

Strategic Outsourcing of Micro-Electromechanical Systems (MEMS)

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BAS Systems Engineering, University of Pennsylvania 1997

BSE Finance, University of Pennsylvania 1997

MS Accounting, Babson College 1999

Submitted to the Sloan School of Management and the
Department of Civil Engineering in partial fulfillment of the
Requirements for the degrees of

Master of Business Administration

And

Master of Civil and Environmental Engineering

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Massachusetts Institute of Technology

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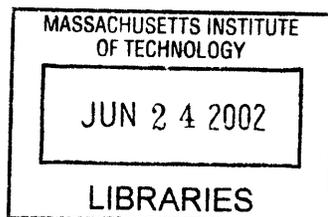
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Abstract

ABB Automation is starting to experiment with Microelectrical Mechanical Systems (MEMS) as an enabling technology for their products. If ABB's implementation of MEMS is found successful, it will be able to create breakthrough products and services that will revolutionize the market in ABB's industrial sensors, instrumentation and analytical areas.

The thesis begins with a description of ABB as a company and then provides a brief overview on MEMS and the challenges ABB faces as it tries to commercialize MEMS enabled products. A literature review is also included to explain how companies can better profit from technological innovations such as MEMS.

An analysis of ABB's decision to outsource MEMS is described with multiple frameworks including a vertical integration versus outsourcing model as well as a traditional make or buy decision assessment from a financial perspective. The decision to outsource is valid given the stage of the technological life cycle and the company's resolution to use MEMS in selected products. Since the strategic fit argument is still questionable through much of ABB, outsourcing is a legitimate choice for MEMS. Outsourcing allows a greater amount of flexibility and the least amount of capital investment.

Although ABB has decided to outsource its MEMS capabilities, it has to realize that there is a possibility of vertical market failure with MEMS. There are very few suppliers in the market today with potentially fewer in the future as mergers and acquisitions begin to take place once a dominant design is established. This vertical market failure encourages vertical integration and not outsourcing.

Thesis Advisors:

Donald Rosenfield, Sloan School of Management

James Masters, Department of Civil and Environmental Engineering

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0. Thesis Overview

ABB Automation is starting to experiment with Microelectrical Mechanical Systems (MEMS) as an enabling technology for their products. If ABB's implementation of MEMS is found successful, it will be able to create breakthrough products and services that will revolutionize the market in ABB's industrial sensors, instrumentation and analytical areas.

The goals and objectives of this thesis include:

- Establish an understanding of ABB's interest in MEMS by collaborating with ABB's business unit and research and development center
- Assess the current MEMS industry and major players
- Benchmark other corporations utilizing MEMS in their manufacturing
- Develop database of MEMS supplier information to provide organizational backbone for future projects
- Create appropriate supplier relationships for ABB in MEMS
- Establish approaches for developing supplier relations for an emerging technology

The 6 month thesis research and internship took place at ABB's Corporate Research Center (CRC) in Heidelberg and Ladenburg, Germany.

1. Introduction to ABB

1.1 Organization Structure

ABB headquartered in Zurich, Switzerland was formed in 1989 when the CEO at the time, Percy Barnevik, merged ASEA AB of Västerås, Sweden and BBC Brown Boveri Ltd of Baden, Switzerland to form one of the largest European engineering firms. Each parent company is to hold 50 percent of the new company.

ABB today serves four customer segments: Utilities, Process Industries, Manufacturing and Consumer Industries and Oil, Gas and Petrochemicals. When the current President and CEO, Jörgen Centerman, joined the firm on January 1, 2001, Centerman quickly reorganized the company to emphasize focus on these customers segments. Centerman hopes this reorganization will facilitate growth by delivering value to the customers.¹ The organization will provide end users with better access to the full range of ABB's products, services and solutions.

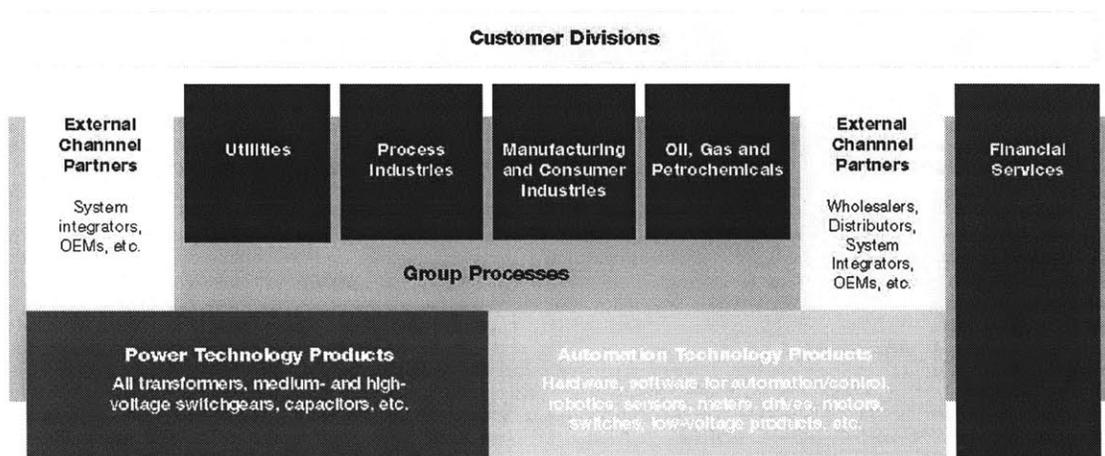
The two product segments, Power Technology Products and Automation Technology Products, will serve the product needs within the ABB. The product segments will also directly service external channel partners, such as distributors, wholesalers, system integrators, and OEMS.

The Financial Services segment continues to provide services and project support for ABB and for its customers. Meanwhile, a New Ventures division was formed to act as an incubator for new businesses and to identify, invest, and accelerate the development of new business opportunities. Centerman states that new technologies continue to be a key driver of growth with the R&D organization remaining critical.² One such emerging technology is Micro-Electromechanical Systems (MEMS.) ABB has chosen to focus its MEMS research in the field of sensors and instrumentation. Specifically, ABB projects in MEMS include gas sensors and fluidic micro components, mechanical sensors and actuators , Optical Sensors, Inductive and capacitive sensors, Spectroscopy, Mechanical

¹ www.abb.com

sensors, Sensor electronics, Intelligent data and signal analysis and Physical modeling. With cooperation with ABB businesses, the research and develop centers are working to formulate complete solutions that meet the needs and technological demands of customers in automation, oil and gas, power, and processing industries. I will discuss the significance of this decision in later chapters.

ABB employs 160,000 employees with approximately 400 factories in more than 100 countries. Sales revenue in 2000 amount to USD 23B with earning before interest and taxes (EBIT) rising 23% to USD 1.345B. In 2000, ABB also finalized its divestiture of ABB Alstom Power to Alstom in France and completed its exit from large scale power generation to focus on small scale alternative energy sources as in wind power, microturbines, and fuel cells.



Source: www.abb.com

1.2 Key ABB Principles

ABB has three guiding principles that align all employees to meet the goals and objectives of senior management.

² www.abb.com

Decentralization

ABB is a highly decentralized organization that operates in over 100 countries that encourages results-oriented action as a means to create value. ABB is constantly reviewing decision making processes to remove bureaucratic barriers while reducing lead time to making decisions. Innovative solutions are actively sought with significant amount of employee empowerment. This paper will later discuss how this has supply chain ramifications with complicated supplier relationships.

ABB needed to establish a structure after the merger of Asea and Brown Boveri. Barnevik decided to use a decentralized structure within a global matrix. Since then there have been numerous acquisitions that were added. However, the decentralized organization allows these acquired companies to maintain their own structure and culture with their own profit and loss responsibilities.

ABB companies are small in size to foster rapid reaction to industry or customer demands. Profit centers are encouraged to create their own identity and culture to encourage a sense of employee belonging and ownership. Barnevik told Business Week, "We are fervent believers in decentralization. When we structure local operations, we always push to create separate legal entities. Separate companies allow you to create real balance sheets, with real responsibility for cash flow and dividends."³

Flat Organization

ABB was recognized internationally for its unique matrix structure that was sorted by business and geographic regions. Originally the business group and regional group had equal power. However as competition became more global and as electrical power industries were deregulated in 1998, the senior management decided to decrease regional leaders' role. Today the regional leaders' role is to encourage improvement initiatives within their regions, while business leaders are responsible for strategic business decisions across their BA or BU.

Global-local

With ABB working in over 100 countries, ABB strives to make its customers more competitive in a networked world by helping them gain competitive advantage from

technology advances and developments in their markets. ABB can accomplish this by leveraging its comprehensive Industrial Information Technologies that combine world class products and services with superior domain knowledge and collaborative commerce.

ABB needed to reduce the complexity resulting from the regulation of the electrical power and transmission industries in each country, a major part of their business at the time of the merger. Local knowledge was required, while product or group strategies could not be decided on a high level due to market and product diversity.

1.3 Role of Corporate Research

ABB spends 8% of its turnover back into research and development at its corporate research centers (CRC) in Finland, Germany, Italy, Norway, Poland, Sweden, Switzerland, and the United States. 75% of ABB's business is based on new developments of products that were non-existent five years ago. Its breakthrough technologies are in the following fields: Automation Technologies, Sensors and Communication, Power, Power Electronics, Oil, Gas and Petrochemicals, Mechanics, Manufacturing Technologies, and Engineering Systems and Software Engineering.

As the company moves towards a focus on customers, ABB's research and development is setting up its product portfolio for growth based on a "One Team" approach. The entire R&D organization will resemble a worldwide network of individual R&D centers each with a specialized mandate. Key areas of work at each CRC will be determined to reduce overlap of resources and encourage global thinking and activities. Each project is to have market orientation that is fully coordinated with a division's technology strategy, which will ensure the right balance between "market pull" and "technology push".⁴

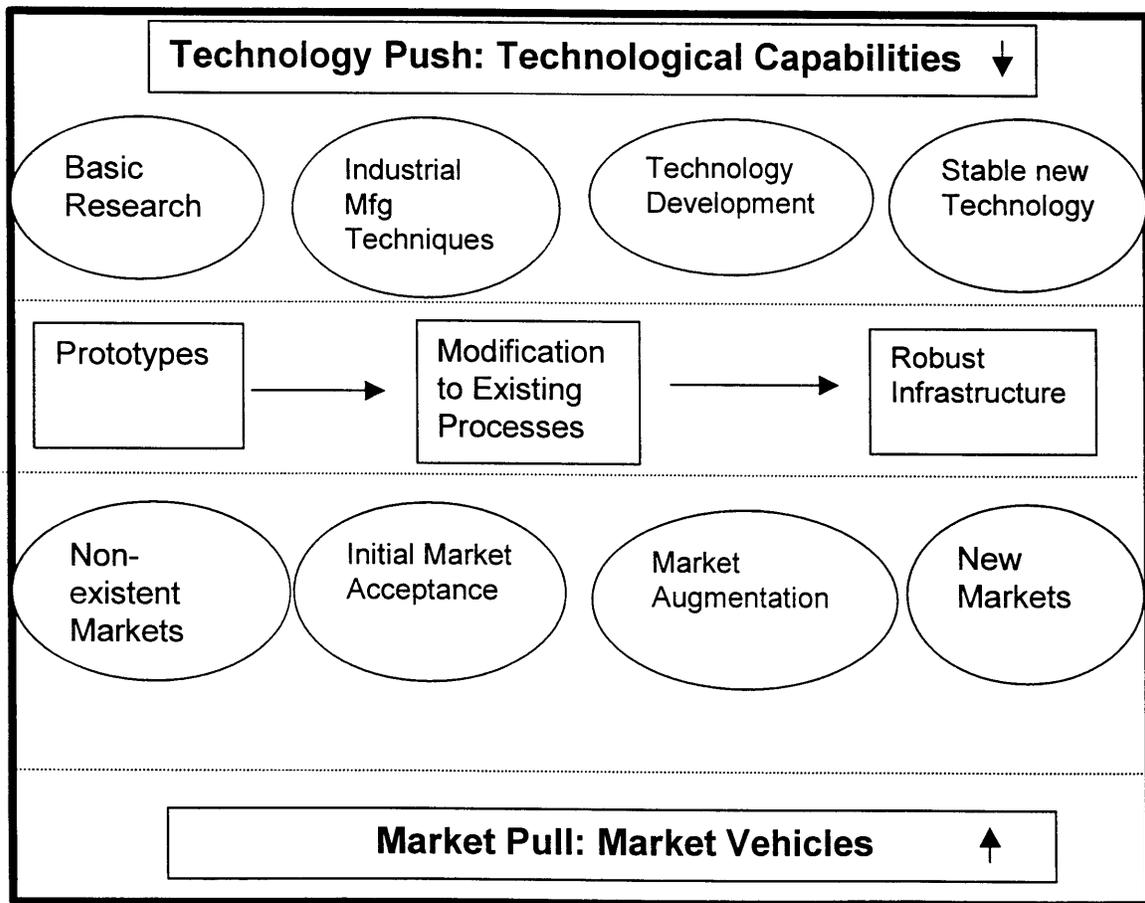
However, there is a need for balance between "market pull" and "technology push." It is very difficult for the business units to be completely aware of the available technologies and their valuable uses. Likewise, it is not possible for corporate research to be fully

³ Business Week, "Mr. Barnevik, aren't you happy now?", 1993.

⁴ Walsh, "Infrastructure Considerations for the Emerging MEMS,"

knowledgeable of the market and its needs. Therefore, there is a natural imbalance of information.

The technology push and market pull is illustrated below in a model below adapted from "Infrastructure Considerations for the Emerging MEMS" by Walsh et al.



In a webcast made by the Chief Technology Officer, Markus Bayegan, professional technology management of ABB's R&D was described in detail to include:

- Gate Models and Valuation Tools (to provide a systematic selection, execution, and implementation of R&D projects)
- Business Technology Evaluation (to understand competitors, customers, and technology)
- Strategic University Projects (to foster new ideas and support basic research fruitful for ABB's needs and interests at schools such as MIT, Stanford)
- Technology Reviews (to understand ABB's position in the market)

2. Background on MEMS

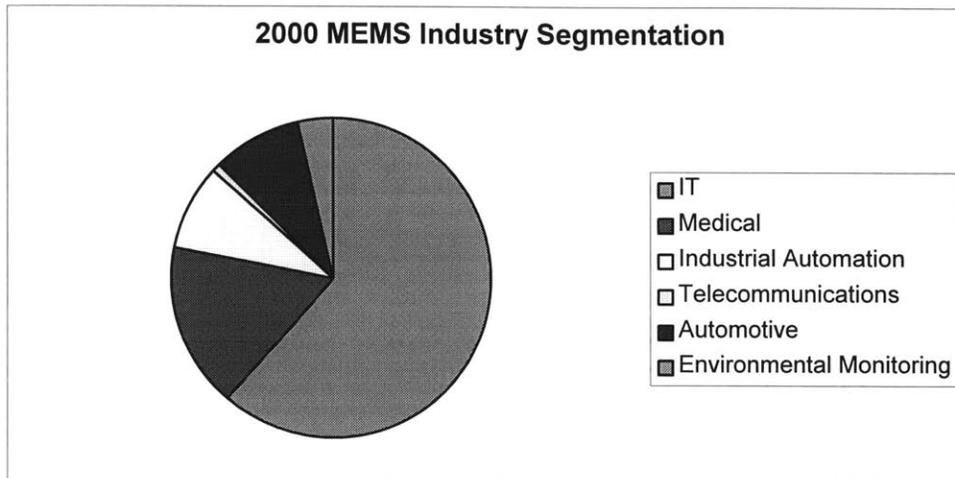
2.1 What is MEMS?

The term "Microelectromechanical systems (MEMS)" was defined in 1954 by C.S. Smith, who discovered that silicon membranes could sense pressure better than metal ones. MEMS is a technology that involves the miniaturization of complex systems using physical effects not applicable to conventional macro system. MEMS devices are small electrical and mechanical devices made using fabrication techniques borrowed from the semiconductor industry. Physical fabrication procedures include lithography, etching, deposition, etc, just as they are in semiconductor fabrication. MEMS have motivated a diverse set of applications. MEMS enabled products to date include airbag sensors used in the automotive industry to drug delivery systems in the medical industry to optical switches in the telecommunications industry. In the miniaturization process, forces related to volume, like weight and inertia, tend to decrease in significance while forces pertaining to surface area, such as friction and electrostatics, tend to become increase.

The MEMS industry today is estimated to be valued at over USD 2 billion with about 45% annual growth by Semiconductor Equipment and Materials International (SEMI), an industry organization.⁵ The MEMS industry can be segmented into Information Technology (IT), Military and Aerospace, Industrial Automation, and Medical. In 1999, the segmentation could be graphically shown as follows. The chart indicates that non-IT

⁵ www.semi.org

segments can be considered growth areas. Currently, much of the MEMS devices in those segments are only in prototype stages and have not been produced in volume as of yet.



Source: www.semi.org

The telecommunications industry is showing the most promise in terms of mass market application. MEMS has been used for optical switching of signals, multiplexers, filters, modulators, detectors, attenuators, and equalizers resulting in enhanced fiber communication. Nortel, Corning, and JDS Uniphase each acquired XROS for USD 3.25 billion, 67% of Intellisense for USD 500M, and Cronos Technologies for USD 750 million in stock respectively to further develop their inhouse MEMS capabilities.⁶

Radio frequency (RF) MEMS are also being developed for cellular and wireless communications. The MEMS versioned microwave functions will replace existing generations of receivers and is expected to be commercialized by 2005. Currently, Raytheon is a company highly active in this field of MEMS.

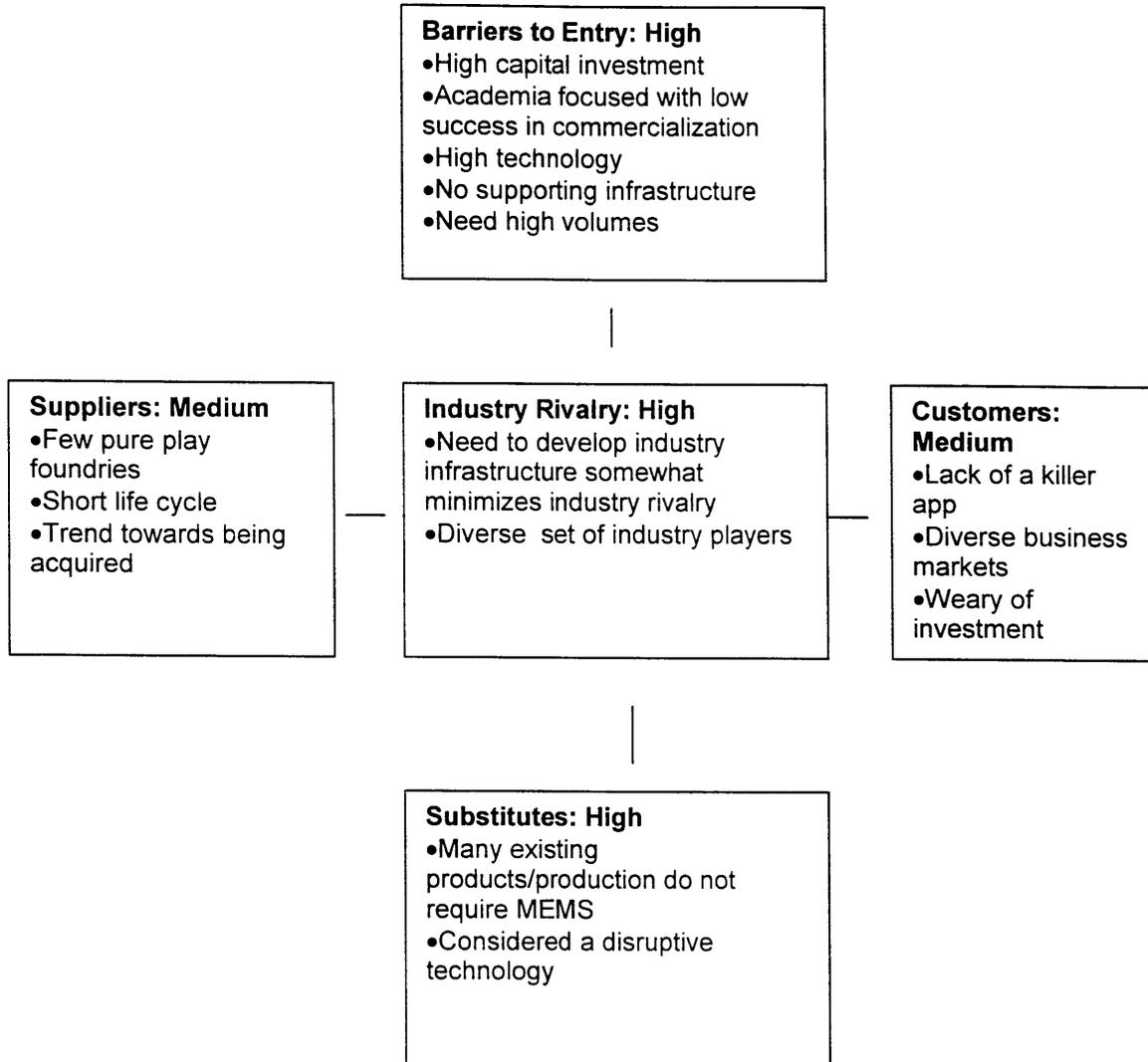
Using a Porter's Five Forces framework⁷, the MEMS industry is a highly competitive one. There are extremely high barriers to enter the market. Many of these barriers will translate into factors that make commercialization difficult. Therefore, they are

⁶ Riestelhueber, , "JDS Uniphase spends \$750M for optical MEMS maker"

⁷ Porter, Michael E., Competitive Strategy : Techniques for Analyzing Industries and Competitors

mentioned briefly below and will be described in greater detail in Chapter 3. Another reason for a competitive industry is that the technology is considered to be a disruptive technology. Disruptive technologies have potential to replace existing technologies. Unless the advantages of using this technology is proven and the benefits highly quantifiable, it is difficult to motivate firms to adapt MEMS. While a disruptive technology initially is inferior to current technologies on the market, successful disruptive technologies displace the existing technologies. Further discussion on disruptive technologies is described later as a significant challenge to the commercialization of MEMS. Therefore, all existing technologies are considered substitutes to MEMS. Although the number of potential customers is high, no killer application has been found to introduce MEMS to the mass market.

Porter's Five Forces applied to the MEMS Industry⁸



2.2 Sensors and Actuators

There are two main types of MEMS devices, sensor and actuators. Sensors can measure the environment without altering it while actuators can interact with the environment through pumps, valves, or nozzles. Sensors are used to measure pressure, temperature, acceleration, or flow. Actuators include micronozzles and microvalves.

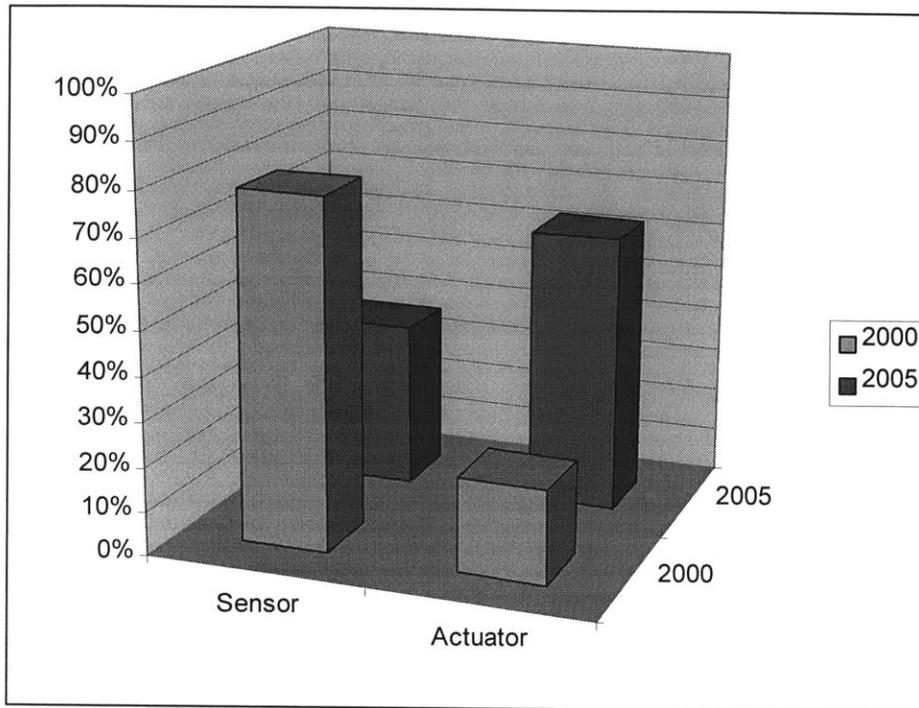
⁸ Adapted from Porter, Michael E., Competitive Strategy : Techniques for Analyzing Industries and Competitors

Sensors and actuators are 44% and 56% of the MEMS market respectively with greater growth to be expected in the actuator market as cost of fabrication begins to decline.⁹ Actuators are currently costing over \$1000 while sensors cost only a few dollars to manufacture. Examples of these MEMS devices are shown below.

MEMS Sensors	MEMS Actuators
Acceleration	Filter
Angular-Rate	Nozzle
Inertia	Pump
Pressure	Relay
Strain	Switch
Temperature	Valve

⁹ The Little Chips That Could: A MEMS Industry Overview and Forecast, Cahners In-Stat Group

Market Share for Sensors and Actuators¹⁰



Sales of Sensor and Actuators (\$M)

	2000	2001	2002	2003	2004	2005
Sensors	2,544	2,741	2,999	3,375	3,901	4,812
Growth Rate		8%	9%	13%	16%	7%
Actuators	686	1,132	1,801	2,672	4,190	7,090
Growth Rate		65%	59%	48%	57%	69%
Total MEMS	3,230	3,873	4,799	6,047	8,090	11,273
Growth Rate		20%	24%	26%	34%	39%

2.3 Current Status of MEMS

MEMS is currently the newest enabling manufacturing technology for a great more applications. The multi-disciplinary technology is bringing together numerous fields to

¹⁰ Cahners InStat Group

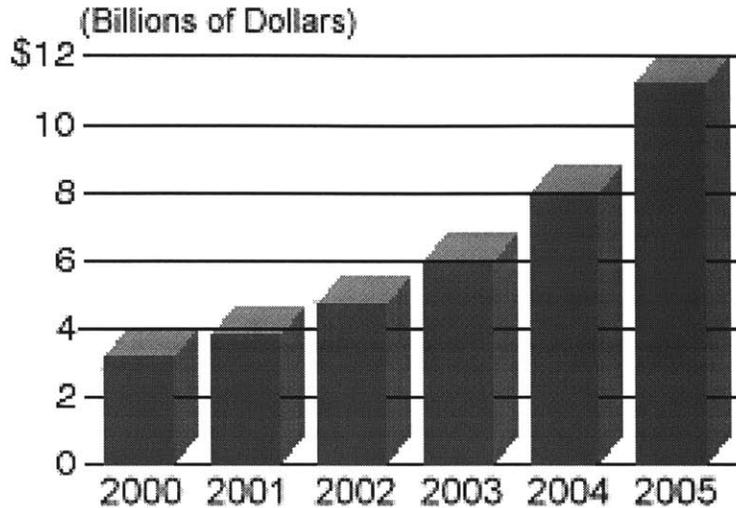
develop applications, from biologists to physicists to radiologists. The MEMS industry has been following trends exhibited in the semiconductor industry over thirty years ago. Like in semiconductors back then, early research and development was funded by governmental grants. However it has since pursued commercialization opportunities by taking their technology and using it to produce devices in production volumes. MEMS is expected to do the same.

Due to the miniscule size of MEMS, it is possible to use them in places where conventional macroscopic mechanical devices could not previously be put, such as inside a blood vessel of a human body. New MEMS applications in development are in optical switching that use MEMS technology to facilitate web browsing, telecommunication for increasing bandwidth, and even high definition television for sharper images.

The medical field will adopt MEMS technology in its monitoring devices for the future. MEMS enables faster, more accurate, and less expensive alternatives to current medical equipment. Current applications include blood pressure monitoring, eye surgery, blood analysis, kidney dialysis machines, inhalers, patient activity monitoring but solutions for the future include personal home care and monitoring systems for patients who do not require hospitalization.

This growth in the MEMS industry can collaboratively be illustrated in the diagram below. However, past experience has showed success for MEMS in only certain small niches such as information technology and the medical field. Venture Development Corporation has found the largest volume of MEMS devices sold is in the hard disk drive heads market with process variable sensors coming in second. Therefore, although dramatic growth is expected, the industry must develop better infrastructure to support more mainstream acceptance of MEMS.

Worldwide Forecast for MEMS



Source: Cahners In-Stat Group

Top Applications of MEMS¹¹

	2000	Percentage	2005	Percentage
1	Automotive	26.0%	Photonic Switches	24.4%
2	Industrial Equipment	14.7%	Projection Systems	14.6%
3	Ink Jet Printing	9.5%	Relays	14.0%
4	Projection Systems	8.2%	Automotive	11.6%
5	Blood Pressure Monitoring	4.4%	Industrial Equipment	6.9%
6	Consumer Electronics	4.0%	Ink Jet Printing	6.0%
7	Biochip	1.6%	Biochip	4.0%
8	Photonic Switches	0.8%	Blood Pressure Monitoring	2.2%
9	Medical Devices	0.6%	Telecom Lasers	1.7%
10	Medical Instruments	0.4%	Telecom Filters	2.9%

¹¹ The Little Chips That Could: A MEMS Industry Overview and Forecast

2.4 What is micromachining?

MEMS fabrication has adopted many of the same processes as those existing in the semiconductor industry. Replacing traditional mechanical equipment such as milling machines, lathes and grinders, MEMS utilizes photolithography aligners, reactive ion etchers, vapor deposition techniques and several new techniques unknown and in some cases prohibitive to the semiconductor industry..

Silicon is the most popular substrate material, but plastics and metals are also used. The material used depends on what desired characteristics the final device ought to have. MEMS fabrication is complicated by the usage of numerous processes that must be incorporated to produce a device. MEMS components can incorporate a variety of bulk micromachining, surface micromachining, LIGA, and nontraditional processes. Nontraditional processes include CMOS MEMS, micromolding, bonding two wafers together, deep reactive ion etching (DRIE), and deep anisotropic wet etches using etchant chemicals such as KOH, TMAH, or EDP. The general process of fabrication begins with silicon, silicon oxide, or metal, that is deposited on a substrate by either evaporation, sputtering, or vapor deposition. These films are then coated with photoresist. A mask is applied to the film with a desired pattern and then exposed to UV light. The unchanged areas of the film are then etched away either by a chemical etch or a reactive ion process. These steps are then repeated until the final device is obtained.

Bulk Micromachining

Bulk Micromachining is a subtractive process that removes a large portion of the substrate. This process requires less precision and is less expensive compared to surface micromachining. This enables taller structures to be fabricated because the initial substrate material can be thicker. Cantilevers, beams, membranes, cavities, and channels can be etched into these wafers to fabricate devices. Single crystal silicon due to the smooth and fatigue resistant characteristics allows for reliable and ideal usage in optical switches or inertia sensors. Glass is popular for integrated optics devices as in power combiners and microgyros as well as for packaging purposes.

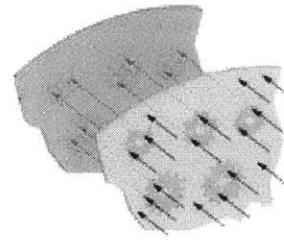
Surface Micromachining

Surface micromachining is an additive process that involves building up layers of materials that have exposed to lithography, deposition, and etching. This process can be used to create gear and hinge devices. Surface micromachining tends to yield low stress features and smooth surfaces. Wafer bonding processes have enabled the use of thicker films to build structures with added height.

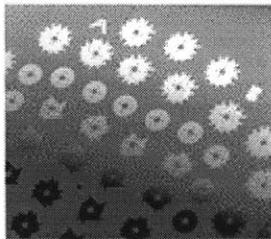
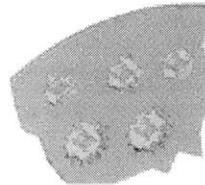
LIGA

LIGA is a German acronym for lithography, plating, and molding. LIGA uses X-ray radiation to etch a photoresist die mounted on a silicon wafer. By using the penetrating power of x-rays from a synchrotron, LIGA allows the fabrication of structures to have vertical dimensions from hundreds of microns to millimeters and horizontal dimensions which can be as small as microns. These are 3-D microstructures defined by 2-D lithographic patterns. Then pure nickel is electroplated into the die. The LIGA process is capable of 0.1 μm resolution with a minimum feature size of 10 μm and is mostly limited to two-dimensional shapes. The final device can have a height of up to 1000 μm . These patterns are then electroplated to create three dimensional molds. LIGA allows many different materials to be used and resulting structures can have a high ratio of height to horizontal dimension, or a high aspect ratio. The height-to-width ratio capability is relevant to the manufacturing of miniature components that can withstand high pressure and temperature, and can transfer useful forces or torques. The material flexibility also offers opportunities to fabricate miniature components using LIGA instead of precision machining approaches. The feature definition, radius, and sidewall texture using LIGA are superior to current precision machining techniques.

- X-rays from a synchrotron are incident on a mask patterned with high Z absorbers. X-rays are used to expose a pattern in PMMA, normally supported on a metallized substrate.

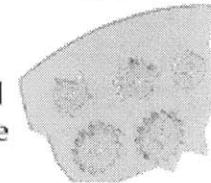
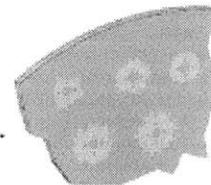


- The PMMA is chemically developed to create a high aspect ratio, parallel wall mold.



photograph of chrome mask

- A metal or alloy is electroplated in the PMMA mold to create a metal micropart.
- The PMMA is dissolved leaving a three dimensional metal micropart. Individual microparts can be separated from the base plate if desired.



Source: <http://www.ca.sandia.gov>

MEMS foundries have attempted to “mass customize” their products by developing a standard set of process modules and by configuring an optimal process flow. Some of these process flows have been adapted from semiconductor manufacturing while others are MEMS specific. Intellisense, a MEMS foundry, has estimated that 80 percent of the processes come from semiconductors and 20 percent are unique to MEMS.

2.5 Lab on a Chip

Many companies, as is ABB, are currently pursuing the development of “lab-on-a-chip” devices. Such a chip will contain MEMS structures that will be able to sense physical phenomena, then use logic to process the information, and finally control an actuator that will control a physical phenomenon in response. The ultimate goal is to combine Complementary Metal Oxide Semiconductor (CMOS) circuitry and MEMS structures into one single process flow.

One such development has been used for DNA testing. The chip allows for metering, measuring, and mixing microscopic liquid samples of DNA with reagents, moving the mixtures to an integrated, temperature-controlled chamber, separating DNA molecules by, and determining the results with a detector.

All components are contained on a single glass-and-silicon wafer, except for external light and air-pressure sources and a printed board containing control circuitry. Costs are reduced through the 1) increased processing speed, 2) lower expenses for labor, equipment, and material; and 3) lower manufacturing costs production through photolithography. The end cost of producing the DNA-testing chip in research-sized quantities may be approximately \$6 per device with mass production further reducing costs more dramatically.¹²

ABB's BODNAP (Biological Oxygen Demand, Nitrate, Ammonia, Phosphate) project is to have similar benefits in respect to the water analysis industry. Benefits include:

- Reduced reagent consumption (by a factor of 100)
- Cost reduction (by a factor of 5)
- Increased time between maintenance

2.6 Key Attributes as an Enabling Technology

Size

Typical MEMS devices have characteristic in-plane dimensions of hundreds of microns with thicknesses on the order of tens of microns. The miniaturization of these devices enhances performance and allows devices to have higher operating frequencies and bandwidths for sensors and actuators.

Micromachined components

Using the micromachining technology described in Chapter 2, hundreds of MEMS devices can be manufactured from a single 8-inch wafer of silicon. Because an entire system can be made this small and in such quantities, prices are decreased as the volume increases.

¹² www.mems-exchange.org

Cost Reduction

The device redundancy mentioned above provides for cost reduction that opens limitless markets for MEMS where the costs of making comparable macroscopic devices were prohibitive. The multiplicity factor also adds flexibility to the design of interconnected electromechanical systems. Instead of designing entirely new components, design can be focused on how the systems of identical and simple components are interconnected.

Embedded Systems

MEMS systems allow for the integration of multiple functions in one system. This introduces modularity in production. ABB sees modularity to be an advantage in ramping up volumes produced. Parts or whole embedded systems can be outsourced to decrease internal production demands. These systems integrate micro electronics components with micron sized mechanical elements of varying complexity to achieve useful objectives.

Reliability

MEMS has expanded the conventional two-dimensional design of chips to building three-dimensional structures into the silicon wafer. The purpose of all this is to give the ability to put an entire system onto a single chip. Furthermore, unique properties of materials used in MEMS allows devices to function in extreme environmental conditions for substantially longer periods of time.

Low Power

The miniscule device sizes reduces the power requirements needed. This can lead to longer battery life or reduced maintenance costs, which also can open new markets. NASA, for instance, is looking for MEMS to enable longer flight missions.

3. Challenges to Commercialization

3.1 A Disruptive Technology

MEMS is considered a disruptive technology. Disruptive technologies are technologies that are new, innovative, and drastically different from existing ones. Oftentimes, they do support the existing product or production standards. These innovative technologies, even though at first to be inferior, are considered “discontinuous”¹³ and are not incremental changes to currently available technologies. In some instances, these new disruptive technologies make existing ones irrelevant and inapplicable. Therefore, firms must be creative to develop products and production methods to capture the innovations to meet an existing or new business need.

Sustaining technologies are technologies that simply improve current product performance. Disruptive technologies on the other hand temporarily worsen product performance. However, successful disruptive technologies will become the competitive ones of the future. The personal computer is one such example. Prior to the wide acceptance of desktop computers, mainframe computers were dominant in providing the data processing capabilities. However once desktops were able to capture the existing market with added user friendly functions, mainframes became extinct. There is an inherent advantage to adopting this new technology, yet companies find it difficult to invest such disruptive technologies. Although these technologies overshoot current market needs, it creates the markets of tomorrow.

Small and large firms face different obstacles in embracing disruptive technologies. Smaller firms lack the resources to develop these technologies fully, while large companies do not wish to allocate resources on a questionable and unproven endeavor. Another fear is the cannibalization of existing products. At ABB, the MEMS enabled version of the BTU meter has potential to eradicate the need for the current BTU meter on the market. ABB has done significant work in re-engineering the existing product and has been able to make the product smaller and easier to manufacture. Many of the engineers are proud of the product and are mistrustful about new and possibly high risk technologies. This makes it extremely difficult to embrace a technology that destroys the current product on the market. However, if MEMS is adapted and is successful, the

way the business unit is making money today will be completely different. The market it currently targets may or may not welcome this new technology. As often the case, there is a misalignment of objectives between corporate research and the business units. Clayton Christensen writes in The Innovator's Dilemma, that there is a characteristic pattern to the commercialization of disruptive technologies. This process as it relates to ABB can be described below.

Step 1: Disruptive Technologies Were First Developed within Established Firms

ABB sees the importance of MEMS in many of its products. The corporate research center in Germany has dedicated personnel in MEMS specifically recruited for their expertise in the field. There is one MEMS program manager responsible for overseeing all MEMS activities in the company. The manager is kept abreast of all industry trends and happenings. All researchers attend industry conferences and many ABB projects have been written up and published in industry journals.

Step 2: Marketing Personnel Then Sought Reactions from Their Lead Customers

With the help of various ABB business units, the corporate research centers can gauge customer interest. In the instance of the gas chromatograph product, marketing has a good sense of the attributes demand, i.e., the helium requirement or the number of gas streams to be analyzed.

Step 3: Established Firms Step Up the Pace of Sustaining Technological Development

ABB has formed numerous partnerships to innovate more rapidly. Academic partnerships include MIT, Stanford University and ETH Zurich. And as a result of this internship, an extensive supplier selection process has begun to find suitable fabrication partners.

Step 4: New Companies Were Formed, and Markets for the Disruptive Technologies Were Found by Trial and Error

The MEMS industry is currently at this step in the process. Suppliers of MEMS fabrication services are numerous. However, at this early stage of the technology, many of the suppliers are small players with niche services. Some may focus only on life science applications while others are meeting the demands of the telecommunication

¹³ Christensen, The Innovator's Dilemma, xviii

industry. There is consensus that as the technology becomes more mature, consolidation will take place in the industry.

Step 5: The Entrants Moved Upmarket

The established firms oftentimes do not aggressively pursue disruptive technologies due to their unattractive margins and market size. In the ABB example, ABB only sees a market for 5,000-8,000 gas chromatographs per year. This is not a large enough market to justify heavy capital investment in MEMS. Meanwhile, the smaller MEMS suppliers with a start up mentality see high potential in volumes and margins for their higher performance products. Here is where the established firm begins to lose ground.

Step 6: Established Firms Belatedly Jumped on the Bandwagon to Defend Their Customer Base

This step in the process is yet to be seen in the MEMS case at ABB. Currently, ABB does not seem to be feeling the pressure brought on by the smaller start up firms in the industry. The work being done at ABB is considered cutting edge with questionable success in its commercialization. ABB will need to resolve the difficulty in matching the work performed at universities to fit business viable requirements to meet successful marketability and commercial success.

3.2 Lack of Supporting Infrastructure

Unlike the semiconductor industry which is more software dominated, MEMS adds value with the development of hardware. The physically moving parts is what enables MEMS products to be useful to the industries they are being used in. Although there are numerous industry organizations formed worldwide to handle infrastructure issues, there has not been much progress in unifying the industry to create standards of design, development, production, or packaging of MEMS.

The funding for MEMS research and development is also not uniform across MEMS applications. A benchmarking study done by EMST indicated that the most important funding sources are from parent companies, venture capital firms, and public funding from organizations such as DARPA, NIST, DoD, and NASA, with some state funding.

Federal funding for universities is also utilized to establish MEMS institutes and labs across the country.¹⁴ It is here that many prototypes for industrial and commercial firms who lack fabrication laboratories of their own take place.

3.3 Non Ideal Design Process

The fabrication process of MEMS enabled products is application specific. Though some basic and common processes such as etching and photolithography are standardized, process design and development for systems of components cannot be shared from existing products due to the vast number of unique design requirements. There is some investment being made in simulation tools to reduce design time and increase time to market, but many industrial and commercial companies are not yet willing to invest in an unproven infrastructure. In addition, multiple design cycles are oftentimes necessary to ensure that all design specifications are met. The average time to market for the existing MEMS enabled products currently available on the market has been about ten years or longer. These time scales have been dominated by the development and adaptation of new processes paving the way for shorter development cycles for future products embracing MEMS technology.

Currently, much design is being done at the university level, which leads to other complications. Oftentimes, lab equipment is being shared by several lab users. Hence, the predictability and reproducibility of results is not guaranteed. Universities may not be able to support the capital investments required to maintain the newest technology available.

3.4 Costly Packaging Requirements

Packaging the MEMS components into a product is another daunting task. Packaging involves all the activities related to protecting the MEMS chip, or die, from harmful and sometimes extreme external conditions. At the same time, it is the responsibility of the MEMS chip to sense or actuate the environment in order to do its job. For instance, in an automobile, the MEMS chip must sense the change in acceleration that enables the airbag to be deployed in time to save its passengers. Medical devices such as those used to test blood must be able to handle fluids.

¹⁴ Matsumoto, "Sandia pushes for MEMS Commercialization"

Interactions the MEMS chip has with the environment may be mechanical, chemical, thermal, optical, or other sense depending on the suggested application. Packaging is much more difficult with MEMS than with semiconductors. MEMS oftentimes are three dimensional and have moving parts.

Typically, packaging accounts for almost 80% of the total product cost due to the application specificity and oftentimes can not be mass produced. Furthermore, little has been done to standardize packaging. With such diverse product made with MEMS, packaging must be unique and hence, a common infrastructure is difficult to establish.

3.5 Few manufacturing standards

There are many players in the MEMS industry. These participants include academia, industrial and commercial firms, simulation tool developers, and the foundries themselves. However, it is not obvious that a standard can be created in the near future. Foundry processes are difficult to standardize due to the diverse business applications of MEMS. Currently, there are foundries such as Standard MEMS based in Burlington, Massachusetts that looks to provide services for many different industries. And there are foundries that have focused on one industry, mainly telecommunications. Many of the latter types have been acquired by the major telecommunications players to form in-house MEMS capabilities as mentioned earlier.

Intellisense has developed design tools to reduce the number of trial and error iterations in development by combining process based model generation and thin film processes with packaging assessment to simulate performance. However, there is still a significant delay from prototype fabrication to full production. Without including production and packaging considerations in the prototype phase, commercial success is still a long ways off.

4. Profiting from Technological Innovation

Based on Teece's article, "Profiting From Technological Innovation," there are other ways to examine what profits ABB expects to obtain from its innovations.

4.1 Regimes of Appropriability

Appropriability measures how ABB is positioned to protect its technology and profits from its competition. This can come in the form of legal mechanisms or may be innate to the technology. If a company's technology is well appropriated, the innovations can not be copied.

Legal Instruments	Nature of Technology
Patents	Product
Copyrights	Process
Trade Secrets	Tacit
	Codified

ABB currently is working on innovating its gas chromatograph product to incorporate MEMS.

The nature of MEMS gives ABB high appropriability in the product but not the process. The fabrication of MEMS utilizes borrowed fabrication techniques from the semiconductor industry. The general process of fabrication begins with silicon, silicon oxide, or metal, that is deposited on a substrate by either evaporation, sputtering, or vapor deposition. These films are then coated with photoresist. A mask is applied to the film with a desired pattern and then exposed to UV light. The unchanged areas of the film are then etched away either by a chemical etch or a reactive ion process. These steps are then repeated until the final device is obtained.

Sharing design and development from existing products is often difficult due to the vast number of unique design requirements and therefore increase appropriability. In addition, multiple design cycles are oftentimes necessary to ensure that all design specifications are met. Thus average time to market is still high in many cases for MEMS enabled products.

4.2 Tacit and Codified Knowledge

The knowledge of the technology is both codified as well as tacit. There are accepted protocols in the fabrication of MEMS called Standard Operating Procedures (SOPs.) For instance, when using the coater to deposit resist on a wafer, MIT Microsystems Technology Lab has determined the following as optimum. These rules are codified as shown in an example below.

STANDARD RESIST COATING:

The coater dispenses the TRL standard photoresist, OCG 825-20 cs; for a typical 1 μ m layer the following parameters are recommended:

Cycle Select	Spindle Cycle (rpm)	Cycle Time (sec)
Resist	500	6
Spread	750	6
Spin	4000	30

However, much knowledge about the design of MEMS is also tacit. Currently, much design is being done at the university level. University labs have multiple projects going on. Results obtained in these labs are often different than those at companies with dedicated runs on the equipment to a particular device. Likewise, different foundries have different experiences with the equipment. For instance, there are ways to tweak the equipment that are not necessarily written in the SOPs. This results in complications in the predictability and reproducibility of results.

4.3 Complementary Assets

Another area to examine is a company's complementary assets. Complementary assets are assets that are necessary for successful commercialization. Examples of complementary assets are either resources or competencies.¹⁶

¹⁵ Teece, "When is virtual virtuous?"

¹⁶ Teece, "When is virtual virtuous?"

Resources	Competencies
Supplier Relationships	Competitive manufacturing expertise
Relationships with Customers	Marketing capability
Brand equity	After sales support

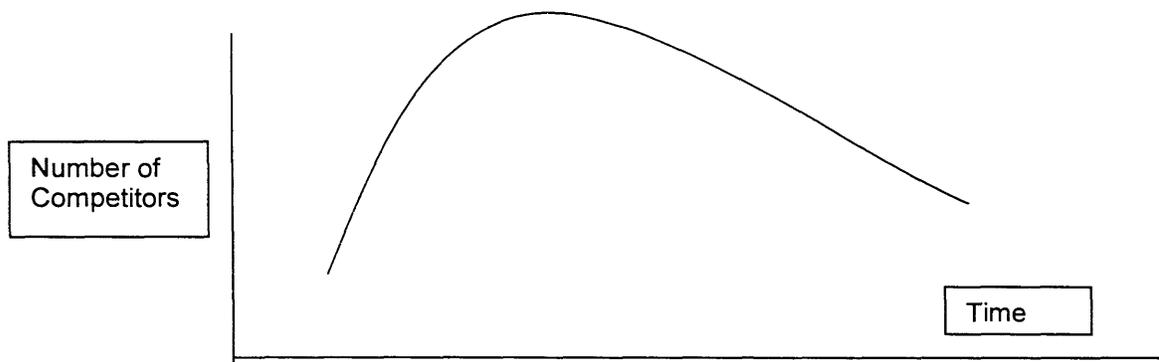
ABB seems to lack sufficient the above complementary assets in regards to the new gas chromatograph product. Its supplier relationships are only in the early stages of formation. MEMS is new to ABB and there are no established relationships with MEMS foundries. From speaking to marketing personnel, the customers that ABB is trying to target with this new product are the same customers as the existing gas chromatograph product, yet it needs a more a solid grasp of what the customers are looking for. R&D, however, aims to attract another customer segment with lower price sensitivities. ABB does however have some brand equity but it is not the top player in this market segment.

The manufacturing of MEMS will be outsourced due to the heavy capital requirements placing an additional need for stronger supplier relationships. Currently, the marketing expertise is about average and the sales and marketing function can not formally gauge the needs of the customers. Therefore, this places bargaining power in the hands of other complementary asset owners and not ABB.

5. The Dominant Design Paradigm

As Utterback states in "Dominant Designs and the Survival of Firms," a dominant design is one that has gained widespread acceptance.¹⁷ Examples of dominant designs are the keyboard, PC, automobiles, transistors, and hard disks. The design of each of these innovations is now dominant in that no one is still trying to redesign the QWERT keyboard. These products are now standardized and only minor design enhancements are being made. MEMS unfortunately cannot be considered a dominant design in any of these applications.

The Dominant Design and Numbers of Competing Firms¹⁸

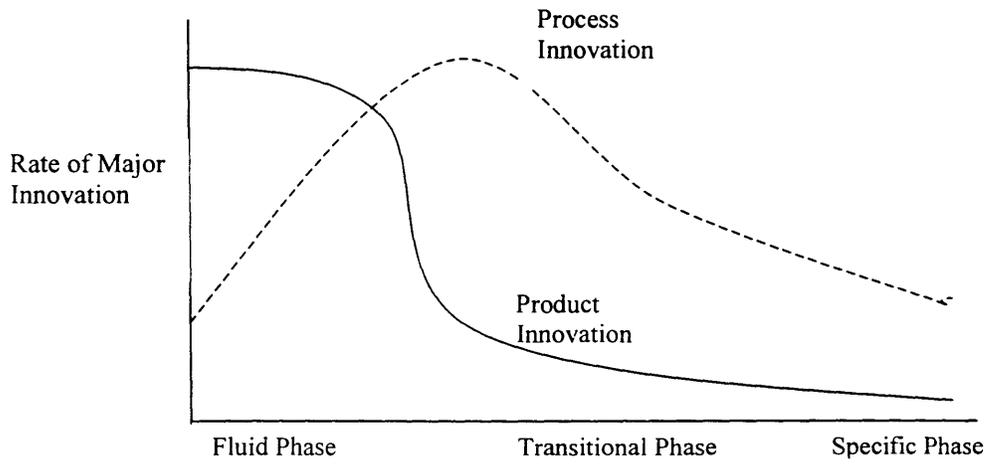


The emergence of a dominant design will be based on many factors. The many industry organizations around are working on exactly what the dominant design will look like. The fluid infrastructure will eventually go through a transitional phase and then to a specific phase of product and process development.

Factors influencing the dominant design are economies of scale, clarification of market and customer needs, technological developments, the formation of standards, and switching costs. The following diagram illustrates this dynamic and how it can be used to analyze an innovation.

¹⁷ Utterback, Managing the Dynamics of Innovation, 26.

¹⁸ Utterback, 31



19

¹⁹ Utterback, 83

	Fluid	Transitional	Specific
Innovation	Frequent major product changes	Major process changes required by rising demand	Incremental for product and with cumulative improvements in productivity and quality
Products	Diverse designs	One product design	Standardized product
Manufacturing	Flexible but inefficient, can accommodate change	Becoming more rigid	Efficient, capital intensive, and rigid
R&D	Unspecified focus with high degree of uncertainty	Focus on specific product features once dominant design emerges	Focus on incremental product technologies but focus is on process innovation
Cost of Process Change	Low	Moderate	High
Competitors	Few	Many, but declining	Few
Basis of Competition	Product performance	Product variation	Price
Organizational Structure	Informal and entrepreneurial	Project groups	Structure with rules and goals

Adapted from Managing the Dynamics of Innovation²⁰

²⁰ Utterback, 94

6. Challenges to finding MEMS suppliers

6.1 Rapidly changing lifecycle of suppliers

When the fourth quarter of 2001 began, it was seen as a critical time for MEMS development in optical switching.²¹ It turned out to be a time of suppliers delaying new product launches and those who closed their doors altogether.

InLight Communications Inc., a maker of optical MEMS subsystems, ended business in November after failing to raise enough money to get its product to market even after securing \$11.5 million in venture capital.

6.2 Acquisitions as a threat to sustainable outsourcing

Most of the development in MEMS is currently in the telecommunications arena, which makes it difficult for ABB to survive in the niche it is seeking. Without internal MEMS capability and resources, ABB relies on external suppliers for development and production. Earlier in 2001, one such supplier that ABB is working closely with was purchased by a larger telecommunications company. The resulting acquisition threatens ABB's sourcing capacity. To date, the new company will continue to partner with ABB but the long term viability is in question, if a market interest conflict develops between both companies. The agenda of a large telecommunications firm is different than that of the start up that ABB initially worked with to jointly develop the MEMS enabled gas chromatograph.

If the company had been purchased by an ABB competitor, the contracts in place would have likely been terminated. This risk is especially prevalent in the MEMS industry where there is a high amount of change and innovation.

6.3 Changing business environment

The MEMS industry is facing two strong challenges, apprehensive buyers, like ABB and investors.

Of course, customers are going to be cautious in a sluggish economy. So being able to ride it out means needing more cash on hand. Although ABB is a large enough

company to support these high risk ventures, without sufficient investment into the MEMS industry at the supplier level, ABB's success is limited to the success of its suppliers.

²¹ www.smalltimes.com

7. Strategic Outsourcing of MEMS

Oftentimes, the MEMS part is a component of a larger system. A company manufacturing MEMS enabled products must decide how much of this system it would like to outsource and how much it would like to produce in house. This requires a complicated make or buy decision that is not simply based on costs of production but also on strategic value.

7.1 Vertical integration vs. outsourcing

In the days of Henry Ford, vertical integration was the dominant strategy for large firms. It was admirable in those days to amass assets. Ford owned everything needed to make its automobiles, tires and all. Today, the decision to vertically integrate or to outsource is a highly strategic one. Successful outsourcing can lead to a competitive advantage that other peers in the industry may not have. Companies now must pursue strategies that maximize value for the stakeholders of the company, which require more flexibility and nimbleness to remain competitive.

Outsourcing includes all the activities that a firm does not do internally. Although, these activities may include human resources and financial services, this paper will define outsourcing in a manufacturing and production approach. Before companies decide what to outsource, they must determine what their internal core competencies are. Core competencies are the innovative combinations of knowledge, skills, proprietary technologies and information, and unique operations that provide a product or service that the customer values.²² A company's skills can be defined as below.

Level of Competence	How it is Defined
Competencies	What a company is able to do
Core Competencies	What a company does well
Competitive Advantage	A core competency that is better than its competitors

²² Greaver, 97

Sustainable Advantage	A competitive advantage that can be maintained in the long run
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Once a company has assessed its level of competence, it can begin to decide what activities are better to outsource or keep in house.

7.2 Insourcing Non-core Competencies

There are, however, exceptions in which case, non-core competencies are not outsourced but kept internally. A company may choose not to outsource a particular activity for its strategic value rather than its competency in that activity. In the Stuckey and White paper, the authors give four reasons to integrate.²³ Some of these reasons are more pertinent to ABB's outsourcing decision of MEMS than others.

1. The market is too risky and unreliable, or vertical market failure.

The authors proceed to describe three features of a failed vertical market as a) small number of buyers and sellers, b) high asset specificity, durability, and intensity, and c) frequent transactions. In the case of ABB, there are few "sellers" of MEMS fabrication services. During the course of the internship, it was determined that there were about 30 worldwide suppliers yet only 15 were valid for consideration for ABB's gas chromatograph requirements. Fifteen suppliers may be sufficient in other industries, yet there is much industry consolidation and the number may decrease in the near future. A smaller number would ultimately be pursued more aggressively for partnerships. ABB certainly faces a vertical market failure given so few potential MEMS suppliers.

High asset specificity refers to how critical a good or service is to the overall process or production of one's good. Assets may include site or location, technical expertise, and/or human capital. In MEMS, the technical specificity is crucial to the production process. Fabrication processes that are developed for certain products have little value in alternative uses. Investment in equipment is expensive and has specific purposes. Less important are site specificity and human capital specificity. Lastly, ABB does not require frequent transactions. In other cases, frequent transactions result in high switching and other transaction costs that are moderated by vertical integration.

²³ Stuckey and White

2. Companies in adjacent stages of the industry chain have more market power than companies in your stage.

This second reason is also relevant to ABB. Suppliers in the MEMS value chain have a significant amount of power. There is a significant amount of uncertainty to ABB. ABB has no control over possible discontinuity in supply. For instance, a supplier, working with ABB, was recently acquired by a larger telecommunications firm. To date, the supplier is continuing its services to ABB but the supplier now has to answer a parent company whose strategy may not include partnering with ABB. Or if the supplier had been bought by an ABB competitor, service would most certainly have been terminated. ABB ought to consider vertical integration as means to defend against the market power of the suppliers. Although it is not evident that the suppliers are able to attain high rents, the uncertainty is great and dependence may not be reasonable.

3. Integration would create or exploit market power by raising barriers to entry or allowing price discrimination across customer segments.

In the instance of ABB, it is not obvious that ABB would desire vertical integration as a means to create or exploit market power. MEMS is viewed to be an enabling technology at ABB and is not applicable in all of ABB's products. In some of ABB's automation and instrumentation products, ABB aims to lower the cost of production in order increase the potential customer base. Production cost reduction is not necessarily a logical reason to vertically integrate. Also, the price discrimination factor is not yet seen to be a factor in the outsourcing decision.

4. The market is young and the company must forward integrate to develop a market, or the market is declining and independents are pulling out of adjacent stages.

This last reason provides some inclination for vertical integration. MEMS is certainly a new technology and with new technologies, some companies need to in-house certain expertise. ABB is currently relying on numerous academic institutions for technical expertise because it is not available in the commercial market. However, the authors indicate that this reason is not a particularly strong one for advocating vertical integration. They state that "there is no point in developing new markets if you cannot capture the economic surplus for at least several years." It would certainly take several

years for an academic start up if supported or acquired by ABB to ramp up production to serve ABB's needs.

Therefore, from the framework above, it is not obvious whether ABB should outsource or vertically integrate its MEMS fabrication. The vertical market failure reasoning certainly supports the argument of in house development. Also, due to the non-modular aspect of MEMS, it is not obvious that outsourcing is the direction ABB ought to take. The MEMS component is highly integrated into the product. The packaging and design relies specifically on the function of the product. The MEMS component can not be fitted for multiple products and is not standardized. Standardization would have facilitated outsourcing.

There is a question of the strategic fit of MEMS at ABB. To date, there have not been any successful ABB products brought to market that utilize MEMS. The R&D group has been actively pursuing business units who buy into this idea of MEMS enabled products but has been overly successful. From the technology perspective of the company, there is strong emphasis on MEMS development, but it is offset by a less enthusiastic push from the business units. It is at the business unit level, that ABB gets a more strategic and market driven view of the business. With the smaller than industrial volumes required by MEMS, it seems more logical to pursue an outsourcing strategy.

ABB can therefore consider "quasi-integration strategies" as suggested by the authors, which are later described as alternative governance structures.

ABB has decided to pursue a strategy of outsourcing. This seems to be a valid approach if further analysis of the downsides to outsourcing are considered. IBM in the late 1970's adopted a modular outsourcing strategy. A modular supply chain strategy is one that utilizes an architecture of multiple suppliers rather than to vertically integrate. IBM chose to outsource their microprocessors and their operating systems to two suppliers. These suppliers, Intel and Microsoft respectively, eventually encouraged the downfall of IBM by motivating the development of IBM compatible yet generic personal computers by companies such as Compaq and Dell. Intel, for instance, made a name for itself with the Intel Inside marketing campaign.

ABB, therefore, needs to consider the effects of outsourcing MEMS on its competitors and potential future competitors who can replicate ABB MEMS enabled products by using ABB's suppliers. The value of the make or buy decision is oftentimes a complicated one. Aside from the strategic value of outsourcing or insourcing, the following chapter discusses traditional make or buy considerations.

7.3 Make or Buy Financial Decision

Leaving the strategic reasoning for outsourcing MEMS aside, the traditional make or buy analysis ought to be considered. Issues to be discussed in determining a present cash flow analysis include:

To Make	To Buy
Cost of raw materials	Price of goods including shipping
Production costs	Anticipated price changes
Labor expenses	One time outsourcing fees
Shipping	Ongoing costs to outsourcing
Storage and handling	Financial implications to outsourcing
Overhead	Cost of training
Cost of invested capital	Cost of poor performance

The cost of invested capital under the "Make" decision is a complicated number to establish. These costs include money spent on facilities, land and equipment, and research and development used on making MEMS. Less obvious is the cost used to acquire these assets, or the company's cost of capital. The cost of capital is what it costs to finance the assets. This cost may appear as interest expense on debt, return to shareholders' equity, but it is also the cost of not being able to use the capital for other purposes. For example, money spent on inventory, cannot be used for other activities.

Investment in MEMS is not an inexpensive activity. The smallest of MEMS foundries can cost between USD1-15 million to the larger foundries being over USD 50 million.

Recent acquisitions of MEMS foundries to be discussed in detail in future chapters, have been valued at nearly a billion dollars. Corning's acquisition of Intellisense and JDS Uniphase's acquisition of Cronos were both valued at USD 750 million.

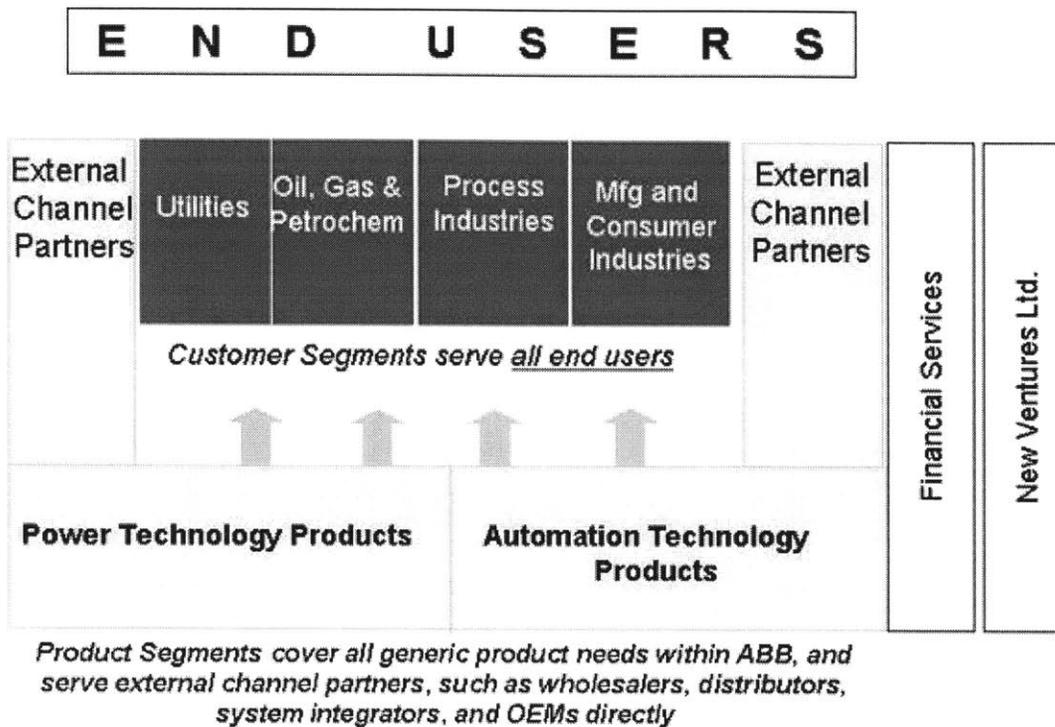
7.4 Organization structure aligned to customer

A company's organizational structure strongly affects its vision on outsourcing. In the past, the size of a company, its complete integration, and its organizational structure based on separate functions were considered essential for success. This tradition has changed into the popular customer focused organization of today.

ABB is one such company that has followed the trend. Process focused organizations hope to encourage employees to understand their roles in order to satisfy end customers better than traditional function focused organization. Processes are the activities that take place in order for products to flow through the organization. The diagram below is published on the internal ABB intranet for easy employee access. From this diagram, it is clear how employees affect their end users. The activities and processes they do contribute to customer satisfaction. This understanding further promotes enhanced decision making at each process.²⁴

²⁴ www.abb.com

ABB: New organization built around customers



With these customer segments, ABB aims to increase time to market, minimize management conflicts, encourage innovation, and promote an exciting corporate culture for its employees. This reorganization also resulted in identifying what processes were not essential or value added. These activities could also then be outsourced.

It is also important to consider the stress that such a reorganization can cause on the employees at the firm. At first, there will be resistance to the change in statusquo. Yet, proper management of employee expectation will facilitate the transformation in such a way that an improved organization results.

7.5 Payment Schemes for Outsourcing

"Renting" technology for increased flexibility

ABB has been working with two suppliers on their MEMS enabled gas chromatograph. One of which is a corporation that is established in the industry while the second one is a university spin-off startup. The "rental"²⁵ pricing scheme with these suppliers is effective

²⁵ Greaver

for research and development for MEMS. Because the product is in the R&D stages of its lifecycle, ABB is willing to provide financial resources to gain commitment from their partners.

However, in the traditional sense of supplier relations, there are other pricing schemes to consider. Some examples are:

Fixed unit price

Suppliers utilizing a fixed unit price charges a single charge for each unit sold. This is effective for activities that are well understood in the market and can be priced accordingly. The supplier bears the financial risk in this case. Therefore, suppliers often anticipate learning curve benefits decreasing the costs of the activity in the future. Payroll or accounting services are oftentimes based in this manner.

Cost Plus

Cost plus pricing is useful for companies who would like to retain rights to the products being developed. Companies manufacturing MEMS enabled products can find this method appropriate. It offers them the ever-advancing expertise of the suppliers. For the suppliers, the cost plus method reduces the financial burden.

Management Fee

Suppliers may charge a management fee for their activities if these activities are short term in duration. Consulting firms often structure their payment plans in this way. The work is done entirely for the benefit of the company and therefore the fees are oftentimes high.

Bonus Schemes

Suppliers may also charge a baseline price with bonuses paid for superior performance. This motivates the supplier to work as hard as it can to deliver the best possible product or service.

The request for proposal should establish the pricing scheme as well as any anticipated changes in pricing in the future. The company ought to understand exactly what it is

willing to commit to the supplier for its opportunistic gains while realizing what motivates the supplier to work with them.

7.6 Holdup Risk in Outsourcing

Chesbrough and Teece write in "When is virtual virtuous?" about the balance between incentives and the risk of holdup in the low presence of suppliers.²⁶ Holdup can occur when there is strong bargaining power in the suppliers. Supplier power was assessed earlier in the Porter's Five Forces model. Although in the case of MEMS at ABB there are few suppliers of MEMS, which increases the risk of holdup, the "rental" pricing scheme with these suppliers is effective for research and development for MEMS. To offset the risk of holdup, there are better aligned incentives for the suppliers to cooperate. The license like agreement encourages the suppliers to innovate. MEMS is a very new technology and large companies like ABB are less inclined to risk resources than smaller start up companies like spin offs from universities. It is also not yet clear that MEMS is the technology to bank on. Therefore, the virtual organization is an appropriate model for ABB at this stature.

7.7 Alternative governance structures

While ABB has used a license governance structure, there are alternative governance structures that may work in other cases of innovation. On one extreme, there is the internal investment approach, which ABB had considered briefly. This requires heavy capital investment on ABB's part to start an internal MEMS foundry. An investment of this caliber is at the least USD10 million dollars. In addition to being an expensive alternative, it is also a high risk one. There is a risk of not being able to successfully leverage the resources a firm may be banking on the wrong technology, which reduces flexibility. But, an internal investment gives ABB complete control over R&D and innovation and allows it to keep proprietary information to themselves and patent rights if any. However, when considering this option, the make or buy decision must justify this alternative.

On the other extreme, is traditional outsourcing approach where a firm goes outside its boundaries to purchase the needed good or service. This transfers control to supplier, but it also provides incentives for the supplier to innovate and perform at its best. The

profit and loss responsibility is on them and not on the larger parent company as the case of the internal investment. This alternative is best for modular or autonomous innovation and is the fastest route to obtaining knowledge and technology.

In the middle of these two extremes, there are joint venture or strategic alliances that merge some of the benefits and risks of internal investment and outsourcing. These midway solutions allow firms to share risk by combining technologies and resources while possibly maintaining rights to complementary assets. Here the risks include imbalance of power, disagreements between partners, and the potential to free ride caused by imperfect information.

Although these options may not fit ABB's needs for MEMS, it can consider them for other R&D projects.

²⁶ Chesbrough and Teece

8. Supplier Relations

8.1 Managing Suppliers

Once suppliers are chosen, additional decisions have to be made over the management of these new partners. These decisions surround production, other operating processes, and strategic and management issues. How much control is the firm willing to give to the supplier?

In regards to production, the resources needed and allocated must be determined. Who manages these resources? Resources include the equipment, capital, and in the case of ABB, technology. Oftentimes, these decisions are better made by the supplier. The supplier knows best how to optimally manage their processes. Yet, decisions on operations also include how work is to be performed and monitored. At ABB, the number of suppliers is currently small enough that performance monitoring and work delegation is ad hoc yet manageable. The process needs to become robust enough to grow with the number of suppliers. There is certainly opportunity for more formal processes to be put in place.

Strategic and management issues include the management of risk and the management of technology. Because MEMS is considered an enabling technology, it is believed that these issues lie with ABB in this instance. The larger product utilizing MEMS is not a core competence of the supplier but ABB. However, long term consideration must be spent on future strategy of MEMS within the larger corporate strategy. ABB should also retain the decision to approve significant changes in the use of different technologies, changes in output, and possibly processes that affect ABB's process or course of business in any manner.

8.2 Communication and Commitment

Communication between the organization and supplier is crucial. In some cases, daily communication between the key relationship manager and the supplier may be necessary. It is likely that more frequent communication is necessary in the early stages of the partnership where there is more room for uncertainty and need for clarification.

The organization's internal customers, whether it be R&D or the business area, has vested interested that the partnership be mutually beneficial.

Meetings between the organization and suppliers are important as well. ABB is able to conduct these meetings on an ad hoc basis and is able to maintain a close relationship with their few MEMS suppliers. However, more formal procedures can be implemented to encourage discussions on performance results, performance issues, customer complaints, potential process or product improvements, new initiatives or technologies, and or other recommendations.

Commitment can be gained through effective communication. Greaver suggest an "oversight council" be formed to:²⁷

- Review annual operating plans, and any major initiatives
- Provide a forum for discussion of the major issues
- Guide management of effective decisions
- Review performance results
- Discuss recommended adjustments based upon performance results
- Review the contract terms and "change orders" to the contract
- Act as an arbiter if problems arise

Furthermore, this oversight council can be used to determine balance of power between the organization and the supplier. Equal representation can eliminate imbalances of power and commitment.

8.3 Monitoring of Performance

The monitoring of performance is currently performed by the R&D group themselves. A more formal process may include the delegation of key relationship manager. At ABB, R&D has a larger role in the development of demonstrators and lab-prototypes but this role is lessened once a product is in production. After the ramp up in production, product changes become more the responsibility of the business area, which has its own development personnel to make further product improvements.

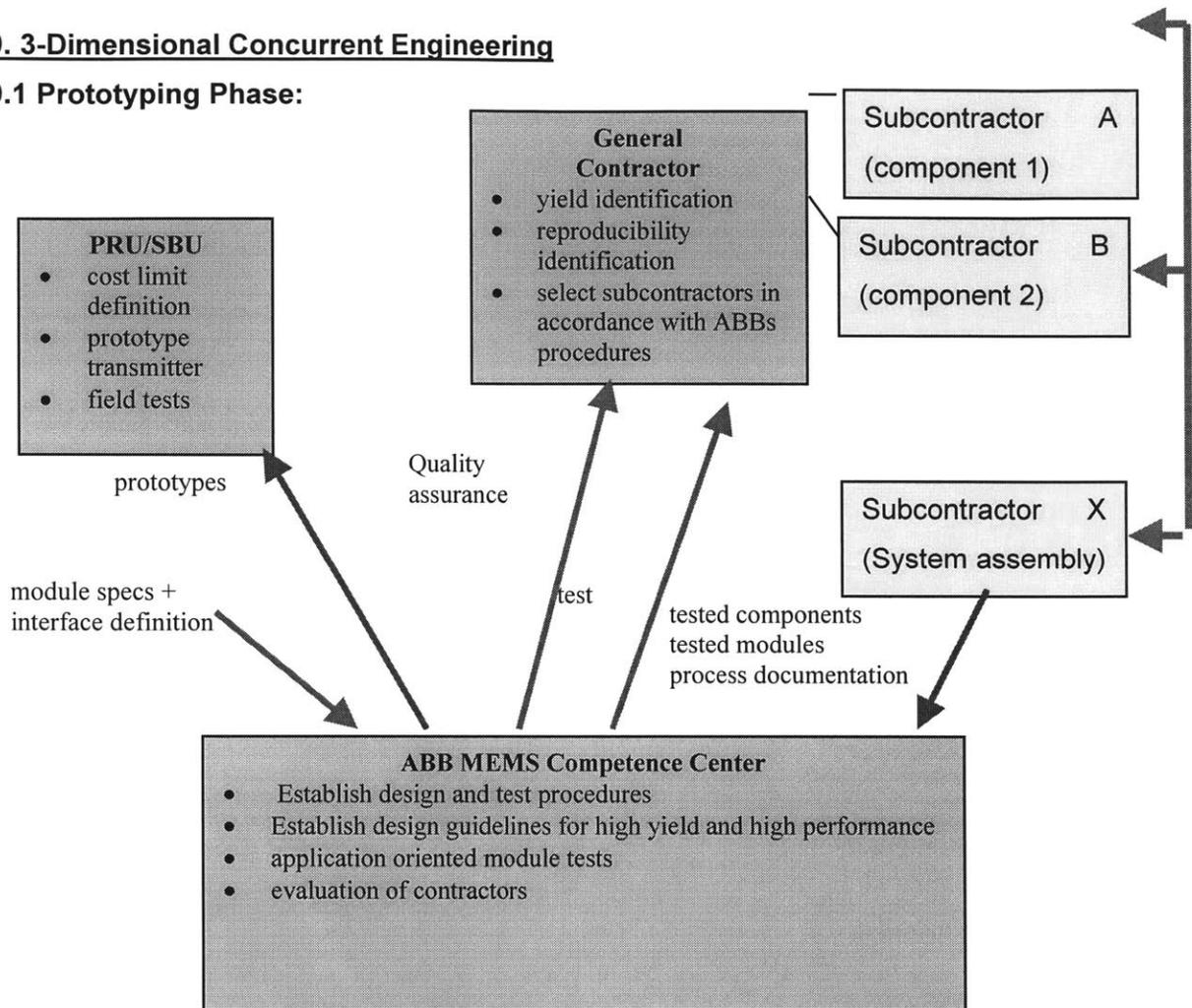
A key relationship manager can bridge the gap between the two stages of the product's lifecycle to provide consistency.

In Strategic Outsourcing, Greaver suggests that without such a person in charge, "provider performance could suffer because the provider takes shortcuts. But more probably it would occur because problems fall through the cracks, the provider cannot get answers to questions (causing delays or inappropriate assumptions to be made), the provider's suggestions for organizational improvement (that affect its performance) are not acted on, and so on. It takes time to manage the relationship."²⁸

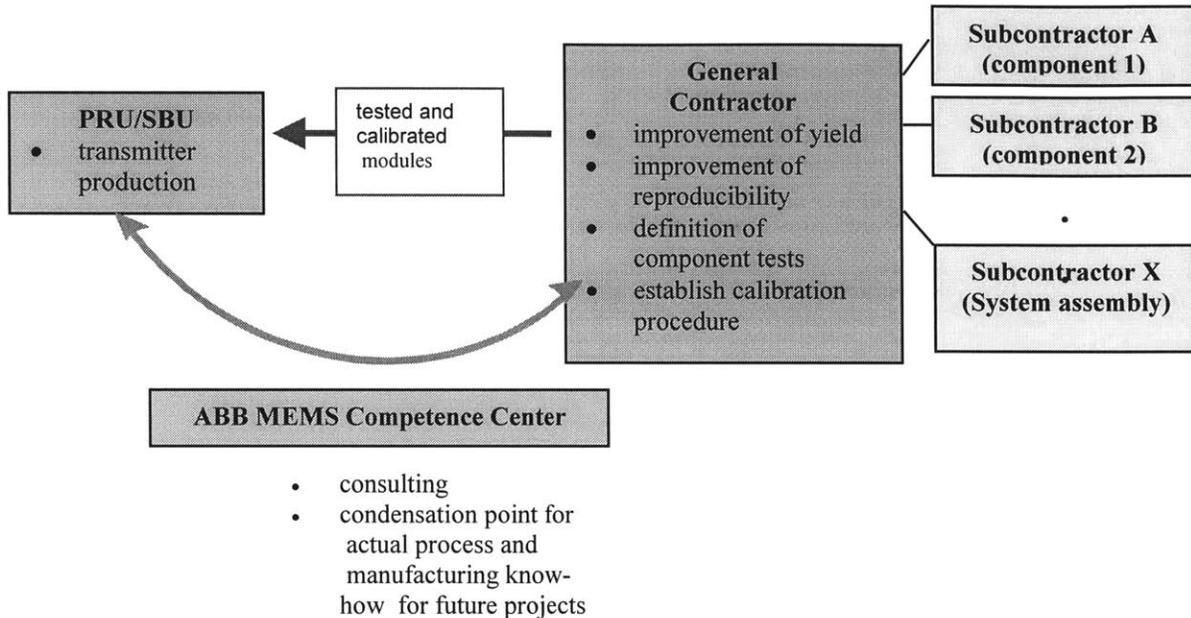
²⁷ Greaver
²⁸ Greaver

9. 3-Dimensional Concurrent Engineering

9.1 Prototyping Phase:



Manufacturing Process:



In recent years, the “throwing it over the wall” concept of design and manufacturing is no longer valid. To replace the functional silos, more attention is paid to design for manufacturability or as Fine coins in Clockspeed, three-dimensional concurrent engineering (3-DCE),²⁹ a process that includes detail in product, process and supply chain aspects of manufacturing. Fine states the key steps in concurrent engineering to include analyzing the architectural design of processes and production, breaking down the product and process systems into components to identify interactions, exploring alternatives to the product design process and manufacturing processes, and working with multifunctional teams working concurrently. Furthermore, one needs to distinguish whether an architecture is integral in nature or modular. Integral architectures have components that are perform multiple functions and are synchronized to work together while modular architectures have interchangeable parts that are standardized and can be individually replaced. Although MEMS processes are difficult to standardize, it is not impossible. Basic, common processes can be standardized. But for commercialization more modular MEMS components must be and are being developed. A goal at ABB is to integrate modular components into current ABB products. Yet the current micro gas

chromatograph product being developed incorporates an entire microsystem that is integrated in the BTU meter as a single module rather than being made from modular parts. There is considerable work ahead in making MEMS more modular for market commercialization.

10. Requirements of Companies producing MEMS enabled products

10.1 Small volume

MEMS is produced using processing techniques similar to IC fabrication techniques, which reduces the cost of each device as more devices are made. Hundreds of devices can be made on a single wafer of silicon.

However, aside from the mass market of air bag sensors or drug delivery systems, many new MEMS enabled products are not yet manufactured in mass quantities. Prototypes are often designed with the help of academia without much attention to design for manufacturing.

The current market for gas chromatographs for ABB is about 500 per year. With the use of MEMS, this number is to ideally increase to about 5,000 per year. Without the larger quantities of production, companies making MEMS enabled products can not capture the cost reduction benefits of utilizing MEMS.

10.2 Unique design

To further decrease the costs of production, manufacturing firms typically increase the numbers produced on the line by coming up with an optimal mix of products that can be made at the same time limiting the costs of changeovers and downtime. However, this is not feasible in the world of MEMS. MEMS are unique in design and it is difficult to manufacture few MEMS devices in a single batch. For instance, MEMS devices sputtered with gold cannot be fabricated with the same equipment as other metals for contamination reasons.

This complicates the scheduling of equipment and increases the cost of production.

10.3 Hedging risk of losing technology to competitors

In these times of fast changing technologies, companies are careful when considering what technologies they do bet on. Oftentimes, these investments are extremely costly and the payoffs are not clear especially when assessing disruptive technologies.

However, there is risk of losing first mover advantages as well. Competitors are oftentimes evaluating the same set of options and the race to capture the most market share is always on.

A survey completed by Walsh, Kirchhoff, and Dowd, analyzed the top reasons for firms to enter the MEMS industry and their strategies for doing so. 73% of respondents replied that technological gatekeeping as a factor or implementing or exploring MEMS.³⁰ Other options with much less response included customer needs and supplier involvement that suggest market pull dynamics are less influential on a firm's business strategy.

10.4 Outsourcing Design and Development

One option to hedge the technology risk mentioned above is to outsource the design and development of this technology. This enables a company to commercially exploit technological skills it does not have internally. ABB works with academia who have well developed skills and unique technologies to do their design and development for their prototypes of MEMS components. It can work with one university for micro TCD development and another for micro FID components. Contracts then stipulate that design developed by the supplier belongs to ABB and cannot be sold to third parties unless authorized and approved by ABB.

ABB can then coordinate with multiple service providers to develop a product of their own. These external suppliers may not have the industry knowledge that ABB has, or the desire to compete in the gas chromatograph industry, yet it can be a participant by providing specialized knowledge. Therefore, ABB can attain existing technology to incorporate in a commercial product of its own.

³⁰ Walsh, Infrastructure Considerations for the Emerging MEMS Markets

11. Conclusions

11.1 Issues at ABB

ABB faces an interesting time with MEMS. MEMS is a new and yet unproven technology at ABB and elsewhere. ABB wants to make sure it stays ahead technologically relative to its competitors, some of whom have begun work in MEMS, yet the industry hasn't seen confirmation that MEMS is the way to proceed.

MEMS can be considered a disruptive technology in following the typical trends of how large companies fail to dominate in the marketplace to successfully commercialize and leverage disruptive technologies. ABB ought to maximize further the needs of the customer through its marketing personnel. There is currently a misalignment between the goals and objectives of the R&D group with the marketing personnel in the business units. Like many other firms, marketing at ABB has a bias towards the current products in its portfolio. This may prevent being open to new and possibly disruptive technologies leading it to miss the wave towards MEMS. ABB must determine that MEMS is a strategic fit for the entire company. There is certainly a technology push but not a market pull for MEMS at this point.

Since the strategic fit argument is still questionable through much of ABB, outsourcing is a legitimate choice for MEMS. Outsourcing allows a greater amount of flexibility and the least amount of capital investment. However, for better integration, ABB can consider alternative governance structures such as partnerships and joint ventures.

Although ABB has decided to outsource its MEMS capabilities, it has to realize that there is a possibility of vertical market failure with MEMS. There are very few suppliers in the market today with potentially fewer in the future as mergers and acquisitions begin to take place once a dominant design is established. This vertical market failure encourages vertical integration and not outsourcing.

11.2 Future direction of MEMS

Within development circles there is a suspicion of technology boosters as too often people promoting expensive, inappropriate fixes that take no account of development realities," Malloch Brown writes in the agency's 2001 Human Development Report.³¹

For this reason, American Council for the United Nations University (UNU), a nonprofit group that links scientists in the United States and the global network of scholars within the UNU, is encouraging that scientists from around the world – not just in the West – actively participate in cutting-edge research. "Global collaboratories," are one such forums in which this is established.

Some regions already are jumping on the next technology advancement in nanotechnology. The Asia-Pacific Nanotechnology Forum brings together governments, industry, and venture capitalists to steer growth in the field and try to ensure that Asia – a leading maker of computers and semiconductors – is not left out in the cold when manufacturing shrinks to the molecular level.

Governmental agencies within the US still continue to support corporations with MEMS agendas. DARPA, the central research and development branch of the U.S. Department of Defense, has provided years of support to high technology industries, resulting in the commercialization of many discoveries. DARPA retains the right to use the results for government applications, while the companies are free to commercialize their results. It was recently announced that Agilent and DARPA are partnering to reduce the cost and time it takes to synthesize DNA for the microarray market with a \$6.1M investment in the effort.

11.3 Projected market segments

The largest business market segment for MEMS is currently the automotive sector with telecommunications taking the lead in the near future. MEMS based photonic switching is predicted to become the first MEMS device to surpass the \$1B in sales. However, the market growth will depend on how fast the optical network gets built. More significant

³¹ www.smalltimes.com

growth in the network is not expected until 2004.³² Markets for DWDM and SONET are currently 20% and 80% respectively but will be heavier weighted in the DWDM segment in 2004. Currently, there are multiple companies competing in this marketplace but market consolidation is expected over the next few years either by mergers or acquisitions. This phenomenon can be explained by Utterback's dominant design theory as mentioned previously.

The events of September 11, 2001 has introduced additional growth in the defense sector. Cepheid has recently delivered field-ready DNA test kits for rapid detection of four deadly biothreat agents to the U.S. Army Medical Research Institute of Infectious Diseases. These MEMS enabled instruments, developed with the Army, detect anthrax, plague, botulism and tularemia. The company said its "freeze-dried"³³ systems allow tests to remain stable for many months at room temperature. Cepheid's reagents are the first supplied directly by the company and will be made available to several other U.S. government agencies for evaluation and validation on its line of portable DNA detection systems. However, in a symposium about science's role in the war on terrorism, Eric Drexler, founder and chairman of the Foresight Institute, a nonprofit educational organization established to help society prepare for advanced technologies, warns, "This is a technology which can reasonably be described as extreme in all directions: extreme upsides, extreme downsides."³⁴

In addition to defense applications, the life sciences area is one with high potential growth. In a report by Rob Ellis, an analyst with Front Line Strategic Consulting Inc., Ellis writes that the DNA microarray market that the Agilent and DARPA partnership has invested in will reach \$3.6 billion by 2006,³⁵ with several segments such as the scanner and arrayer markets growing at a compound annual growth rate of 44 percent. Lower prices, greater production needs and increased use will drive the market.

Clinical diagnostics will benefit by allowing physicians to detect genetic biases to specific diseases and to customize treatment on the basis of the patient's genetics.

³² MEMS and Optical Networks: Switching the Light Fantastic, Cahners In-Stat Group

³³ www.cepheid.com

³⁴ Drexler, www.foresight.org

³⁵ Ellis, www.frontlinesmc.com

As dimensions in which scientist think of new possibilities becomes smaller and smaller the next step in the technological revolution is the development of nanotechnology, and another technology that Gerald Yonas, vice president and principal scientist at Sandia National Laboratories in Albuquerque, N.M., describes as an emerging field he calls "cognotechnology,"³⁶ a convergence of nanotechnology, biotechnology and information technology. He also discussed a developing field that focuses on remote sensing of brain function, including the intention to commit deception. Such mind control technologies could be helpful in ferreting out potential terrorists from airports. Successful implementation is of course debatable.

In summary, we are still in the early stages of the MEMS life cycle. There are many more applications for MEMS to be developed and ultimately commercialized for market use. Many of which will enhance our standards of living and change the way we live.

³⁶ Matsumoto, "Sandia pushes for MEMS Commercialization"

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APPENDIX

ABB Introduction Survey

Company Name

Company Contact

Name:

Phone Number:

Fax Number:

Mailing Address:

Email:

BUSINESS DESCRIPTION

Provide a brief description of your business.

Do you have existing products and processes for MEMS?

YES NO

FINANCIAL INFORMATION

What are your annual revenues?

Do you have audited financial statements?

YES NO

Do you have sales forecasts for the next 5 year?

YES NO

RESEARCH AND DEVELOPMENT

List Key R&D personnel information

	Name/Title	Publications	# of Patents
1			
2			
3			
4			
5			

Describe research, product development, process development methods and results.

List major equipment and software used in research, product, and process development.

	Name	Purpose
1		
2		
3		
4		
5		

MANUFACTURING CAPABILITY

Do you have process flow diagrams?

YES NO

List major equipment by name and quantity

	Name	Quantity
1		
2		
3		
4		

Describe overall assembly, packaging, and test operations.

Description of design rules, lists of technologies, and tooling design process.

Do you have documentation of yields, control charts of each process, SPC, etc.?

YES NO

Describe typical die sizes and wafer diameter used.

Do you perform studies on sensitivity on process margin or yield monitoring?

YES NO

Do you calculate lead times on major products?

YES NO

If yes, provide information on the calculation of lead times.

Do you have records of delivery history and statistics?

YES NO

What is the number of shifts per day?

ENVIRONMENTAL STANDARDS AND PROCEDURES

Do you have environmental assessment reports?

YES NO

Are reports made to the Senior Management relating to environmental matters involving business operations?

YES NO

Are you ISO 14001 certified?

YES NO

SUPPLIER MANAGEMENT

Do you assess your suppliers?

YES NO

If yes, please provide information on how assessments are made?

Do you establish annual supplier goals?

YES NO

Do you document change orders?

YES NO

Do you manage second tier suppliers?

YES NO

QUALITY ASSURANCE

Do you have a third party Certified Quality System?

YES NO

Are you ISO certified?

YES NO

Are you QS9000 certified?

YES NO

Do you have collect and record quality information?

YES NO

Do customers have access to quality records?

YES NO

Are records protected from unauthorized access?

YES NO

Are corrective actions documented?

YES NO

TECHNOLOGY ASSESSMENT

Do you have the following technologies available?

Bulk Micromachining

YES NO

Surface Micromachining

YES NO

KOH

YES NO

RIE

YES NO

Deep RIE

YES NO

Silicon Bonding

YES NO

Anodic Bonding

YES NO

LPCVD

YES NO

Sputtering

YES NO

Packaging/Assembly

YES NO

Galvanic Coating

YES NO

Conventional Machining

YES NO

LIGA

YES NO

Injection Molding

YES NO

MATERIALS ASSESSMENT

Do you work with the following materials in your processes?

Silicon

YES NO

Metal

YES NO

Ceramic

YES NO

Plastics

YES NO