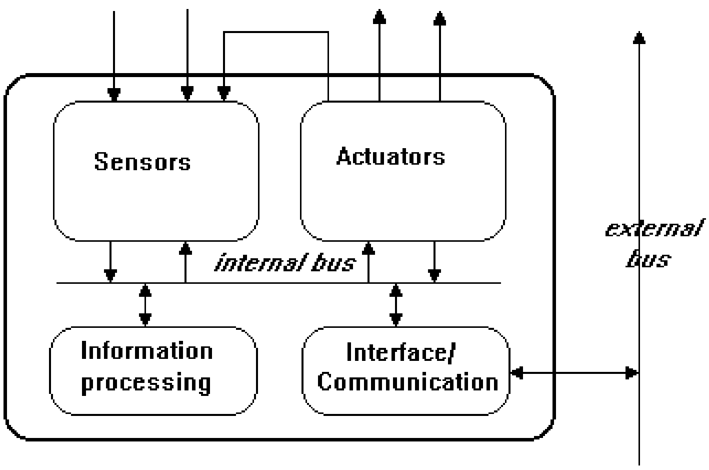


Figure 1. Example of Microsystem Architecture (Source IMT Karlsruhe)

It can carry out four basic functions:
- perception of the environment, with a sensor

- signal processing, data analysis and decision-making, with a microelectronic circuit
- reaction upon environmental input according to data received, with an actuator
- communication with the outside world, with signal receivers or generators.

For about ten years, integrated circuit manufacturing techniques have been adapted to provide for the building of various types of miniaturised sensors. Design and manufacturing of these sensors also call upon other technical fields such as micromechanics, microoptics, chemistry, biology, etc.

Applications

Generally speaking, microsystems meet the growing demand of the market for systems that are increasingly ***reliable***, ***multifunctional***, ***miniaturised***, ***cheap***, possibly ***self-managed*** and/or ***programmable***. As previously indicated, two main requirements account for the evolution towards system miniaturisation:

- Manufacturing at very low unit cost for mass applications.
- Reducing the size of devices for applications aimed at very narrow spaces or requiring minimal weight.

Some advantages of microsystems can be illustrated as follows:

- Angular rate sensors, used in the automotive sector (ABS, etc.) are now available with a classical design (mechanical gyroscope). If one electronic module is added, the required system can be built, but at a price of several hundred dollars, which is not acceptable for such a product. On the other hand, a microsystem solution that would integrate the sensor and the signal processing on the same silicon substrate would be sufficiently cheap to justify the introduction of such a feature in a car without increasing its price greatly.
- Analysis systems (chemical, biomedical, etc.) that would integrate microsensors, micropumps, signal processing and so on, could have a massive number of applications. Reduced size and energy consumption are major assets for many portable and self-managed applications.

The main factors justifying the microsystem choice can be summarised as follows:

For the manufacturer	***For the user***
Collective manufacturing: - Cutting of production costs for mass-produced series - Great reliability of the products - Reproducibility	**Miniaturisation:** - low size and weight - access to very narrow spaces
Design and manufacturing flexibility (CAD): - application-driven design - easy transition from one product family to the other	**Complex assembly of elementary features:** - new features and performance - compactness
Final system in the form of a chip: Secrecy of know-how protected	**Less connections:** a smaller number of connections are required when installing
	Decrease in command power: reduced energy consumption

The main application areas are the following:

- automotive
- consumer electronics
- telecommunications
- biomedical engineering
- environment protection
- production technologies
- electrical goods industry and home automation
- aerospace science

- traffic control and navigation systems
- surveillance and security systems
- instrumentation

Among the various applications, it is worth distinguishing between marketed microsystems and microsystems that still are at development stage. This difference rests upon the maturity and compatibility levels of the technologies. Some application domains can be detailed in a more precise fashion.

Automotive Industry

Each year, more than 35,000,000 cars are manufactured worldwide. As far as improved performance, comfort, and security (with system self-management) are concerned, Microsystems seem the best-suited technology. The existing or currently developed Microsystems include an accelerometer used for airbag triggering, new injection systems and navigation systems.

Consumer Electronics, Electrical Goods and Home Automation

This is a growth sector for low-cost microsystems: infrared temperature sensors, analysis devices to sense the indoor air quality in order to start cleaning or filtering action, TV and computer screens based upon optical Microsystems, image sensors for camcorders, etc.

Medical Applications

Microsystems enable the introduction of new, more efficient techniques: endoscopy, instrumentation for minimum invasion therapy, remote microsurgery (wireless system), in situ chemical analysis (with minisensors), neuronal prosthesis, implants and implantable dosing systems ("artificial pancreas").

Environment and Biotechnology

The analysis of chemical substances is a major concern for the environmental technology field. An on-line analysis and decision-making system is often required and can be made possible by microsystems based upon biochemical sensors.

World-wide MST Activities

The majority of industrialised countries have recognised the importance of microsystem technology. In 1991, 300 companies and organisations were active in MST projects worldwide. Currently, in Europe alone, about 20,000 companies are estimated to be involved or interested in this technology. Nevertheless, the majority of microsystem projects are developed in the United States, followed by Japan and Europe. The market distribution between the United States, Europe and Japan is assessed to reach a ratio of about 40 / 35 / 25 for the year 2002.

The ascent of these technologies involves the participation of research institutes, universities, technical and professional organisations, as well as private companies and political and administrative institutions. The subjects of fundamental and applied research, which tackle the various obstacles to overcome, are very similar from one country to the next, and the stages of development are very much alike.

Activities in Europe

The DGXIII authorities of the European Commission have recognised that microsystem technologies will play a leading role in the future development of European industries. Specific research orientations have therefore been integrated into the Commission’s fourth framework programme. Europe, as opposed to other powers, has a very large number of small and medium-sized companies. This feature can be an asset in terms of flexibility and resilience, but it also requires great efforts in co-ordination and co-operation. In 1992, the NEXUS network was created in the framework of the ESPRIT programme. As to the EUROPRACTICE and FUSE programmes, they play a key role in the improvement of the competitiveness of European industries by disseminating information on microsystems and providing practical examples.

Within the European Community, Germany has the largest contribution as far as research in microsystem technologies is concerned. Between 1990 and 1993, 180 million dollars were invested in research by the German Ministry of Research and Technology, in a country where about 70% of R&D expenses are traditionally met by private companies. This clearly illustrates the importance given by the German government to this technology.

Switzerland also benefits from a very strong position in Europe in the field of microtechnologies. Its reputation derives from the work of laboratories of higher education institutions and industry. The M²S² group gathers 14 public and private laboratories, the main actors being FSRM (Foundation behind the European training programme on microsystems), CSEM and ETH from Lausanne and Zurich.

The other main European centres for microsystems include:

- Great Britain, with the MCIG research group, founded by DTI and gathering about 100 companies, research institutions or universities.
- France, the main institutions involved being CNRS, CEA, various Ministries, ANVAR, etc.
- The Netherlands, with the Twente university and its new MESA Institute as a main player in the field.

Activities in Japan

In 1991, the Ministry of International Trade and Industry (MITI) launched a programme called Micromachine Technology, and founded MMC (Micromachine Center) in 1992. Many industrial companies are involved in this centre and participate greatly in its financing. The first goal was robot miniaturisation. The microrobots could be used in medicine, for example, and enable analysis and therapies in inaccessible locations. Current efforts relate to integration of miniaturised systems.

The three main orientations of Japanese research are base technologies, functional module technologies and system technologies. The various poles include Tokyo University, Tohoku University in Sendai, and research laboratories of NEC, Toyota and Seiko.

Activities in the United States

So far, the United States have dominated in the field of microsystem research, with the largest number of patents and an annual regular budget of 5 million dollars. Furthermore, their edge has derived from their deep knowledge and vast experience in silicon technologies as applied to microelectronics. Most of the projects are industry-orientated because government support is weaker than in Europe and Japan.

The National Science Foundation (NSF) in the United States has founded the MST programme, centred on universities and research institutes. Other MST-related projects are supported by other federal agencies such as ARPA (Advanced Research Project Agency) or NASA.

In microsystem research, the United States have three highly reputed centres: Berkeley University, MIT (Boston) and Utah University in Salt Lake City. Those academic laboratories are often collaborating with several major companies such as IBM, AT&T, Texas Instruments, Analog Devices, Honeywell, Motorola, HP, General Motors, Ford, Siemens, etc. Those companies are the major investors in microsystem technologies. Currently, the increased contribution of small and medium-sized companies that are interested in the development of minisensors and actuators is also to be noted.

Perspectives

Key application areas

The markets to be reached by microsystems can be classified in three main categories:

- *Large production volumes* - Mass markets such as electrical goods, consumer electronics, automotive manufacturing, computing, food-processing control dominate in terms of volume, but imply very low unit prices.
- *Medium production volumes* - In the production technologies market, chemical industrialisation processes, metrology and biomedical engineering, the price of sensors could be higher. In this field, the small and medium-sized companies regularly market new products and adaptations.
- *Markets relying upon public activities* - Those markets, such as those dealing with gas and effluent emissions, fire or smoke detection in buildings, require a great amount of precision and, for

chemical sensors, a great selectivity. They could be considered in volume terms, and are more difficult to access.

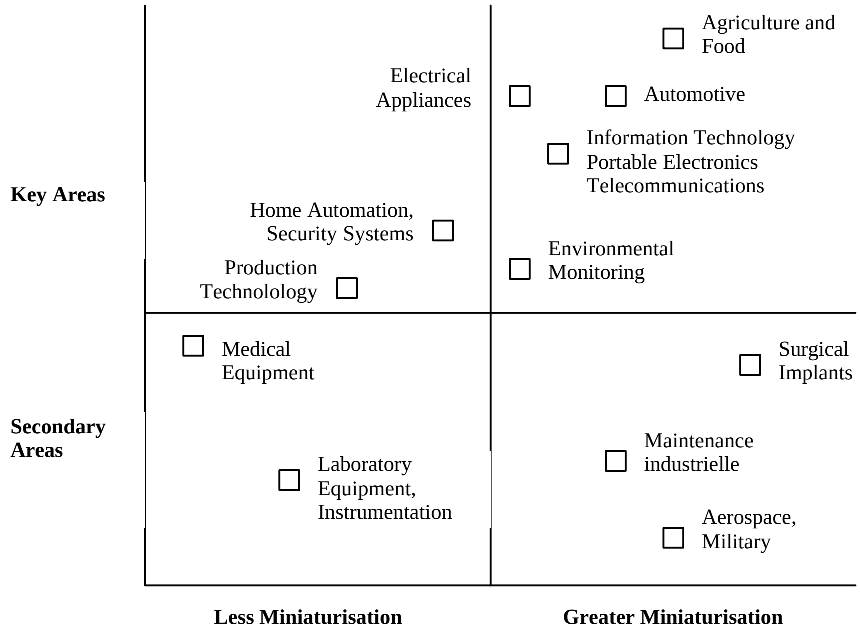


Figure 3. Critical Application Domains for Microsystems

Economical Evolution

According to experts, the whole market of microsystems will take off at the end of the century. It will account for 20% of the global market of microdevices (microsensors, microactuators, etc.) which is estimated to reach 100 billion dollars by the year 2000.

Although the limits of the concept of microsystems may vary greatly from one expert to the next, the market studies carried out all indicate an estimated average yearly growth of 19% for the whole of microtechnical, micromechanical and microoptical devices. Hereunder are the results of a study that shows the market segments for MST in the year 2000.

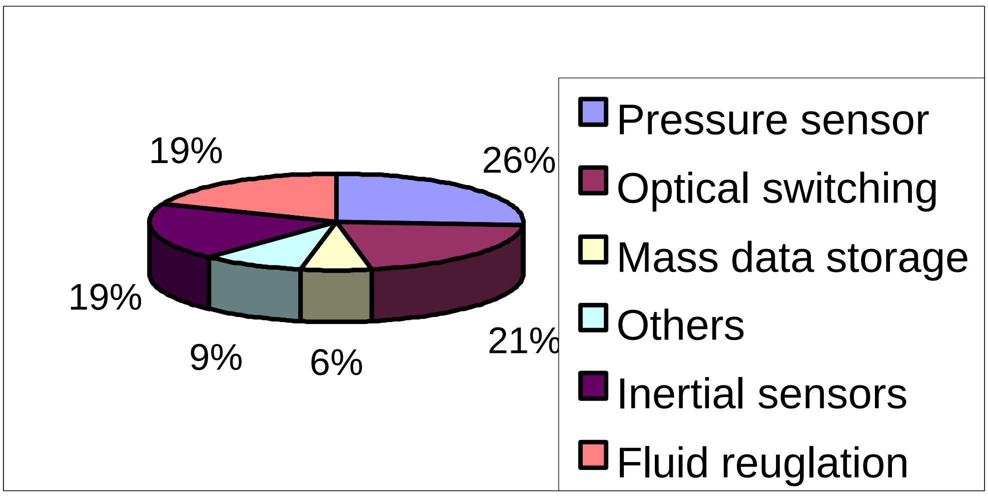


Figure 4 MST Market Segments

3. Assessment and Selection of MST Technology

Methodology

The assessment and selection of a suitable MST technology should be made using a sound methodology that takes due account of both business as well as technical factors. The starting point must be a clear understanding of the product requirement and commercial objectives. Ideally this should be documented in the form of a product requirements specification.

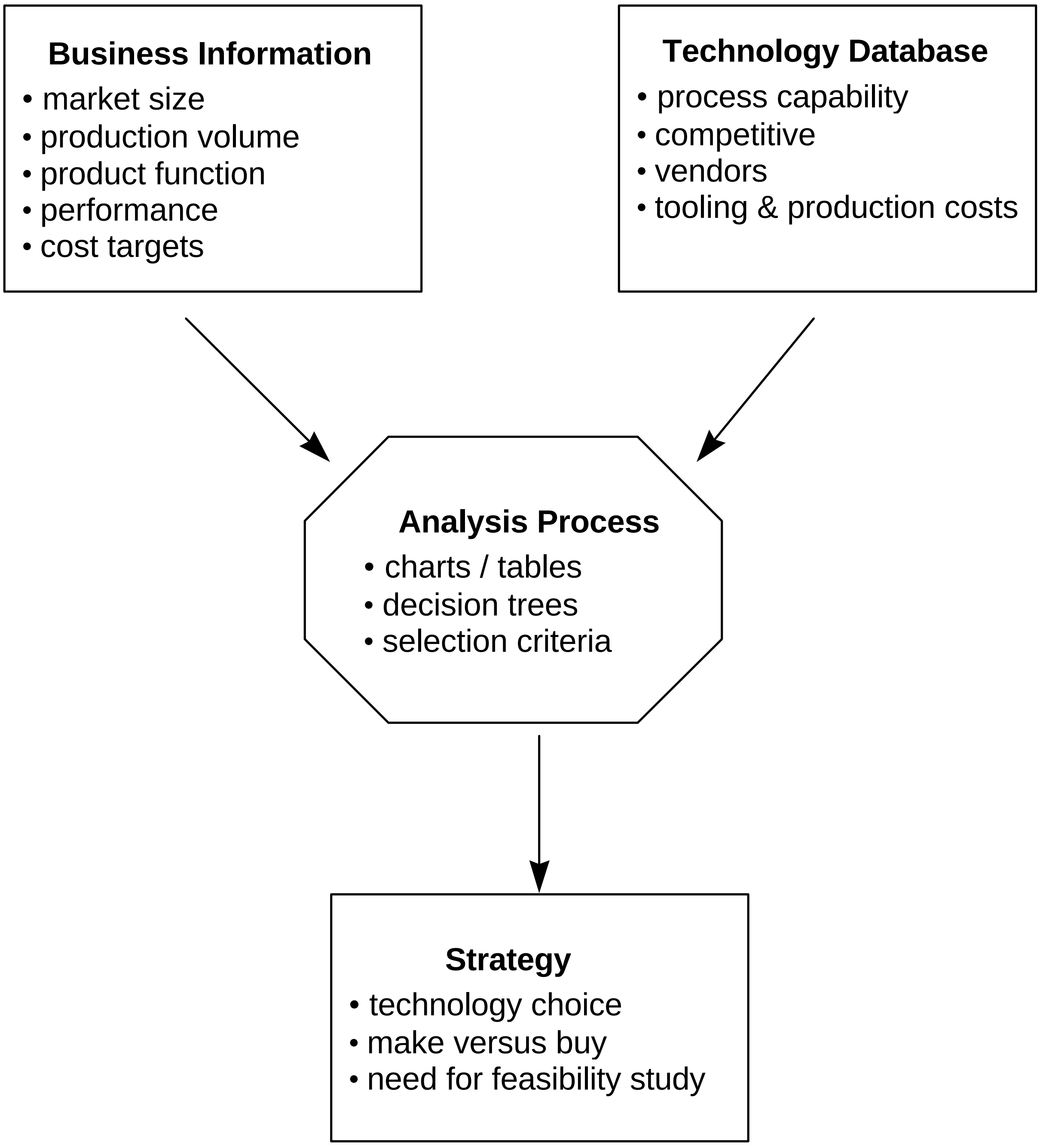
Once this requirement has been defined, then the supply side can be considered in terms of which technologies might provide the best blend of performance, cost, timescale and risk. In the case where there are multiple suppliers with capability in the chosen technology, then the final stage will be to select the best suppliers. Figure 1 shows the methodology in diagrammatic form.

At the end of the selection process the following key questions should have been answered:

- How long will the development take?
- What are the design and tooling costs likely to be?
- What are the production cost targets?
- What trade-offs might be possible between cost and performance?
- What is the level of risk and uncertainty in the project and is it appropriate to consider a feasibility study or prototype phase before committing to a full product development?

Figure 1

Methodology for Choosing a Technology



In the following sections we look in more detail at the steps in the process of choosing a technology and give some check lists, charts and decision criteria.

Product Requirements Specification

The first step in the process of choosing a technology is to compile a list of the requirements in terms of the product functionality, performance and cost as perceived by your customer. This list should provide a clear picture of the benefits and value to the customer of the specific product features. Keeping the customer's needs in mind is essential when considering the various costs/performance trade-offs that are inevitably involved when choosing between various technologies.

Product requirements are not fixed, but reflect market dynamics and competitive pressure. In general there will be a 'window of opportunity' for a given product and this time window will define the available development schedule for the product. One of the factors that should be considered in the choice of technology is the ability to make future product enhancements as the technology develops and matures.

As far as product costs are concerned, the customer is usually trying to minimise the whole lifecycle cost. Hence factors such as component reliability, power dissipation, and consumables all should be considered. As an example consider a medical diagnostic device: one approach might be to try and make the sensor part cheap and disposable – pointing the way to technology "A". But lifetime cost considerations, plus customer attitudes toward environmental issues might make a more expensive reusable sensor system which can withstand the high temperature and pressure of sterilisation more marketable – thus favouring technology "B".

At this stage it is worthwhile to take stock of the resources available in your company to manage the project and carry out the technical development. Part of the overall project budget will be taken up with training and development of your existing staff or recruitment of new staff. Your choice of technology will influence these costs and they should not be neglected.

Figure 2 shows how the different elements of the product requirements specification might map into available microsystems technologies and how these, in turn, influence the system partitioning and packaging decisions. These options are discussed in more detail in the next section.

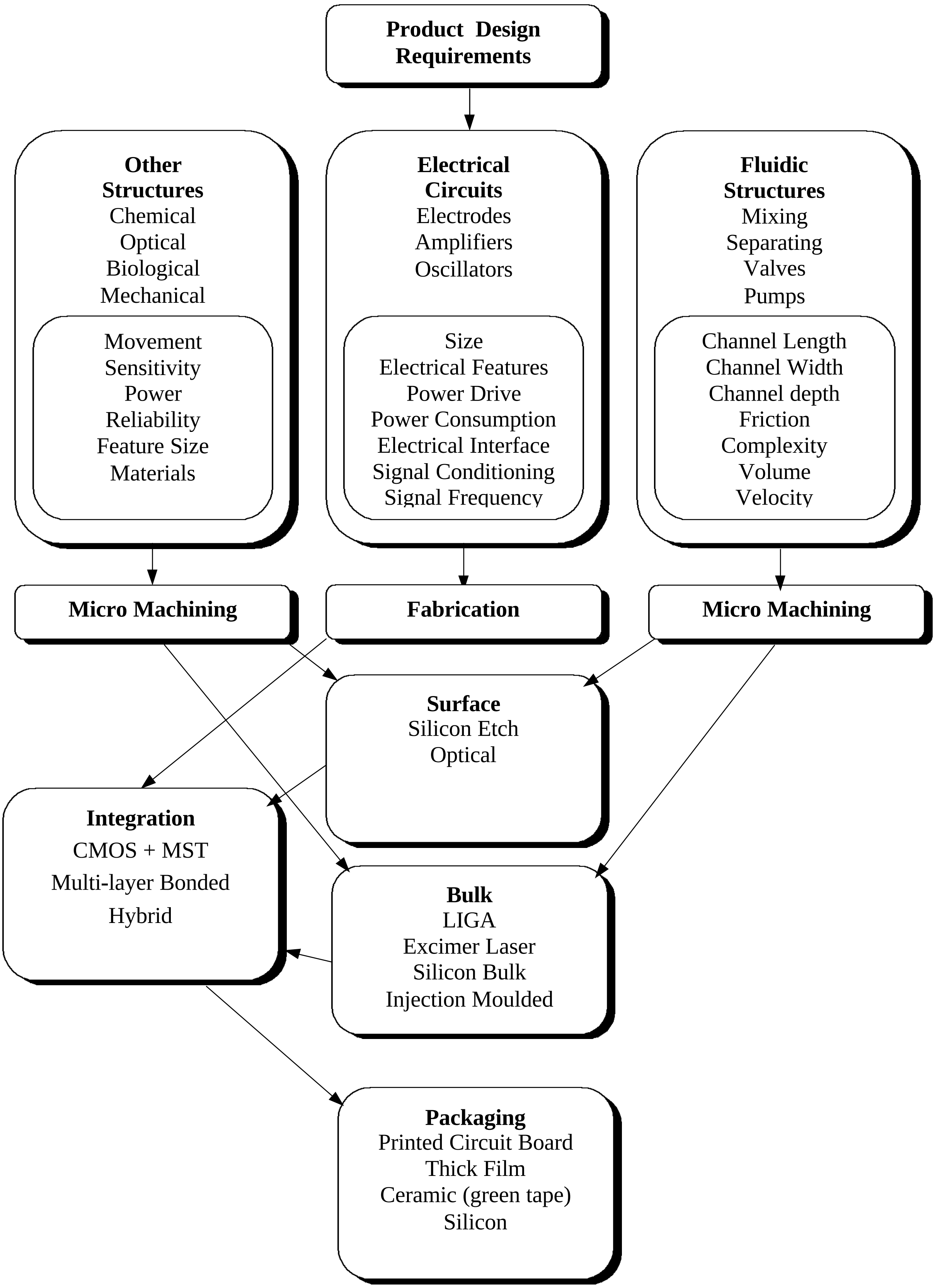
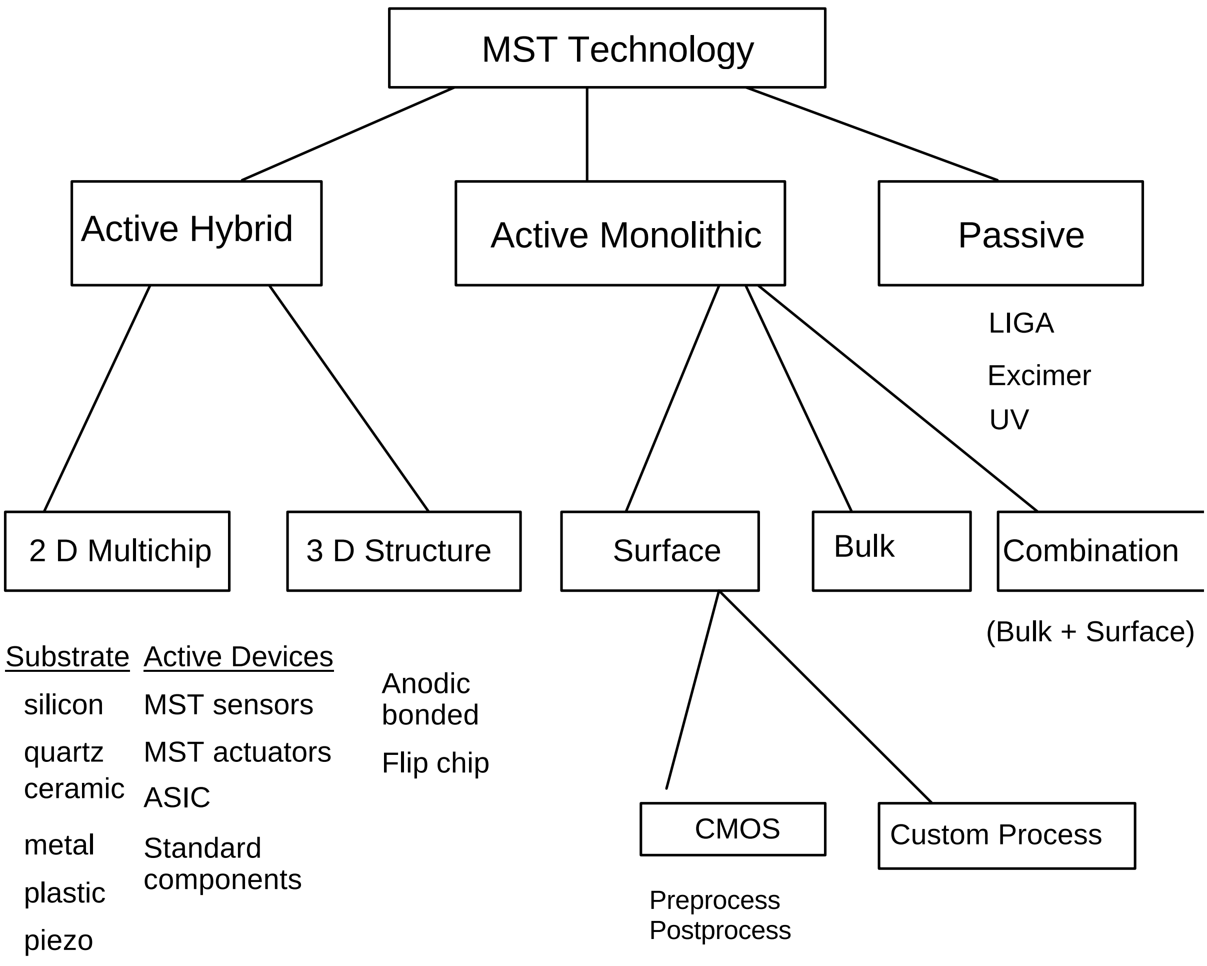


Figure 2

Mapping product requirements into available technologies

Figure 3

Taxonomy of Microsystems Technology



Microsystems Technology Classification

The various Microsystems technologies can be classified as shown in Figure 3. The diversity of MST process technologies is a result of the wide range of materials that can be used and the number of different forming or machining techniques. Materials used include silicon, quartz, ceramics, metals, plastics, glass and piezoelectric layers. Forming and machining processes include standard photolithography, laser ablation, photoforming in resins by 3D stereo-lithography, x-ray lithography, electroplating and combination processes such as LIGA (in German « LIthography Galvanoformung Abformung » = « lithography electroplating moulding »). LIGA uses synchrotron radiation to form a deep pattern in photoresist, which is then replicated, first in metal by electro-plating and then, using the metal pattern, into plastic using moulding.

Machining
Conventional machining using machine tools is usually limited to structures with dimensions of greater than 100 micron and with tolerances of 10's of microns. The use of lasers which can cut by melting or by ablation has extended the capability down to structures of 10 micron size and with tolerances around 1 micron. The main limitation of machining techniques is that only one structure is produced at a time and so production volumes may be limited.
Lithography
Lithography has been the foundation of silicon chip production and can now produce structures with sub-micron dimensions with 0.1-micron tolerances across substrates up to 300mm diameter.

Conventional chip technology uses lithography to pattern layers of silicon, silicon dioxide or nitride, and metals with thickness around one micron. MST has extended these techniques in several ways:

- By using anisotropic etches (i.e. faster in certain directions) to cut much deeper patterns where the shapes and depths can be controlled by crystal properties
- By using doubled-sided lithography, where patterns are cut from both sides of the substrate
- By using sacrificial layers to create suspended structures.

In MST, the resultant structures are usually classified as "bulk" or "surface" micromachining. Bulk structures tend to be deeper, even using the whole depth of the silicon or quartz substrate, and use anisotropic etches. Surface structures are shallower, typically one to ten microns thick and rely on sacrificial layers and conventional isotropic etches, although reactive ion etching is extending the capability in terms of both depth and materials which can be etched. In many cases, structures are often made by a combination of bulk and surface techniques.
Active Microsystems
In many cases, mechanical structures formed by the techniques described above are combined with active electronic circuitry. There are two major techniques employed, monolithic and hybrid. Monolithic microsystems combine the mechanical and electronic functions on one chip. Examples are the ink-jet print head or the accelerometer produced by Analog Devices Inc. In general, monolithic microsystems are only considered where the production volumes are expected to be very high (several 10's or 100's of millions of parts per annum).

Hybrid microsystems combine mechanical and electronic structures that are made on separate chips and often from different materials. An example is the accelerometer from SensoNor that combines a quartz mechanical structure with a conventional silicon ASIC on a metal lead frame. Hybrid structures can be formed in a 2D fashion (using conventional multi-chip module technology) or stacked vertically in a 3D structure. The latter methods rely on the new processes of anodic bonding and flip chip attachment.
Anodic Bonding
Flat substrates of silicon or glass can be bonded together using a combination of heat and pressure under vacuum or in a special gas environment. It is also possible using optical techniques, to accurately align patterns on the two or more layers to be joined. Thus very complex mechanical structures such as valves, pumps and gas-filled cavities can be produced. One advantage of this technique is that whole wafers of many 1000's of devices can be bonded in one process prior to separation into individual devices. This technique is also being used to form chip-scale packages that can provide mechanical or environmental protection for active devices.
Flip Chip Technology
Electrical and mechanical connections can be made between multiple microstructures using the flip-chip technique. This relies on solder bump technology where re-flowable metal bumps are formed on one of the structures to be joined. The other structure needs to have a compatible metal layer to which the melted solder will adhere. Alignment of structures depends on surface tension effects to pull the matching patterns into registration.

Surface Micromachining of Active Monolithic Devices

The choice of process for active monolithic devices is between CMOS or custom processes. The majority of conventional integrated circuits use CMOS technology and so this is well developed and there are many foundries and design houses who can develop and produce structures for you. The disadvantage is that only a limited range of microstructures can be produced in a CMOS-compatible process. Pre-processing or post-processing the silicon wafers before they are put through the CMOS process has extended this range. However not all CMOS foundries are willing to handle pre-processed wafers as they could have the potential to contaminate the CMOS process.

Custom processes have been developed at many research institutes and some companies. In general the production economics only favour a custom process if the production volume is expected to be very high or if the added value is very great. The Hewlett Packard ink-jet device is produced on a custom process with a production volume of about 100 million parts per annum.

Partitioning and Selection of Technology

From the review of technology available given in section 3, it is clear that the selection of technology can be a daunting task. A methodology to help with this task is as follows: partition functionally, analyse the capabilities of the various technologies to match the functional requirements and then, from the candidate technologies which still remain for consideration, see how these might be combined in a hybrid or monolithic structure.

Figure 2 shows how the Product Design Requirements might be mapped into electrical, fluidic, mechanical or other functions. Each of the required functions will have critical parameters that can be matched against the capabilities of the various technologies. Table 1 below shows how this mapping might be done in the case of fluidic requirements. In the example shown, the column for ‘Requirements’ has been left blank. Once this column has been completed then a subset of the available processes and materials meeting the requirements will be left.

In the event that the various functional elements can all be produced in silicon then the next step will be to consider the integration options. Here the choice has to be made between monolithic or hybrid integration and, within the silicon processing whether a CMOS or custom process can be used. Production volumes and economics will mainly drive the choice.

Figure 4 shows the typical range of application of the various processes, and some examples of products where they have been applied.

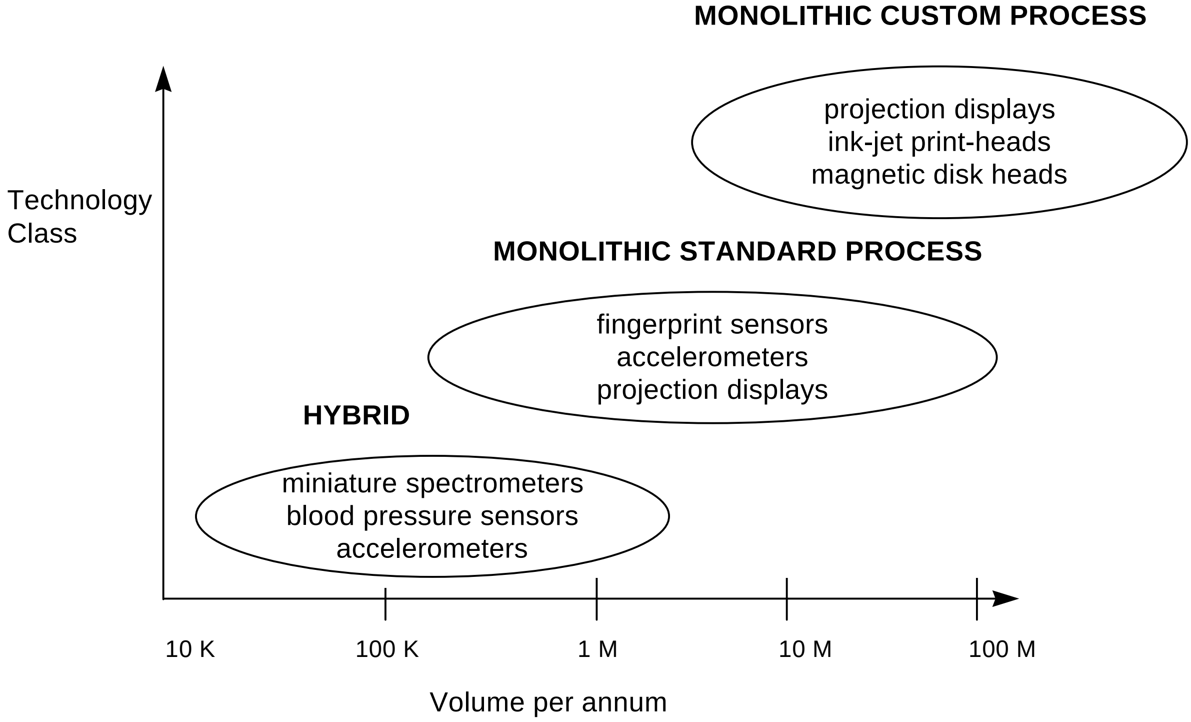


Figure 4

Choice of technology according to production volume

In the event that the various functional elements cannot be produced in one material or by one process, then a hybrid solution is needed. Dependent upon the size and space constraints, a 2D or 3D solution can be chosen. In general a 2D solution will involve less risk and lower cost because it relies on the well-established multi-chip module (MCM) technology. However for some applications e.g. medical catheters a flip-chip 3D approach has been chosen because of the severe space constraints.

In every case an important consideration will be the production costs both for tooling and piece parts. It is difficult to obtain accurate values before some preliminary design trade-offs have been made, but even at this early stage it is essential to have some ballpark numbers to assess the overall project viability. Cost models should be continuously updated throughout the later stages of design implementation to ensure that assumptions have not been invalidated.

Table 1

Technology	**Requirements**	**Silicon Bulk**	**LIGA**	**Photo Etch Glass**	**Reactive Ion Etch**	**Excimer Laser**	**Injection Moulding**
Application Areas	Fluid mixing, separating, controlling (pumps, valves), measuring (viscosity, density, temperature)						
Technology Features							
Width typ (μm)		10	10	20	2	10	200
Width min (μm)		1.5	1	15	1	3	100
Depth typ (μm)		5	100	10	10	100	100
Depth max (μm)		300	1000	50	150	1000	5000
Die typ (mm^2)		5	60	400	25	100	400

Technology	Requirements	Silicon Bulk	LIGA	Photo Etch Glass	Reactive Ion Etch	Excimer Laser	Injection Moulding
Substrate Width Wafer Dia (mm)		75 100 150	150	75	150	150	>150
Available Materials							
		Silicon	Plastic Metal	Glass	Silicon Quartz Glass	PMMA (plastic)	Plastic
Production							
Masks/Steps		6	1	1	1	0	>1
NRE Tooling (k$)		20	10	2	5	2	5-100
Piece Part ($)	Low Volume	>20	1.26	0.10	0.48	0.28	1.26
Piece Part ($)	High Volume	1.54	N/A	N/A	N/A	N/A	0.03

Table 1 Requirement compared to technology capability for a fluidic function.

Examples from the FUSE Portfolio

Here are some examples of the thinking behind the choice of technology in demonstrator projects from the FUSE portfolio.

Firstly, in AE 27436, as well as many other points about the choice of technology for an integrated optical barcode reader, the First User considered the past track record of the subcontractor. Together with the choice of a technology the subcontractor already used, this minimised the risk in the design innovation step that the project necessarily involved:

« The choice of IMEC as main subcontractor is based on their recognised experience in the design of optical sensors. They already have developed many different sensors in CMOS technology (the FUGA series). A sensor with exactly the characteristics required by this application has not yet been designed but IMEC owns all the competencies necessary to do it. The choice of the ALCATEL-MIETEC 0.7 technology is based on the experience that IMEC has in the design of image sensors with that technology. This process is mature, has a high and reproducible yield, and known optical characteristics. The process is also suitable for co-integration of analog and sensors parts and digital electronics. Extensive digital libraries and design tools are available…. For the prototype fabrication a Multi Project Wafer service offered by ALCATEL-MIETEC will be used ».

In AE 23569, the following rationale was used to combine the processing, temperature sensing and actuating (heating) requirements to arrive at a cost-effective and relatively low-risk hybrid MST solution for a pheromone evaporator for an insect trap:

« The intelligent control element needed the capability to meet specific customer demands, handle alternative pheromone materials and allow factory adjustment of the temperature control algorithm. The lowest cost solution to provide these features was demonstrated to be a low-end 8-bit microcontroller.

Discrete component implementations were avoided because of the additional space required for the completed assembly, and application specific integrated circuits (ASICs) were rejected because of the requirements for design flexibility and because of the high initial costs of adopting this technology.

Several possible solutions were considered for the heater technology, including wire based, encapsulated heater units commonly used in automotive applications. Because of the relatively low power requirements for the heater and the need to produce a uniform heat profile over the heater surface, the use of a ceramic heater using resistive inks printed on the surface was selected. The availability of the ceramic substrate meant that the reverse of the heater assembly could be used to mount the microelectronic components. The construction therefore incorporated the heater, temperature sensing devices and control electronics on a single common substrate.

Several alternatives were considered for the temperature transducer. These included analogue and digital integrated circuits, and thermistors. Thermistors were finally selected on the basis of low cost. The interface to the sensor was performed using a capacitor charge timing technique commonly used with low cost microcontrollers. The controller incorporates a software based lookup table to accommodate the selected thermistor characteristics ».

(Note that the above choices interacted: for instance the choice of microcontroller also allowed the low-cost thermistor to be used with few external components).

In AE 23595, as well as many other points about the choice of technology for an angular position detector, the First User considered the risk/cost/benefit trade-off of using a standard process vs. a customised one:

« Our special requirements for the technology proved to be a problem. In order to be able to achieve satisfactory performance, a low threshold voltage was required. At the same time, our patented switched MAGFET sensor required a 2nd polysilicon layer. These two requirements were not both offered in any available standard CMOS process. Through the CAST program offered by IMEC it was possible to modify a standard process in order to meet our requirements but this was known to be an expensive solution. At an early stage, it was recognised that Alcatel-Mietec offered a low low threshold voltage CMOS process called C05M. Based on experiments it was decided to rely on a less restrictive MAGFET sensor principle that removed the second requirement. This enabled us to proceed with a standard CMOS process which was accessible through the Europractice MPW service ».

In AE 25923, the technical case for the use of Surface Acoustic Wave (SAW) technology was quite hard to make: however a thorough economic analysis helped convince the First User and the subcontractor that it was worth trying on a “best efforts” basis:

« The use of a SAW microsystem was very exotic for many people active in the field of RF identification systems. Although clear indications were available that the microsystem could be produced no hard information about the yield and especially the coding costs were available. So it was unknown if the device could be produced in volumes at an economic price - a fact which bothered the potential suppliers.

We started with a marketing analysis showing the big market potential of a tag based on a SAW microsystem and we also wrote a comprehensive and finally convincing Business plan. We also talked to potential customers to check if the concept of a microwave, read only tag was attractive to them. This way we gathered a lot of information which proved to be useful in convincing us to invest into the development but it also gave as precious input for the design of SAW microsystem.

To start the AE we accepted a "best effort" contract as the supplier still hesitated. In the course of the AE the supplier started to fully realise that the SAW microsystem can be industrially produced and even more important, new way were found to enhance yield and reduce coding costs. At the end of the AE both supplier and ourselves look with very good confidence into the future and continue close collaboration ».

Next: small is not always beautiful! It is important to realise that not every physical factor improves with shrinking dimensions. Parameters such as actuator output power will naturally reduce and surface effects such as friction in particular have a proportionately higher effect at micro scale. These factors can often be offset through design innovation (e.g. in nature the design of an insect is not just that of a scaled-down elephant). In other cases they may mean MST is just not applicable.

In FUSE AE 529, a micro-filtration analysis system, assembly operations such as gluing and welding were affected in this way:

« By scaling down the system size, it is more difficult to have ‘grip’ on the system; special test facilities are necessary. This requires very good design rules, design knowledge of the technology (for example gluing, welding) and product constraints (allowed materials in biotechnology). This information has to be supplied partly (technology) by the subcontractor and partly (product constraints) by us and has been used to overcome the product size barrier. »

Finally in this section, we refer to the breakdown of technology choices for AE 26793, a microsystem for use in asthma management. This is quite complex, as any real technology choice exercise should be, so it serves as a good “full-scale” example. It is included at Appendix I. The analysis covers:

- choice of sensor
- options for design innovation based on existing sensor technology
- risk analysis of the design innovation
- packaging options
- design route to be used for the electronics
- choice of processing element

4. Choice of Subcontractors

Introduction

Once the initial choice of technology and partitioning has been made, then the supply side can be investigated. Microsystem development projects are inherently multi-disciplinary – they need to bring together expertise in the medium to be sensed or acted upon (e.g. gas chemistry and flow), the sensing or actuating mechanism (e.g. hot-wire anemometer) and the processing electronics (e.g. microcontroller). Few first-time users can cover this range. In addition, competence is needed in each of the different project phases such as specification, design, prototyping, evaluation, production, packaging and test.

Common MST project elements which lead to increased risk are:

- Dependence on multiple specialist suppliers
- Dependence on single-source supply
- A high degree of process or design innovation

These factors tend to intercept critically in the **pre-production** and **production ramp-up** phase. In addition, a high degree of innovation means it is necessary to be absolutely clear about **Intellectual Property Rights (IPR)**.

General Industry Structure and Major Choices

The overall structure of the MST industry and the options open are shown in Figure 5.

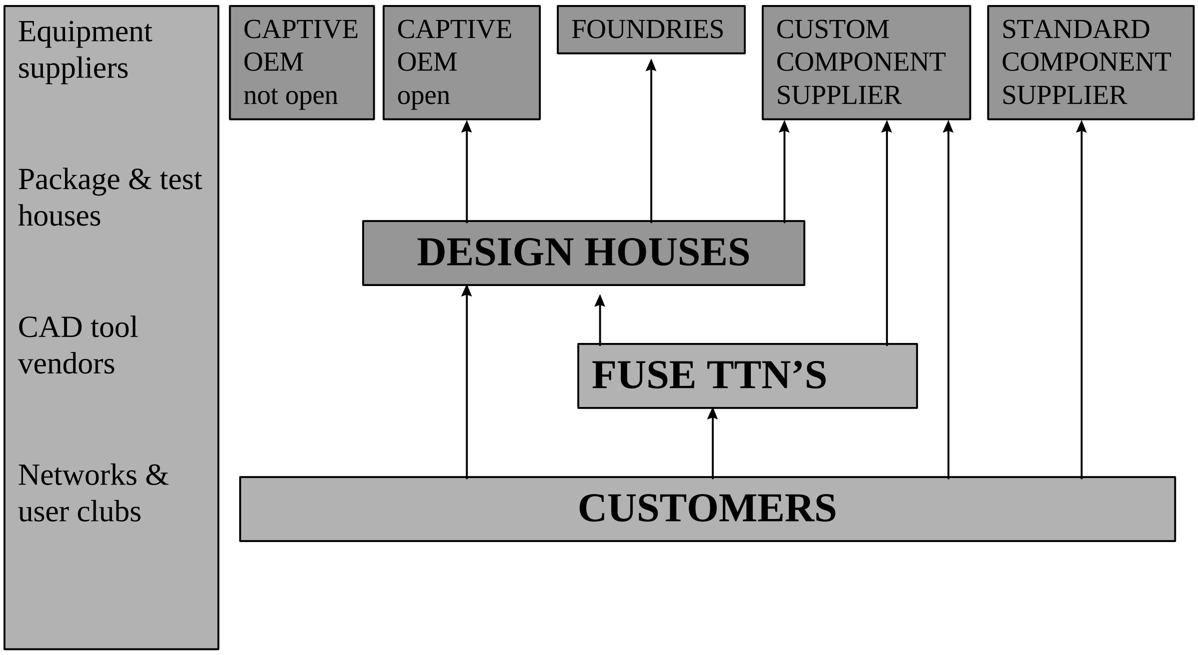


Figure 5 Microsystems Industry Structure

Note:

- Some TTN's are also design/service centres
- Some standard product manufacturers are also foundries e.g. SensoNor
- Design Houses and Service Centres can be based at Universities, Research institutes or can be commercial concerns.

The simplest option is to use an existing standard product. This will reduce the technical risk and speed up the time to market. However this will give little protection to the customer as your competitors can take the same approach. A wide range of pressure sensors, accelerometers, gas sensors and other functions are available as standard products.

The next simplest option is to choose a vendor who can offer a complete design and manufacturing solution. This route allows the customer to leverage the design skills of the supplier but retain uniqueness in the finished product. The disadvantages may be high design charges, single source of supply and a design schedule that depends on the priorities of the supplier.

Using Design Houses or TTN's can provide a solution for accessing foundries or captive OEM suppliers where the customer does not have their own design expertise in-house. The disadvantage is that the relationship with the manufacturer is indirect and a degree of control has been lost.

Finally, choices will be made not only on technical capability but also on cost, cultural, geographical and contractual criteria (which are discussed in more detail in the chapter on Management of Subcontractors).

Here are some reasons given in the FUSE portfolio for subcontractor choice:

In AE 22843 flexibility on behalf of the subcontractor was identified as an advantage:

« (The first user)… has learned the high value of selecting a design support subcontractor who can accommodate some flexibility in the workplan. Previous experience of dealing with a wide variety of sub-contractors has indicated the preference for a firm schedule by subcontractors. The need for first users to consider these factors in the selection of subcontractors has been a valuable lesson »

In AE 23569 the first user identified the importance of selecting a subcontractor of the right size:

« … We have developed an ability to assess subcontractor capabilities more effectively. The importance in developing excellent communications with the selected partner is crucial. Our opinion is that this can be best achieved by operating with companies of a similar size and turnover to one's own company. Operating with larger subcontractors, with high sales turnovers means that these companies may be more interested in dealing with larger volume contracts and not in assisting non-standard product development. It is advised that potential first users assess these factors before entering contracts, possibly by completing a formal review of subcontractors, or defer subcontract signature until appropriate ».

AE 24575 also experienced some « cultural incompatibility » with a research-oriented supplier:

« …At the beginning of the AE our first contacts with subcontractors were not so easy. The problem was that the mentality of research institute personnel was far from the one of people working in a small company.

We had some problems in understanding what was possible with the microelectronic technology, while the research institute personnel had trouble understanding that a small company needs to be product oriented in a short timescale. These problems were solved in the first months because we discussed these differences in order to understand each other's different backgrounds, skills and limits. The discussion gave us the possibility to find a "meet in the middle" trade-off and since then we decided both the strategy and the work plan to be followed in order to reach the final goal ».

Despite the distance involved, AE 25923 selected a US-based subcontractor who would value their business:

« The area of SAW components is booming and the output of most suppliers is limited by production capacity. In this situation a supplier must have a real strategic interest to enter into the domain of a small number of non-standard, technologically demanding SAW microsystem parts. We evaluated three suppliers having interest. One of them was eliminated for competition reasons and a second one did not meet the requirements for production equipment. Finally, a USA-based company was our choice for prime supplier. We found that geographical distance was no major problem: we made extensive use of e-mail and phone to ensure that the project went the right way. However, this does require sufficient spoken and written communication and language skills.

Schedule, Cost, Performance and Risk Trade-Offs

The options open and their impact on schedule, cost, performance and risk are shown in Table 2

Option Chosen	**Schedule**	**Impact on Cost**	**Performance**	**Risk**
Use Standard Product	Fastest	low	Medium low	low
Use foundry with separate Design house	Fast	Medium	medium	medium
Use complete solution provider with existing process	Medium	Medium	Medium high	low
Use complete solution provider new process	Slow	high	High	medium
Develop your own process	Slowest	Highest	Highest	highest

Table 3 Schedule/Cost/Performance/Risk Trade-offs

Within each of these options there are further choices which can be made which will affect the schedule, cost, performance and risk:

- Using a foundry that offers a Multi-Project Wafer (MPW) service can reduce tooling costs and offer a route to prototyping and low volume production.

- Using standard cell libraries can speed up the design cycle and offer a lower level of risk than full custom, and a faster schedule at some small sacrifice in performance. Very few MST standard cell design libraries exist at the moment but they are expected to become more widely available as the industry matures.

Supplier or Process Qualification

Since process or design innovation can be expensive and increase risk, it is vital you are aware when it is happening. A lot of microsystems technology is very new, and there is much potential yet to be realised. This creates business opportunities, but also brings risk. For instance, a supplier may be tempted to bid for your custom on the basis of a design technique or process they have not yet fully mastered, but hope to on the basis of your business. Even if they do not intend to use your funds in a misleading way, they will be exposing you to hidden risk.

If a supplier claims that a process or design technique is established, you must ask for and follow up references to other clients who have used this technique. Research papers and samples alone are not enough - find out what quantities have been produced. The supplier may claim to be bound by confidentiality agreements (see below) and therefore unable to supply references. In this case you may get suspicious - if their capability really is established, surely there ought to be a non-competing client they can refer you to? Alternatively, you could ask what other evidence the supplier can give as to the established nature of the technology.

One First User chose their supplier after being shown samples of parts produced using a particular process and technical papers about the process' capability. However, only after their own prototype parts were designed and manufactured did it become clear that the process was failing – even to the extent that parts were physically falling apart! The supplier had seriously "oversold" the capability of a process still under development.

In AE 23617 the First Users gave the following qualifying reasons for the choice of their fabrication, training and testing:

« Firstly, IOT is not a competitor of ours. They have five years of experience and know how in the manufacturing of Integrated Optical Chips (IOC). They possess the complete equipment for the fabrication of our IOC and they have a very elaborate qualification process of their products providing the environmental stability and mechanical robustness needed for the field deployment of industrial products. For example, all chips have to pass an extended temperature and humidity load cycle program. They have a very low reject rate of their products.

CSEM operates a training centre especially devoted to support SME's. They have 60 engineers and considerable experience in the field of integrated optics, optoelectronics and microsystems. They provide all facilities and equipment for the qualification of IOCs and the hybrid coupling of IOCs.They have the expertise for hybrid coupling of diodes and lenses ».

Another First User commented:

« In micro fluidic systems there is not much choice in subcontractors. Most are strongly affiliated with the academic world … there was an attitude difference between ourselves (result minded) and the subcontractor (not directly focused on achieving results). The attitude of some designers is often quite conceited: ‘I understand your problem - this is the solution’. But with relatively new technology, there are more solutions possible. Designing is thus a creative process of development with better solutions if the design team has more engineers. In fact, by having more subcontractor working on sub-tasks, the overall design can benefit from the different point of views from the subcontractors ».

A sound approach to gaining confidence about a supplier’s capability is to hire an expert consultant to do a technical audit or benchmark exercise at the supplier on your behalf. Locating the expert might be hard, but the cost could easily be worth it, especially if the expert exposes any weaknesses you have failed to see.

Single- vs. Multi-Supplier Working

Because of the multi-disciplinary nature of MST, you often need multiple suppliers to complete a project; e.g.: specialist design services plus a foundry; two foundries with complementary processes or a foundry and packaging plant. The advantages of using multiple suppliers are wider expertise and possibly lower overall cost. The disadvantages are increased management complexity, exposure to problems occurring independently at either supplier or the possibility of a dispute occurring between suppliers as to who is at fault in the event of problems.

Of course, in normal trading you should obtain competing quotes from suppliers. However, in many cases in MST you may be placed in a single-supplier or single supply-chain situation and you need to assess the extra risk associated with this. During the next few years it is anticipated that this will become more of an issue and a few standard processes may emerge with multiple suppliers.

Organising Multiple Suppliers

You need to decide if you are going to manage the interfacing between multiple suppliers, allow one to act as “broker” for the other(s), or bring in a third party to manage the whole chain.

Self-Managed Multiple Suppliers

If you are managing the inter-supplier interfacing, include a reference to the need for collaboration with other suppliers in each supplier contract. You must also plan carefully the necessary management effort needed to orchestrate the suppliers.

In several FUSE MST projects, clients admitted they initially underestimated the effort required to set up and manage the supply chain. Being mostly smaller companies, there was a limit to the resource they could devote to this and so they ended delaying the real start of their own project as a result.

Multiple-Supplier Broker

Where brokering is happening you must check carefully what guarantees the brokering party will make on behalf of their subcontractors. Will they take responsibility for all problems arising? Can they provide evidence that they have worked successfully in this role before?

Another issue with a brokering arrangement is: what will happen when the design is complete and the product enters the production phase? At that point you may want direct access to the source supplier(s). However, the brokering party may seek to intervene in this phase, for instance by insisting that you place production orders exclusively through them or by demanding a royalty on production orders. Such an arrangement could be in return for reduced fees at the design stage and this may be acceptable to you. However, you need to be clear from the outset whether this is the broker's intention.

Any on-going exclusivity agreements (such as guaranteeing to use a certain supplier) need to be made clear as part of the contract, and possibly limited in scope, e.g. up to a maximum order value, quantity or duration.

Third Party Recommendations
You should also be wary of one supplier recommending another as a suitable partner. It may be that the second supplier is a good choice, with the benefit of an established working relationship with the first supplier. However, in the event of a problem with the second supplier, the first will usually disclaim all responsibility! As manager, you must be equally diligent over the choice of all suppliers, as they are all critical to project success.

Sub-Subcontracts
Project management through an extra unplanned-for level of subcontracting may be difficult – you should limit subcontractors' freedom to reassign all or part of their work without your consent. If a further level of subcontracting is unavoidable, it is important to make sure that sub-subcontractors:

- Are bound by the terms of the main contract, especially the confidentiality terms
- Do not retain foreground IPR

Contracted-out Supplier Management

On a larger or more complex project you should consider hiring a consultant just to help manage the project (e.g. by chairing progress meetings) and help ensure suppliers perform adequately and in your best interest.

AE 26170 used an external consultant (in addition to the TTN) to help manage their suppliers. The consultant chaired monthly progress meetings, wrote the minutes, chased up actions and deliverables and maintained an on-going project plan using MS-Project. This freed up the time of company chief executive, and only the technical director needed to attend the monthly meetings

At first the client planned just two major suppliers, but when it became clear that there was a gap in their combined knowledge, the consultant:

- Scheduled extra side-meetings to discuss the matter
- Helped the end-user to select a third supplier to bridge the gap

When it appeared that technical problems with process innovation might put the ideal project outcome at risk, the consultant and TTN encouraged the suppliers to propose a lower-risk fallback solution based on established processes. In the end the problems were solved and the fallback solution was not required. Nevertheless, it was sound practice.

In AE 529 the First User company stated:

"As micro system technology is a new technology for us, it was important to have a third (independent) 'partner' during the project, besides the subcontractor. In our case this was the TTN"

Further FUSE Case Studies –Technology and Vendor Choices

As stated above, the choice of technology and of vendor are often very closely raleted and must be considered together.Here is a tabulation of the relevant factor influencing the choice for four different FUSE AE s :

Choice of Technology and Vendor

Case Example	LIGA IR Spectrometer	Microfiltration System	Liquid Level Sensor	Optical Torque Measurement
Size of company (No. of employees)	8	2	40	10
What Technologies were considered	only LIGA	• Milling • Moulding • bulk silicon	only MOS	various optical
Production Volume Needed	2000 p.a.	100 p.a.	1600 p.a.	?
Product Motivation	leadership	Leadership	catch-up	leadership
Choice Process for Technology	advice of consultant	own judgement	advice of supplier	own judgement
Most Important Criteria for technology choice	• match to product requirements • clear route to production • proven process	• nearby supplier • match to product requirements • cost model	• nearby supplier • size reduction • cost reduction	• match to product requirements • clear route to production • vendor reputation
Hybrid or Monolithic Custom or Standard Process	Hybrid Standard	Hybrid Custom	Hybrid Custom	Hybrid Standard
Design House Used?	No	Yes	Yes	Yes
Major problem areas	• learning how to	• IPR	• IPR	• none

	manage R & R	ownership • Technical failures in valves	ownership • no route to production	
Feasibility study used	Yes	Yes	No	Yes
Number of Prototype Iterations needed	2	2	2	1

5. Construction of Workplan

General Principles

A workplan should be realistic, well-defined from all points of view (user and supplier) and must also have an element of flexibility built in. Some key principles are:

- Divide the work up hierarchically into « work packages » such as management, specification, training, design, evaluation, field trials, pre-production, etc. Subdivide work packages into a number of discrete tasks.
- Divide the results up hierarchically into major phases (« milestones ») and more detailed results (« deliverables »)
- Make it clear who is responsible for each task and deliverable – down to the individual level in your own organisation.
- Make sure individual tasks are not too long (easier to tell if they are on time or not) and that there is a regular flow of deliverables to measure.
- Set up a system for monitoring actual effort (timesheets) and compare « planned » vs. « actual » at the end of the project. Noting what you got wrong should help you to plan the next project more accurately.

Be clear about the distinction between effort, person-loading and duration (duration = effort * loading), and consider person loading down to the level of named individuals. Don't forget to allow for holidays, illness and non-project activities like regular committee meetings etc – because everyone has them!

The ability of any individual to devote themselves completely to one task is usually in inverse proportion to the size of their company – here is the experience of AE 22843 :

« The management and planning of the project highlighted many real world problems in undertaking new technology development programmes. The demands of customers, product support needs for existing technology, and marketing support for modifications to existing products are always present, and the ability to totally decouple the engineer involved in the knowledge development process from such pressures is often difficult to achieve. This factor should be programmed into work plans produced by first users of microtechnology ».

Another factor to consider is building in as much concurrency into your plan as the resources will allow. Software project planning tools can help do this automatically. AE 23569 followed this principle :

« The original work plan employed a sequential approach to the programme of work. The workplan was amended during the application experiment to assist the company in resolving several issues concurrently, including:

- assessments of various technical options
- the identification of optimum performance parameters
- to enable trials to be conducted at the test site
- to resolve final packaging options »

Where relevant, include training activities in the deliverables. Try and arrange a regular flow of deliverables from suppliers from the very start of the project: this gives an easier means of control if they fail to deliver.

Deliverables could include:

- Specifications, design and test drawings and documents
- Progress reports
- Samples, prototypes, test rigs

If you consider the project timescales to be a little speculative, it may be better to explicitly define a contingency procedure for unavoidable delays. This *could* provide a temptation to slackness on behalf of the supplier, but it can also prevent embarrassment and even extra legal costs in the event of a reasonable delay occurring.

Several otherwise successful MST projects in the FUSE portfolio overran by about 3 months (i.e. by 20-25%). As well as technical difficulties, common causes included specification problems, legal and IPR issues, illness of key personnel etc. Budget overrun was not usually significant, as the delay often slowed the rate of expenditure. However, the cost of any delay must also be calculated in terms of the increase in the predicted payback period and the corresponding lower rate of return on investment, loss of total revenue through late entry to market etc.

Simulation vs. Experiment

Unless you are using a well-established MST process and design, for which published "data sheets" are available, the finer points of design or even the whole technical feasibility of the project will need to be verified as soon as possible either through simulation or experiment.

If your project involves design innovation on a well-established process, simulation may be an option. However, the multi-nature aspect of MST makes simulation quite complex – possibly requiring a mixture of finite element analysis and/or fluid dynamics, as well as better established electronic simulation techniques. Also, like most computerised operations, simulation obeys the rules of "garbage in = garbage out". In other words, unless the underlying process parameters really are accurately known, the results will be meaningless. Consequently, a project involving any process innovation will almost always need to be evaluated by experiment.

Here are some MST simulation experiences from the FUSE portfolio. In AE 22869, simulation of a force sensor gave good results…

« The force sensor principle was simulated with ANSYS tools and comparisons made between practical and simulated results. The results showed a very good correlation between simulation and measured values, having a deviation not exceeding 10%. This gave the team enough confidence that we were heading in the right direction ».

… However simulation of the force sensor under its intended operational conditions failed to predict problems of fragility that came to light when prototypes were manufactured:

« During integration and manipulation of the sensor chips, it was noticed that the yield of the production was strongly affected by breaking of the silicon cantilever. To overcome this issue, we had to implement mechanical end stops for overrange protection which were additional parts and process steps not in keeping with the cost constraints of volume production »

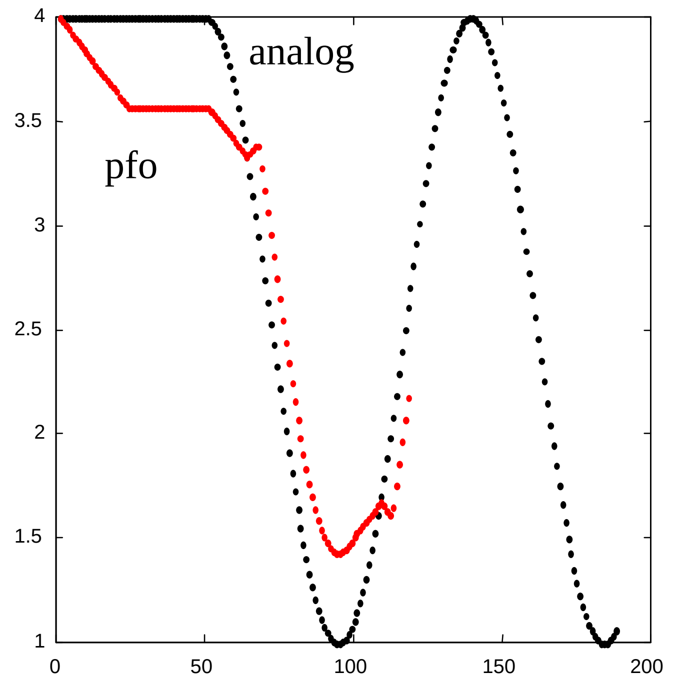
… They then revised the design and predicted its performance through simulation:

« The results between new designed cylindrical chip and ANSYS evaluation showed also a very good correlation between simulation and measured values, having a deviation not exceeding 5 to 8%.
It has been verified that accurate simulation tools and their correct use allows to reduce development time and costs. This new design requires fewer masks for manufacturing the silicon sensor chip and the torque force sensor assembly is much less fragile.

In AE 27436, which used fairly well established optoelectronic processes to implement an MST bar-code reader, the First User company found that high-level (or behavioural) simulation was a useful tool which allowed them to experiment with the design without getting too involved in detailed implementation. It also provided a clear means of specifying what was required – helping the subcontractor interface. They reported:

« The first idea was that our designers would work at a "logical level", providing a schematic description, while all the problems related with the "physical level" would be managed by the foundry. However, this was abandoned because of the difficulty in learning quickly a job that the subcontractor was already able to do. So, the new approach was for us to describe the design … (at a high level) … using suitable mathematical software tools (MATLAB).

Each block definition involved several steps of revision and finding an optimised implementation in accordance with the constraints of chip-area was harder than we thought. Nevertheless, the result was an adequate technical communication interface, using specifications in the form of description via discrete-time algorithms of the analogue blocks using functions implementable in the subcontractor's technology »



Behavioural Simulation of Peak Follower in Bar Code Reader

In AE25923, experimental testing using specially written analysis software was used instead of simulation:

« Modelling and the development of supporting software tools can often be recommended, but it takes a lot of engineering time. We now have a test set-up to investigate the SAW microsystem. We developed the software to analyse this measurement data and purchased a test fixture. The component was tested with a vector network analyser over a wide and narrow frequency band. The set-up of a test facility was an important step forward for us. It allows us to analyse the component under different conditions, to ensure quality, to get information for refining the design and to investigate damaged microsystems ».

… A similar approach was taken in AE 26170, which also used SAW technology.

Finally, in AE 23595, a mixture of simulation and experiment was used to gain confidence:

« Modelling of the magnetic system proved to be a difficult problem. After several purely analytical calculations, practical measurements on test mock-ups and elaborate ANSYS 2D and 3D analysis, the desired confidence in the level and profile of the magnetic flux from the permanent magnet was established. »

Training

When considering both the acquisition of MST expertise and the route through to final production, training should bear a part. As well as the project management aspects that this training material seeks to cover, training may also be required in the specific technologies being used, as well as design and simulation software tools where relevant. Whether you plan for any part of the manufacturing or assembly process to be done in-house, or just testing and evaluation, training of technical staff in the appropriate procedures and equipment may also be necessary.

The form of training may also be important: management issues may be best learned in a workshop format. However design, software and manufacturing skills may best be learnt in a hands-on mode, perhaps through an extended placement at a supplier or a training institute. In certain situations computer-based interactive packages may be applicable and are likely to become more widely available in the future.

Within Europe, one particular network of MST training providers stands out: the UETP-MEMS programme, co-ordinated by FSRM in Switzerland. They offer a full range of courses from highly theoretical to fully hands-on and process-related courses.

Here are some MST training experiences from the FUSE AE portfolio. AE 22869 reports:

« We wished to acquire the capacity to specify and design miniaturised systems having silicon components in their heart. We considered that the only way to understand a new technology is to practice it. In the frame of the FUSE program, a training course was planned and implemented at an early stage, allowing the project engineers to do "hands on" training work. That is, our engineers literally followed the design and manufacturing process at the sub-contractor's site (IMT), going as far as to do part of the process themselves. This kind of design approach ensures a maximum of knowledge transfer ».

AE 23569 realised that the during a first-time MST project a high priority must be given to learning the right managerial lessons, even amongst the engineering staff involved:

« The objective of the engineer training changed from becoming technically proficient to becoming more skilled in microelectronic technical management. The company’s experience was that full design capability could not be acquired in one product development, and the objective of the training was amended to reflect the development of a Technical Management capability. The company’s priority for this first use of microelectronics therefore was to be able to exploit this technology, especially in the short term, by developing a capability for managing electronic development and manufacturing programmes using external subcontract support effectively ».

When considering training in how to programme the microprocessor controlling their temperature sensor, AE 22843 found an interactive training package much more use than a traditional course with a fixed agenda:

« A 2-day training course on assembly language programming for the selected microcontroller was attended at the beginning of the application experiment. Unfortunately, the course was of limited value as it was designed for people with a more thorough understanding of microcontroller development process and so the material was of little benefit to a first-time user. The course also promoted the whole family of processors at the expense of a more specific training on the device of interest. This caused some difficulties at the start up of the application experiment until alternative training material was located. Eventually, a tutorial style training aid was identified by the TTN and purchased. This package provided an excellent introduction to the microcontroller device and programming it in assembly language ».

Training capability may be a factor in choosing the type of subcontractor to use. A research institute or University is likely to be very well set-up for providing training – allowing both technology transfer and knowledge transfer to be combined, as in AE1805:

« During the project training was carried out by combining the lectures with the items to be delivered, i.e., as soon as each milestone was reached the subcontractor informed the first user and passed on the results. Thus a continuous flow of information, corresponding to the actual position of the project, was guaranteed. Meetings and lectures took place on the following subjects:

- Specification: training in evaluating technological and economical options
- Specification: acquisition of critical requirements for the specification
- Introduction to design environment: training in design environments for field calculation (Quickfield)
- Introduction to mask layout: training in design environments for mask layout (ACAD)
- Introduction to design and technology and related technology: introduction to the design and technology of thin film technique, special setup and related technology
- Suppresion of interference: introduction to electrical and mechanical interference »

Complete Workplan Example

Appendix II contains a complete example of a workplan from AE 24575, an optoelectronic microsystem for an industrial motion encoder. The workplan has a tabular definition of work packages and tasks. Each Workpackage has a clearly defined aim, task breakdown and definition of each partner’s role. There is also a time-line (or Gantt) chart, modified after the project to show planned vs. actual deviation.

6. Management of Subcontractors

Contracts: the need to get specialist advice

Many suppliers' pro-forma standard contracts or terms of business are weighted wholly in their favour and should be viewed with caution. Training material like this can help, but there is no "golden contract" that can be used to cover all possible scenarios. Specialist legal advice must be sought as a form of insurance – certainly where contract value exceeds 20 KECU. Everyone complains about how much lawyers are paid (except lawyers!), but good legal advice or assistance in drafting a contract can be obtained for under 2 KECU – less than 10% of the cost of a 20+ KECU subcontract.
(It is worth noting that legal contracts are not subject to copyright, so you are free to copy "useful" clauses from existing contracts, provided you are confident about what you are doing).

There is no such thing as a « golden contract », but even if there was, it couldn't entirely make up for a bad supplier or the wrong choice of supplier (see the previous section). Even with a "watertight" contract, the best you can expect is to minimise your expense, and (with careful monitoring) the time to the point where you decide to terminate the contract. It still does not guarantee a successful MST project! In addition, no supplier will sign an agreement accepting liability for consequential loss, i.e. the lost profits through late entry to the market because of delays etc.

Key Personnel

If you consider the supplier's performance to be dependent on the expertise of key expert personnel, their availability to work on your project should be written into the contract. At the very least, a contract or agreement should identify the person responsible for the project at the supplier's end. The impact of individual personnel may be inversely related to the size of the subcontractor: however key experts can have a big influence even in a large organisation.

If your own performance is dependent on certain key staff, you may wish to prevent the supplier from "poaching" or "head hunting" them from you during, or for a certain period after any contract.

Performance and Monitoring

Projects using an established process or design technique should be subcontracted on a "guaranteed performance" basis, with penalty clauses or deferred payment clauses if the supplier fails to perform. Projects involving process or design innovation may have to be subcontracted on a "best efforts" or "reasonable endeavours" basis which will limit the suppliers' liability considerably. But what does this mean? It is open to interpretation and the client and supplier can easily disagree as to what is "reasonable".

You must arrange an agreed schedule of design/process review and progress meetings. Clearly define pass/fail criteria for deliverables, e.g. have written screening, testing or acceptance procedure(s). Specifications, Test Procedures, formats for reporting and the overall workplan etc. should be in the form of annexes to the main supply contract. There will need to be an agreed mechanism for updating them if the need arises.

You should also specify an agreed level of record keeping by the supplier (e.g. to allow tracing of faulty devices back to a wafer batch) and the level of access to these records. Reference could be made to international standards the vendor is qualified to, e.g. ISO 9000. For process innovation or outsourced design, the design and process documentation the subcontractor must produce should be clearly defined.

You must specify the level and regularity of technical reporting by the supplier. A key indicator is yield information: this is critical to successful transition from prototype to production, especially where process innovation is involved. For instance: a supplier may be able to produce the required 10 prototype device samples. But if they have processed 20 wafers to obtain just 10 working samples, the design stands no chance of economical transfer to production without serious design or process changes. Yield information will mean you are aware of the situation.

Other logistical matters to consider are: split batch and/or MPW arrangements; mounting, packaging and delivery arrangements; prices, quantities, timescale and quality/reliability targets for re-production runs.

You must include provision for what happens if things go wrong. Firstly, the level of liability any party will incur in the event of damages, disputes, injury or negligence must be defined. The contract should also contain details of an arbitration procedure in the event of a dispute (e.g. the appointment of a mutually accepted independent expert as an umpire).

Detail the procedure to be followed if the supplier is failing to perform and any penalty measures in the event of a failure to perform. If there is a problem of this nature, do not delay in informing the subcontractor in writing and if necessary starting the arbitration procedure. The legal jurisdiction (e.g. country) the contract is to be interpreted or enforced under must also be made clear, since MST projects are very often international.

As well as good paperwork, a lot of the success in monitoring depends on the “psychological angle”. Regular face-to-face meetings allow you to fully communicate your feelings to the supplier about performance etc. If you agree a plan of action with the supplier to rectify a performance problem, you must be especially vigilant in keeping to it and making sure the supplier keeps to it. They could interpret any slippage on your part as an indication that you are not concerned about the timescale. Use every opportunity to give the supplier the message that you are serious about making the development a success and finishing on time and on budget.

In AE 25923 the First Users concluded:

« It is important to talk as much as possible to all people involved on the subcontractor's side to ensure that no misunderstandings grow. The exchange of written documents does not always help as they are not always carefully studied. »

If you are not contracting-out any of the supply management task, it is important to dedicate enough resource to it – AE 529:

« Co-operation with a sub-contractor demands special skills depending on the tasks performed, the communication level (president, manager, or engineer), the interaction of subcontractor with the project, plus the size and the experience of the subcontractor. It is ideal to have one employee completely focused on the project for the continuity, rather than an employee who has more tasks in the company and thus has to share his attention over more projects ».

Financial Basis

A fixed price basis for all subcontracted development work is strongly recommended. The alternative, fully variable price basis, should only be used with “open-book” accounting, but may be very hard to administer and control costs for. It is better to introduce a degree of variability through stage payments, a variable number of prototype iterations at a fixed price, etc.

You should agree a clear schedule of payments related to deliverables and timescale, referenced to workplan or technical annexes. State the amount and purpose of any up-front payment e.g. for process innovation (since such costs may not be recoverable from any of the supplier's other clients). Agree other variable costs such as prototype reiterations (re-spins). Obtain quotes for volume pricing, lead times and minimum order quantities.

It may be impossible to fix all the relevant costs up-front where process innovation is involved, but the supplier should be able to give an indication. It should however be possible to fix such prices for a standard process.

You must define each party's financial liability in the event of early termination of the contract. You also need to agree the actual or underlying currency basis (for instance, silicon wafers are always priced in $US – will the supplier guarantee prices if the EURO-$US rate varies widely?)

Confidentiality

Protect the confidentiality of your project by getting suppliers to sign a Non-Disclosure Agreement (NDA) before you start to negotiate with them. Suitable confidentiality clauses should also be built later into the main development contract(s). A supplier may ask you to sign an NDA with respect to their process details: try to avoid this until you are absolutely committed to using them.

You may need to define a procedure for any party to publish information about the project, either for academic or publicity purposes. Publication of key project details can give commercial benefits to either party without necessarily compromising confidentiality or IPR. It may also be a requirement if you are receiving public funding in any form.

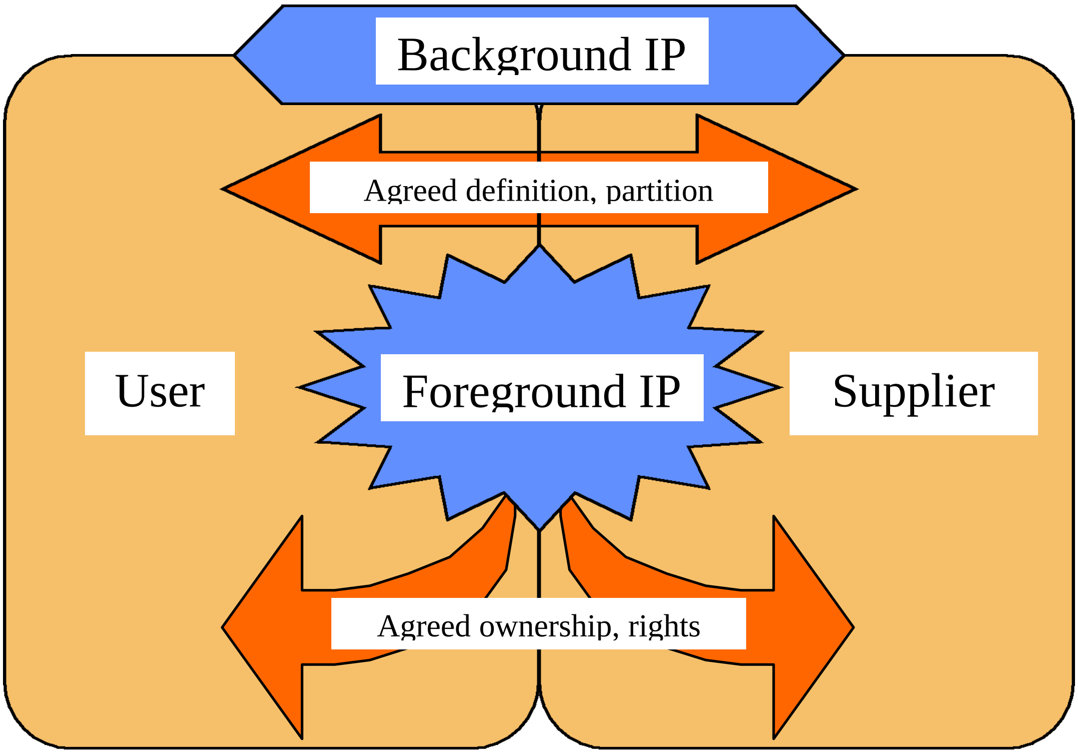
You may want to consider a clause preventing a supplier from working on a similar project for a competitor during the contract period. You may also wish to specify the level of physical security the supplier must provide, with reference to standards where applicable. Key documents and/or materials to be returned at the end of the project may also need to be specified.

With regard to confidentiality and finance elements in the subcontract, the TTN for AE 22824 reports:

> The agreement contains a confidentiality clause or non-disclosure agreement (the parties are tied for a period of 3 years) and a target price for volume production (this clause should prevent subcontractor from raising the component price). A payment clause (payment against milestone achievements) is included in the contract and payments are linked to the FUSE award cash flow.

Intellectual Property Rights (IPR)

Firstly, you must be clear about the difference between **background** IPR (also known as "prior art") and **foreground** IPR (rights to Intellectual Property arising directly from the project). Foreground may include inventions, "works" (including software), designs, « know-how » and « show-how ».



The Intellectual Property Picture

Establishing Background
Firstly, make sure that your own ideas do not infringe any existing patents etc., even if you are not going to patent them yourself. You may need to do a patent search, which can partly be done on-line, or better still get a patent agent to do a search for you. If you are infringing someone else's patent then ignorance is no defence and you could become liable for substantial royalties.

Secondly, insist on seeing evidence that your supplier(s) are also the true owners of the background IP they claim or get them to include an undertaking in the contract that they will take responsibility if their background turns out to infringe someone else's IPR.

It was only after one FUSE AE started that it became known that the supplier had given the rights to their patented technology away to another company. To furnish the first user with the necessary rights for building the sensor, many lengthy negotiations about licences took place. In the end, two contracts had to be worked out using the services of a patent lawyer: a license contract and a patent-use contract. This resulted in extra delay and expense and could possibly have destroyed the project completely.

The license contract assigned the end user an exclusive license for designing, manufacturing and selling the sensor in the food industry sector. The patent-use contract defied the royalty the patentee would receive for the use of the technology and that for this fee they were obliged to disclose full technical details of the technology to the end user.

Foreground
Firstly, you need to be clear about the distinction between design, product and process-related Foreground. With respect to ownership of Foreground, there are several options:

Where ownership is retained by subcontractor/supplier:

- Are you granted an exclusive license to use it?
- Or can the supplier use also license it for use on any other clients projects, or only clients that are non-competitors?
- Is any royalty payable?

Where ownership is retained by you, the end user:

- Are there any restrictions, e.g. on using a competing supplier or foundry?

In general, joint ownership of Foreground should be avoided.

Whoever retains foreground rights will normally be obliged to protect the IP (e.g. through patents), which may involve considerable expense. Where royalty payments are applicable, the precise value and other terms (such as regularity, duration, maximum value etc.) must be defined.

The duration of ownership and licenses needs to be defined. They may be assigned permanently or they may be defined to revert to the other party or lapse:

- After a certain time
- On non-performance or failure to exploit or protect the IP or license
- On company take-over or insolvency

Cancellation terms

Finally, you must establish the grounds for cancellation of any supplier agreement, as well as the precise cancellation procedure to be followed. There could be some “staged exit ” points e.g. if process innovation fails to succeed and all parties wish to withdraw at that point. Other grounds for cancellation could be:

- Non-performance of the supplier
- Supplier company take-over or insolvency
- Departure of key staff from supplier where relevant
- « Force Majeure »

You also need to allow yourself room to cancel the contract with minimum liability in the event of commercial problems internal to your own business, such as market collapse, bankruptcy of your own client, etc.

Appendix I – Extended Technology Choice Example

MICROSYSTEM FOR USE IN ASTHMA MANAGEMENT

AE number:	26793
First User:	Mediwatch
Contact TTN:	Glamorgan

AE Abstract

Mediwatch is a small company engaged in the design and manufacture of a number of diagnostic and prosthetic medical systems. The company has 15 employees of whom 4 are involved in electronic design and production. The company's existing product is the SPIROPEAK. This is a battery-powered, hand-held instrument, which is not only suitable for clinical use but also for more general use in respiratory monitoring. This includes fitness and general health especially in asthma and chronic obstructive pulmonary disease patients. It uses pressure measurement (as a secondary measure to direct flow) to determine the rate of airflow from the lungs (expiration). The current product is based on the use of microcontroller technology. The improved SPIORPEAK will utilise Microsystems technology to deliver a product that is significantly better than the existing system in several ways. These include.

- It will incorporate a micromachined differential flow sensor, which no other products currently use.
- It will have the capability of measuring bi-directional flow making it suitable for future products, which require inspiration measurement.
- It will greatly reduced in size making it convenient for transportation and use by children.
- It will be more accurate than the current product.
- It will be cheaper than the existing product costing 40 ECU as opposed to 140 ECU to manufacture.
- It will be easier to calibrate and less prone to drift.

The improved product will result in an increase of 22,000 units sold in the second year of manufacture, generating sales revenue increase of approximately 155%. The payback period for the investment in microsystems technology is approximately 6 months.

Flow Sensor

Possible measurement methods include:

a) Pressure - a differential manometer

Advantages	**Disadvantages**
i) Off-the-shelf technology	i) Obstruction to air flow
ii) Relative simple technology	ii) Turbulence causing non-linearity
	iii) Cost and size - both large
	iv) Drift and stability - both poor
	v) Difficulty with cleaning
	vi) Hysteresis

b) Turbine

Advantages	**Disadvantages**
i) Direct digital output	i) Poor response time due to inertia ii) Poor repeatability - because of friction iii) Problems with bearing contamination iv) Expensive v) Not bi-directional

c) Fluidic Oscillator

Advantages	**Disadvantages**
i) Pulse output ii) Simple construction iii) Cheap	i) Poor resolution at low flow rates ii) Create turbulent flow iii) Create back pressure iv) Not bi-directional

d) Hot wire/film Anemometer

Advantages	**Disadvantages**
i) Simple construction ii) Cheap in volume iii) Bi-directional iv) Cleanable v) Accurate	i) Requires control circuitry ii) Mainly used at low flow rates below 200 1/m

Thus the selected approach is to use a film type anemometer. The sensitivity of this device depends on the film and the support having low thermal inertia and high thermal insulation from the surrounding structure.

Operation

Thin film thermally isolated microstructures utilising the thermoresistive effect are commercially available as effective hot wire anemometers. These devices comprise of adjacent heaters and resistive detectors. In operation, gas flows over the sensor surface and heat is transferred from the heater to a detector. Due to the advances made in thin film technology these devices offer a very large temperature response over a broad range of flow velocities. When packaged in a suitable gas flow channel to provide laminar flow the sensor response can be calibrated for velocity, mass flow or differential pressures. This type of sensor combines the advantages of high sensitivity with small size, low power and low cost.

Redesign of the Sensor

A survey of commercially available micro-machined flow sensors has been performed and a number of potential suppliers identified. Of the companies reviewed some are small start-ups offering sensors that have recently been commercialised. Other devices are well established and have a proven track record. An evaluation of the sensors and services supplied by the companies in terms of flow rate and

media compatibility has resulted in the products from two suppliers being chosen as likely to achieve the requirements of Mediwatch in terms of performance, size and cost.
The key modification required with the hot wire anemometer so far as this project is concerned is achieving measurements at the flow rates required (up to 800 l/min).
Most micro-engineered hot wire anemometer sensors currently available function at flow rates below 200l/min. For this reason a modification to the sensor housing is required to compensate for the higher flow. Fig 3a shows the standard housing designs for a silicon hot wire anemometer sensor.
A common way of measuring the flow rate range of such sensors is with a bypass. This is an alternate flow channel for the main flow. Only a sample of the flow (well within the normal sensor operating level) actually goes through the sensor. The smaller the bypass ratio, the better behaved the output. Fig 3b shows a simple bypass system. A screwdriver can be used to adjust the bypass ratio from the initial value of greater than 100 to 1, to the desired final bypass ratio. In this project the flow shunt will need to be redesigned and alternatives evaluated to minimise its size.
Another problem with the hot wire anemometer sensor is due to the influence of humidity on the characteristics of the sensor. In order to overcome problems associated with humidity a simple membrane across the mouth of the shunt to protect the channel from moisture can be easily implemented. In this project a number of filters will need to be evaluated to ensure that the performance requirements are met.

Risk Analysis of Proposed Sensor Modification

In general for micro-engineered sensors the packaging development to suit the application is significantly more challenging and costly than the sensor die development. This applies to the flow sensor required by Mediwatch. In the original proposal no mention was made of the packaging. Only the development of the flow sensor die was addressed and it was not clear which company would address the packaging of the sensors and by what means. The risks perceived in the current development are outlined in table 3.

Low risk = 1. High Risk = 5.

Risk	**Level of Risk**	**Reason**
Failure to develop a sensor housing that will meet the required specification	1	Previously demonstrated by manufacturers of sensors, designs already exist.
Failure to develop suitable hot wire sensing die	1	Die is already commercially available from a number of suppliers. This risk is therefore significantly reduced compared to the original proposal
Failure to identify a suitable filter to avoid moisture ingress onto the sensor	2	Filters are already included in packages provided by the manufacturers.
Failure to address the high flow range required	1	Sensors are already available which by using flow shunt address this range.
Failure to modify existing sensor housing within budget available	2	Budget analysis already performed.
Failure to develop a sensor housing suitable for large volume production	1	Analysis of requirements already performed
Failure to meet size constraints	1	All micromachined hot wire anemometer sensors are based on silicon die of the order of 3 mm square by 1 mm thick. Figures show commercially available packaged sensors that include moisture filters and flow taps to address

the high flow range required. This requirement can be achieved by a suitable layout of the board.

Packaging

An interim packaging scheme will be developed to permit the proposed device to be easily handled and assembled into a demonstration prototype system. The packaging will allow for easy connection to the electronics and external accessories. In the short-term this is likely to be in the form of a simple small printed circuit board and utilising wire mount and surface bonding techniques. For practical purposes to enable ease of testing and incorporation into a prototype system the sensor will be on one side of this PCB and the associated electronics on the opposite face.

Possible methods include:

MCM

Advantages	Disadvantages
i) High integration, small package size	i) High NRE cost
ii) Less risk of plagiarism	ii) High risk
	iii) Required to have sensor exposed to airflow

PCB and SMT

Advantages	Disadvantages
i) Low risk	i) Lower integration than MCM
ii) Small NRE cost	

Because Mediwatch have used PCB and SMT technologies in the past they are well placed to manage this aspect of the experiment and will utilise this technology as part of the improved product.

Development Methodologies

Sensor

- Simulation
- Choice of materials
- Physical design
- Fabrication.

The Electronics

Possible technologies include

PLD & FPGAs

Advantages	Disadvantages
i) Simple to implement digital circuitry	i) Design requires analogue circuitry - not possible with this technology
ii) Low risk	

Discrete Components

Advantages	Disadvantages
i) Low risk ii) No NRE costs	i) Size - low integration means more bulky design ii) Manufacturing cost iii) Plagiarism

Mixed Signal ASIC

Advantages	Disadvantages
i) Analogue & digital circuitry all integrated ii) As an array the design is simple and low risk iii) Economic in volume iv) Design security v) Testability	i) Higher NRE costs than programmable devices

Although it was originally proposed to use an analogue ASIC, this will not now be possible given the change in supplier's terms and conditions for the production of the ASIC. The proposed solution will therefore be based on standard discrete components.

Microcontroller

The existing product microcontroller will be used as part of the application experiment. Mediwatch will fund the development of the software for this component. Mediwatch has experience with this technology and have included it in a number of its other products.

Appendix II – Full Workplan Example

OPTOELECTRONIC MICROSYSTEM FOR ENCODERS

AE number: 24575
First User: ELTRA
Contact TTN: COREP

AE Abstract:

The company Eltra (Italy) is a small enterprise that designs, produces and sells encoders for heavy industrial applications. In this AE the company has developed a microsystem based on optical sensor and electronics on chip that will replace discrete analog devices in their main incremental encoder product. The dedicated ASIC is specifically designed to work with photodiodes either integrated on chip (microsystem) or external (MCM - Multi Chip Module): its main characteristic is flexibility in order to operate in different applications. The design of the package has to foresee the possibility of using an opto-Asic or an ASIC chip with external photodiodes already available for this specific optoelectronic application. In such a way the microsystem chip permits a "universal" approach so that it is possible to substitute the huge variety of the discrete components.
Advantages of this microsystem are component cost reduction, easier assembly, better yield and performance, improved noise rejection and smaller dimensions. In addition this microsystem can be utilised also on high-resolution encoders therefore opening wider market opportunities.
The company has 37 employees with 2 involved in the electronic development. The total cost of the application experiment is 110 KECU and it has been completed in 12 months.

Tabular Workplan

Each Workpackage has a clearly defined aim, task breakdown and definition of each partner's role.

WP1 - Training and specifications

Ø Aim: specifications definition and personnel training

- § T11 - microsystem specifications (2 months)
- § T12 - simulation of both the design and the technology for the ASIC and the photodiode (2 months)
- § T13 - simulation of both the design and the technology for the microsystem package (2 months)
- § T14 - training of First User technicians (1 month)

Ø Role of First User and Subcontractor

- § First User: microsystem specification
- § Subcontractor1: choice of the design and fabrication of the ASIC
- § Subcontractor2: choice of the design of the package, technical training

WP2 Design

Ø Aim: design of the ASIC and the microsystem package

- § T21 - package design (3 months)
- § T22 - ASIC design (3 months)
- § T23 - package serigrafic masks (1 month)
- § T24 - ASIC reticules (1 month)

Ø Role of First User and Subcontractor

- § First User: supervision
- § Subcontractor1: ASIC design and reticules
- § Subcontractor2: package design and serigrafic package masks

Time-Line Workplan (Gantt Chart)

Showing planned vs. actual deviation.

	Mon. 1	Mon. 2	Mon. 3	Mon. 4	Mon. 5	Mon. 6	Mon. 7	Mon. 8	Mon. 9	Mon. 10	Mon. 11	Mon. 12
	05 / 97	06 / 97	07 / 97	08 / 97	09 / 97	10 / 97	11 / 97	12 / 97	01 / 98	02 / 98	03 / 98	04 / 98
WP1												
T11	PLAN											
	REAL											
T12	PLAN											
	REAL											
T13	PLAN											
	REAL											
T14		PLAN										
		REAL										
WP2												
T21			PLAN									
			REAL									
T22			PLAN									
			REAL									
T23					PLAN							
					REAL							
T24					PLAN							
					REAL							
WP3												
T31						PLAN						
						REAL						
T32						PLAN						
						REAL						
T33									PLAN			
										REAL		
T34										PLAN		
										REAL		
T35											PLAN	
											REAL	
WP4												
T41												PLAN
												REAL
T42												PLAN
												REAL
	M1	M2			M3		M4	M5	M6	M7	M8	M9

First User's Comments and Conclusions

Thanks to the guidance of TTN we were able to manage the AE all along its development.
We have obtained the scheduled results as they have presented in the original proposal, the tasks have been concluded on the scheduled time and the only delay has been for the ASIC fabrication.
In particular the ASIC fabrication was foreseen to last three months but it took one month longer for the device testing.

The following tasks recovered the lost time, particularly tasks T33 and T34, whose duration was halved, allowing the task T35 realignment. Thus the AE was completed in the planned time. This was possible thanks to the two Sub-contractors that worked together with very good collaboration.

Before this project, ELTRA did not plan its activity as well as we have done for the AE. Probably the best lesson learned is to plan the activity with scheduled times, deliverables, tasks and milestones. This lesson gave us also a valid help to be used in the ISO9001 certification that has been obtained during the period of the AE.

The main difficulty encountered during the AE feasibility study was to acquire a correct planning methodology to be used for this project. As mentioned before, this was the main positive lesson learned, but at the beginning phase the main difficulty too.

During the implementation phases several technical documents and progress reports were produced for each AE working month. Probably too many documents were foreseen at the beginning of the AE and, for this reason, during the implementation phase a lot of time was dedicated to document writing.

We consider that for a small company like ELTRA, involved in the AE to study and to realise a new encoder with a new microsystem with ASIC, probably more time was to be dedicated to the real working phases while some documents could be written not for every month but for a quarter.