MEMS TECHNOLOGY HOLDING, LLC
A STRATEGIC INTRODUCTION

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I. EXECUTIVE SUMMARY

Microsystems, the science of building nearly microscopic machines, is on the verge of creating another technology revolution. The ability to incorporate hundreds of diverse mechanical, optical, thermal, pneumatic, or fluidic functions into a footprint the size of a pinhead has ramifications for our world that are at least as broad as the 1964 miniaturization of transistors onto silicon.

In a decade, microscopic machines will be as ubiquitous as integrated circuits are today. Revolutionizing medicine, communications, transportation, and the consumer marketplace, Microsystems technology will transform our society and improve our lives.

A. WHAT ARE MICROSYSTEMS?

"A microsystem is an intelligent miniaturized system comprising sensing, processing or actuating functions. These would normally combine two or more of the following: electrical, mechanical, optical, chemical, biological, or magnetic properties, integrated onto a single or multichip hybrid." *(Microsystems in the 4th Framework, IT, Sept. 1996.)*

B. WHY MICROSYSTEMS?

What advantages does miniaturization offer over comparable large-scale systems? There are several:

Cost. Microsystems, once designed, are inexpensive to produce. As hundreds or thousands of Microsystems devices can be "stamped" onto a single silicon wafer or polymer substrate, manufacturers can produce a Microsystems device at a fraction of the cost of its macro-sized counterpart.

Size. The smaller a device is, the more places it can be used and the more likely that it can be used in ways considered impractical on the macro-scale.

Low Power. Microsystems devices use a fraction of the power required by their macroscale counterparts.

Disposability. Microsystems can be made in huge quantities at a low cost, so that it becomes practical to use them in ways that wouldn't make sense for larger, more expensive, less easily-replicable devices.

Interactivity. Microsystems can be designed and integrated with traditional integrated circuits to sense a stimulus (*microsensors*), process it (*integrated circuits and software*), and then respond (*microactuators*), thus cost-effectively closing the feedback loop with the real world.

For the last twenty years, patent registration of Microsystems has grown at more than 40% per year, creating a wealth of intellectual property on which to draw for future growth. In its May 2000 study, Venture Development Corporation predicts that the Microsystems market will reach $18 billion by 2004. Nevertheless, the Microsystems community has a number of characteristics that present challenges. Currently, researchers are disconnected from industry, while industrial companies are focused on their core products and are ignoring recent innovations. Likewise, intellectual property is fragmented between multiple parties and most is not "productized." The industry has neither a trade organization nor a major publication, and its participants are generally poor at networking. Finally, unlike Internet startups, emerging Microsystems companies need access to capital-intensive equipment to develop and commercialize their technologies. This equipment is expensive to both acquire and operate.

C. INDUSTRY ACCELERATOR

For these reasons, we believe that the right vehicle to commercialize Microsystems technology is an **"Industry Accelerator"** that will possess the following features:

- Like a *venture capitalist*, it will have capital to invest in startups and early stage companies;
- Like an *incubator*, it will provide business and technical resources to support these companies;
- But *unlike* these other vehicles, it will also develop industry-building resources such as prototype/pilot fabrication facilities, a trade publication, a web site, trade shows, and a Microsystems-focused recruiting company.

MEMS Technology Holding, LLC ("MEMS Tech" or "the Company") is that vehicle.

D. MEMS TECH'S VISION

To be the leader in bringing commercial Microsystems solutions to the global marketplace.

E. MEMS TECH'S MISSION

To grow our business and create substantial revenue streams and shareholder value by:

Acquiring and aggregating intellectual property ("IP") rights. MEMS Tech will create a defensible competitive position through the acquisition of key Microsystems patents or licensing rights therein from universities, research laboratories, and corporations.

Starting new businesses to develop commercial/industrial applications. MEMS Tech will identify the best and the brightest people in business and academia, and employ them to build world-class Microsystems companies utilizing MEMS Tech patents.

Investing in developing companies. MEMS Tech will identify existing companies at the cutting edge of Microsystems design, build relationships with these companies, and invest in them when appropriate.

Creating an efficient channel of distribution for microsystems technologies: MEMS Tech will form relationships and strategic partnerships with companies along the entire Microsystems value chain, thereby creating an efficient channel of distribution for our companies' products. Our affiliate companies, focused on fabrication, recruiting, and publishing, will help to grow this industry and raise the demand for our products and technologies.

F. WHERE MEMS TECH STANDS TODAY

We have already completed two investments in Microsystems companies, and we have option agreements with two major universities to create startup companies based on their patents and other IP. We're also negotiating broad working agreements with several major institutions regarding commercialization of their IP.

G. CONCLUSION

This is an exciting time for Microsystems. After more than two decades of research, the technology has moved out of the laboratory and into the "real world." The National Research Council attests that "[this] technology is now poised to enter a second phase of product realization, which is marked by the creation of entirely new markets." Over the next few years, there will be an explosion of new applications and companies focused solely on Microsystems, and by the end of the decade, some Microsystems companies will be as well known as Intel and Cisco are today.

MEMS Tech intends to drive much of this growth and be a leader in the sector for years to come.

II. THE OPPORTUNITY

A. A CHALLENGE

December 29th, 1959. It's a warm, sunny day as Richard Feynman arrives at the California Institute of Technology where the American Physical Society is holding its annual conference. Feynman is at the height of his career and the most respected mind in theoretical physics. The audience anxiously awaits his talk. With a sly smile, he approaches the podium, takes a deep breath, and issues "An Invitation to Enter a New Field of Physics." He is known as a maverick and there are more than a few skeptical faces as Feynman challenges:

> "Why cannot we write the entire 24 volumes of the Encyclopedia Britannica on the head of a pin?"

Feynman speaks of a new science, "the science of the small", where microscopic machines perform surgery from within the human body and motors smaller than a pinhead shuttle tiny machines around our world. He closes his talk with a challenge, offering $1,000 to the first person who can take the information contained in a book and publish it in a form that can only be read with an electron microscope.

B. SILICON MACHINES

Feynman called the talk *There's Plenty of Room at the Bottom* and it's one of the classics of his career. It sparked much discussion and debate, but more importantly, it fired the imaginations of countless researchers who took his challenge to explore the "science of the small." Novelists and popular science writers quickly embraced Feynman's idea, but material progress wasn't made until the early 1980s. Applying similar techniques to those used in semiconductor fabrication, researchers began to etch structures into silicon. By 1985, two researchers from Stanford claimed Feynman's prize, when they published Dickens' *A Tale of Two Cities* on a silicon membrane a mere 5.9 μm[1] square.

In the last fifteen years, a new industry has formed around this technology, often referred to as "Microsystems". Used in a large array of applications, from automobile airbags to blood pressure sensors, the market for Microsystems devices is estimated to be $8 billion in 2000 and is growing at a compound rate of 25% each year[2].

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1 "μm" is shorthand for a "micron" or one millionth of a meter. A human hair has a diameter between 70 and 100 microns.

2 Microstructures Technology and MEMS: An Applications and Market Evaluation, Venture Development Corporation, May 2000

For an overview of the technology and projected growth of the industry, please refer to Exhibit 1 to this Appendix C, "*Microsystems: A Primer"*.

C. PROBLEMS AND OPPORTUNITIES

The Microsystems industry exhibits the following characteristics:

The industry is highly fragmented: Currently, there is no "Silicon Valley" for the Microsystems industry. In the United States, activity is distributed amongst a number of research institutions focusing in this field. Europe and Japan are also heavily involved in Microsystems, especially from a research standpoint.

Intellectual property is crucial: IP is widely dispersed and fragmented. Nevertheless, Microsystems patents are important and defensible. Owning the right IP is key to success in this industry.

The industry has an inefficient commercialization/distribution channel: With few major players and activity distributed amongst a variety of industry sectors, there are few examples of how to develop and market a Microsystems product. Furthermore, researchers and entrepreneurs are disconnected from potential customers and vice-versa.

Industrial companies are focused on their core products, not component innovations: These companies are concentrating on design, product integration, and sales and marketing, while component innovation has been driven down to the supply base. Because the supply base has limited resources, they have been unable to focus on disruptive technologies like Microsystems.

The industry suffers from limited networking and few trade shows or publications: While the research community has numerous journals and conferences, the commercial Microsystems community is underserved in this area.

Microsystems talent is scarce: Scientists are hard to identify and recruit and, because it's a nascent industry, qualified business, operations, and marketing people are even more difficult to find.

Microsystems startups are capital-intensive: Unlike Internet startups, young companies focused on Microsystems need access to capital-intensive equipment to develop and commercialize their technologies. Fabrication facilities often cost more than $20 million. The associated operating costs can also be substantial.

D. SOLUTION

Based on an analysis of the issues above and successful business models from similar industries, we believe the answer is MEMS Tech, the industry accelerator for Microsystems.

III. BUSINESS MODEL

A. THE MEMS TECH INDUSTRY ACCELERATOR

The Microsystems industry has enormous potential, and it has been gaining momentum slowly for the past twenty years. Until recently, most efforts have been focused purely on research, with limited attempts to commercialize the technology. If events proceed at their current pace, the industry will inevitably reach a point of technological convergence and rapid growth, as the integrated circuit industry did in the late 1980s. However, MEMS Tech believes that with appropriate leadership, this convergence process can be significantly accelerated. The MEMS Tech Industry Accelerator is the engine that will drive this rapid growth, and it will do so in several ways:

- Like a *venture capital* firm, it will invest capital in startups and early stage companies;
- Like an *incubator*, it will provide business and technical resources to support these companies;
- But *unlike* these other vehicles, it will also develop industry-building resources such as prototype/pilot fabrication facilities, a trade publication, a web site, trade shows, and a Microsystems-focused recruiting company.

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D. IP MANAGEMENT

IP ownership is a key competitive advantage to companies who wish to lead in the Microsystems arena. Unlike the Internet space, where patent protection is unreliable at best (often taking a back seat to first-mover advantage and quick customer acquisition), the Microsystems sector lends itself to solid, defensible patents. As such, IP management is a crucial component of MEMS Tech's business strategy. The process can be broken down into four stages or areas of operation: Identification, Acquisition, Origination, and Administration.

IDENTIFICATION

Through its Microsystems industry contacts and internal research staff, MEMS Tech will keep close tabs on who is active in Microsystems research, in both the public and private sectors. By developing strong relationships with universities, research institutions, individual inventors, and commercial entities, MEMS Tech is well positioned to learn about new Microsystems research as it emerges.

ACQUISITION

Universities are doing tremendous research in the Microsystems industry, and are excellent sources from which to license intellectual property. A number of universities have Technology Management/Transfer offices, whose mission is to commercialize technology developed and patented by university research centers. However, a growing problem with many universities is that the process of taking an idea and following through to filing for and being granted a patent is costly and time-consuming. Furthermore, if an application is not filed within one year of a discovery's publication, the opportunity to do so is lost and the idea becomes part of the public domain. Even when patents *are* filed, they often cover too narrow a spectrum of use, leaving the idea freely available to others for applications perhaps not considered at the time of filing.

In order to acquire rights to Microsystems-related intellectual property, MEMS Tech offers universities help in organizing and patenting their research. MEMS Tech will:

- Review and assess university-held intellectual property and patentable ideas
- Offer patent drafting and filing assistance to researchers
- Help universities design incentive and reward programs to encourage IP disclosures
- Offer financial assistance for patent filing and prosecution
- Help commercialize IP through startup companies and capital

- Create incremental revenue streams through licensing royalties
- Aggregate related IP from other sources, where appropriate
- Offer equity positions in startups to researchers and universities
- In return for the services we provide to universities, MEMS Tech benefits from licensing agreements (both exclusive and non-exclusive), rights of first refusal, and "first looks" at developing technologies, shared ownership of co-developed IP, and equity stakes in startup companies. By building partnerships with universities, MEMS Tech will ensure consistent access to the newest developments in Microsystems research.
- Many not-for-profit research institutions also do interesting work in Microsystems. Often, these institutions have an interest in spinning off their work into private startups. MEMS Tech will work with these institutions, offering many of the same benefits that we do to universities.
- Similarly, MEMS Tech will also acquire IP from private corporations who have developed Microsystems technologies with applications outside of their field of use. MEMS Tech will acquire these patents in exchanges for cash or, in some cases, equity in the MEMS Tech companies they enable.

ORIGINATION

MEMS Tech expects the companies it creates (explained in more detail below) to generate significant intellectual property. MEMS Tech will have the legal expertise to obtain patents for its companies' discoveries and to defend patents when required.

ADMINISTRATION

One of MEMS Tech's greatest strengths will be its ability to strategically manage its IP, whether it originates within the company or is licensed from an outside source. To this end, MEMS Tech intends to:

- Monitor patents and licenses as they are created.
- Combine patents into groups that enable new products and/or new companies.
- License patents to third parties, creating an important revenue stream, while maintaining a defensible competitive position.

E. INVESTMENT ACTIVITIES

A major component of MEMS Tech's structure is its growing investment portfolio of Microsystems-related operating companies. Some of these companies will originate within MEMS Tech and will be incubated; others are existing companies in which MEMS Tech will make a venture capital-type investment.

STARTUP COMPANIES

Technology incubators have been around for years, and many have been successful. Most incubators have a stated mission of "giving life to new ideas" and "graduating companies" once they have achieved a stated level of maturity. This mission is shared by MEMS Tech, with the overarching goal of building a strong commercial Microsystems

industry. The creation of new companies is a natural follow-on to MEMS Tech's IP acquisition, and as these companies develop IP of their own, they help to perpetuate and grow MEMS Tech's patent portfolio. Once MEMS Tech has established a collection of IP related to a particular marketable application, we will create and incubate a startup company to develop and commercialize it.

To facilitate the rapid growth of our startups, MEMS Tech will provide them with supporting services crucial to their development. MEMS Tech will provide the following services to our startup companies:

Business Planning: This includes strategic consulting, cost analysis research, business plan writing, and business development advice, as well as management training for employees.

Marketing and Public Relations: MEMS Tech will help analyze the market and bring strong positive attention toward the company's product offering.

Recruiting: Through our recruiting services affiliate, MEMS Tech will provide the key executive and scientific talent to make the startup a success.

Physical Infrastructure: MEMS Tech will provide our operating companies with furnished office space, copiers, fax machines, and computer systems.

IT services: A fulltime computer network support staff will maintain the computer network of our incubated companies.

Professional Services: These include legal, accounting, human resource, and public relations services.

Access to Fabrication Facility: Companies involved in Microsystems have special requirements unique to the industry. MEMS Tech will provide our operating companies with access to state-of-the-art Microsystems fabrication facilities. (See "MEMS Tech Fabrication Facilities")

EXISTING COMPANIES

MEMS Tech will complement our incubation activities by making equity investments in existing early-stage Microsystems companies. Our experienced team of industry experts will identify the best young companies in the field, performing thorough due diligence before recommending a MEMS Tech investment. In this regard, we will act similarly to a traditional venture capital fund, but our tight focus on Microsystems and our team of experts allow us to offer our portfolio companies expertise that traditional VCs cannot.

F. CHANNEL DEVELOPMENT ACTIVITIES

Because the Microsystems industry is still relatively underdeveloped, it currently lacks an efficient channel for commercialization and distribution of technologies. Established industries generally have a clear path for moving innovations from the lab to companies for commercialization and into the hands of the product's end-user. This channel doesn't exist in the Microsystems industry. Oftentimes, our startup companies will require specific market information, industry contacts, and/or other market assistance that is difficult or costly for a young company to acquire. Furthermore, as they bring products to market, an efficient channel of distribution will be an important factor in their success.

INDUSTRY AFFILIATE ACTIVITIES

For these reasons, MEMS Tech will help develop the channel through a number of affiliated companies. These companies will serve the industry as a whole, rather than focusing internally on MEMS Tech. While MEMS Tech is prepared to build these affiliates from the ground up, we are currently exploring joint ventures and partnerships in creating a number of them. We anticipate investing significant sums of money in creating these affiliates, but expect that after the startup phase, these companies will be financially self-sustaining entities.

MEMS TECH FABRICATION FACILITIES

Many university researchers and small Microsystems companies lack the facilities to adequately prototype, pilot, test, and manufacture microsystems devices in low volumes. University researchers often share facilities with their colleagues. Critical tests involving repeatability cannot be performed due to the rotating use of key equipment. Contamination of materials on shared equipment can also be a problem. Likewise, small companies generally lack the capital to build a fabrication facility and have to purchase these services from a third party. With the industry consolidation that is occurring, this tactic might become even more difficult to pursue in the future, as large industry players purchase the few independent fabrication plants that currently exist. MEMS Tech will invest in pilot facilities, both to support our portfolio companies and to provide services to third parties. We have identified three possible locations for such facilities:

- Ann Arbor, Michigan
- Berkeley, California
- Albuquerque, New Mexico

These locations have been strategically selected based on the concentration of Microsystems research and relationships that we are establishing with major research institutions in these areas. (See "Milestones and Risk Factors")

The model for a prototype facility is:

- 1,000 square feet of Class 10 clean room space[3]
- 5,000 square feet of Class 100-1000 clean room and other lab space
- Design facilities
- Packaging and assembly equipment
- Testing and prototyping equipment
- Low-volume production equipment
- Fabrication infrastructure and support facilities including water system, process gases, compressed air, vacuum, liquid nitrogen, and safety and detection systems

MEMS TECH MARKETING/MEDIA

In the early days of the PC industry, Ziff Davis created publications and events that helped grow the overall marketplace. Looking back, it's hard to imagine the PC industry without publications such as *MacWorld* and *PC Magazine* and tradeshows such as *Comdex*.

Currently, the microsystems industry has no similar media organization. While the research community is well served by a number of technical journals and frequent conferences, there are no industry trade magazines and only one small trade conference. (See Exhibits 2 and 3 to this Appendix C for a list of existing publications and conferences.)

MEMS Tech intends to fill this void with a media organization whose mission is to be the premier supplier of news, analysis, and education for the Microsystems industry. To that end, the media group will build a consistent, meaningful brand in the industry and produce the following:

A Microsystems Magazine. Ziff Davis ("ZD") helped to define and grow the PC industry in its infancy. Today, with 21 million readers, ZD is the leading authority on technology and the Internet. The time is right for a Microsystems technology publication, creating the appropriate "buzz" for developing companies and technologies. The magazine will provide Microsystems news and analysis, and build community within the industry.

A Web Site. With a similar mission to the magazine, the web site will cover breaking news stories and provide community-building services, such as discussion groups and employment listings. An email-based newsletter will also be offered by the web site. This will allow us to establish 1-to-1 relationships with members of the Microsystems community.

Microsystems Industry Trade Shows. Microsystems events have historically been limited to technical and academic conferences. With the exception of an annual

[3] Clean rooms are "classed" by the number of dust particles 0.5 microns or smaller in size present per cubic meter of air. The lower the class of room, the cleaner it is. As a comparison, normal outdoor air has a class rating of *2-3 million.*

conference on microsystems commercialization, there is no forum for sharing product development and marketing breakthroughs. Our tradeshows will provide such a forum, focusing on commercial applications of the technology.

Microsystems Knowledge Base. Another important role of the marketing/media group will be tracking and documenting activity in the Microsystems industry. The media group will maintain an extensive document library covering news, research, intellectual property, and competitor tracking. This information will be available online.

MEMS TECH TALENT

One of the challenges facing a Microsystems company is finding the business and scientific talent required to be successful. Microsystems is an evolving technology that from a commercial standpoint is still in its infancy. As a result, there is a finite group of qualified Microsystems engineers, and a much smaller set of engineers that have been successful in delivering commercial solutions. Likewise, attracting qualified business and marketing executives can also be a challenge. In addition to commercial resources and talent, there is a need to track academic contributors to the field - both faculty and students.

The best current source of available talent is a resume posting service provided by the MEMS Clearinghouse (http://mems.isi.edu/index.html). This service currently lists 30 available candidates located throughout the U.S. This same site has a job posting board with just over 30 available positions. By point of comparison, the leading technical publication in the field has 13,000 subscribers and an estimated 20,000 readers. With well over 20,000 professionals in the field, the MEMS Clearinghouse is clearly an inefficient and incomplete marketplace.

In order to help grow the industry efficiently, MEMS Tech will create an affiliate dedicated to recruiting and placing qualified personnel. This firm will be responsible for hiring employees for MEMS Tech's operating companies, and it will also serve the industry at large.

The goal of the firm will be to provide high quality, informed search services for clients in the Microsystems industry. We will establish an interconnected network of job search and resume exchange services, providing:

- Position description and promotion
- Matching and screening of potential candidates
- Maintenance of proprietary talent database
- Interviewing and presentation of qualified candidates
- Assistance in hiring, compensation and benefits

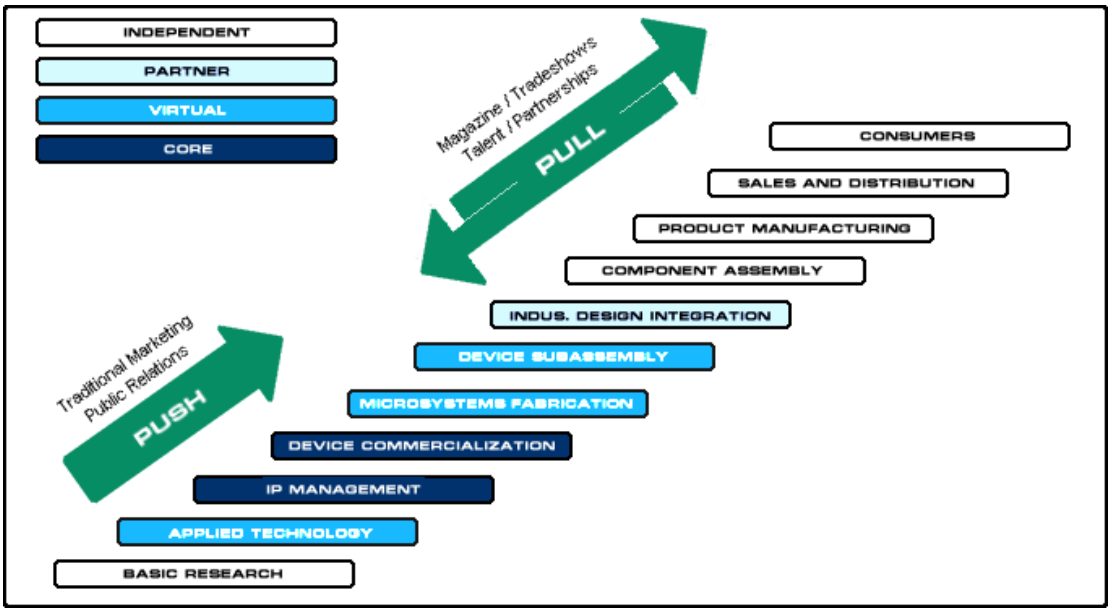
BRIDGING THE CHANNEL – CLEARINGHOUSE FOR INNOVATIVE SOLUTIONS

MEMS Tech's operating companies will provide enabling technologies that allow for breakthrough end products. MEMS Tech does not plan to deliver end-products to consumers through its operating subsidiaries. Rather, MEMS Tech will provide

investments, licenses, business development, and marketing for its operating companies. In turn, these companies will produce the components that enable end products. The goal of our Channel Development strategy is to help create an efficient channel in which to bring these components to market.

The supply chain that links MEMS Tech's ideas to end products is shown below:

FIGURE 1 – THE MICROSYSTEMS SUPPLY CHAIN



Basic Research — MEMS Tech will monitor and track, but not fund or perform basic research. In specific situations, MEMS Tech will fund applied research.

Applied Technology — Through our operating companies and some third-party partners, MEMS Tech will explore the application of technology to specific tasks and problems.

IP Management
Device Commercialization — At its core, MEMS Tech is an IP holding company and an engine for device commercialization.

Microsystems Fabrication
Device Subassembly — Our operating companies will design, and license or fabricate devices. In some cases our companies will use a MEMS Tech Fabrication Facility to build their devices.

Industrial Design Integration	MEMS Tech believes that the industrial design companies will be important in ensuring that our components are used in new products. We intend to partner with these designers and encourage the adoption of Microsystems technologies.
Component Assembly Product Manufacturing Sales and Distribution Consumers	With few exceptions, component assembly, product manufacturing, marketing, and sales of end user products will be left to the established players in their respective verticals.

We intend to focus our efforts on the four key areas that we expect will have the most upside potential in the next few years:

- Optical Communications
- Biomedical
- Wireless
- Industrial Applications

(See Exhibit 1 to this Appendix C, "*A Microsystems Primer"*, for a description of these industries).

MEMS Tech will bring a wealth of business and marketing expertise to our portfolio companies, helping to "push" these products to market. To that end, we have budgeted significant resources for marketing and public relations. We are currently assembling business development and technical teams in the optical communications, biomedical, and wireless arenas, and anticipate having these teams in place in the near term.

Nevertheless, for the channel to be truly efficient, we need to generate "pull" on behalf of our customers. The market needs to be asking for Microsystems products, and not vice-versa. It's with this in mind that we're creating these affiliate companies. Our goal is to accelerate growth in the Microsystems industry and thereby expand the market for our companies' products and services.

IV. MANAGEMENT TEAM

A. CURRENT TEAM MEMBERS

Biographies of the principal officers of MEMS Technology are included within the text of the within Offering Memorandum.

B. TARGETED POSITIONS

By December 2000, MEMS Tech intends to hire the following additional personnel:

MEMS Tech Holding Company (11 FTE). Planned hires include VP of Human Resources, VP of Finance, VP of Intellectual Property, and VP of Corporate Communications, as well as staff positions in the areas of business development, technical development, university relations, industry relations, human resources, finance, information technology, legal, and administration. We are currently in active discussions with candidates for VP of Finance and VP of Corporate Communications.

MEMS Tech Fabrication Facility (1 FTE). A president for the fabrication affiliate will be hired. We anticipate hiring 25-30 additional employees during 2001 for the fabrication facility.

MEMS Tech Talent. Hiring for the talent group will begin in 2001 with a search for a president for the group. This group will grow to 5 people by the end of 2001.

MEMS Tech Marketing/Media (2 FTE). Our first hire will be a publisher/editor for the Microsystems magazine. We have a strong candidate identified for this position. We've also identified 10 to 15 additional positions that will be filled during 2001.

MEMS Tech has an aggressive growth plan with a number of hires targeted for 2001. (See "Financial Needs and Opportunities".)

V. COMPETITIVE LANDSCAPE

At present, MEMS Tech has no direct competitors. The Company's industry accelerator model is, as far as we have been able to determine, unique to the Microsystems industry (if it were not, the industry might not be as fragmented as it is today). However, MEMS Tech does have numerous *indirect* competitors (many of whom may become partners). Most of these are profiled in a report entitled "MEMS: Powerhouse for Growth in Sensors, Actuators, and Control Systems" (Technical Insights, John Wiley & Sons, Inc. 1999). We have categorized these competitors as follows:

A. SMALL COMPANIES

Most companies involved in Microsystems today are relatively small. Often, they have been spun out of universities or other research organizations. MEMS Tech considers these companies to be potential competitors to its operating companies, but recognizes that many may turn into partners, with technology complimentary to ours. There are over a hundred of these companies in the United States. A representative sample follows:

COMPANY NAME	BRIEF INFORMATION
Aclara	The company (formerly Soane BioSciences) develops microfluidic and microfabrication products for use in genomic (DNA- and RNA-related) and pharmaceutical research. 1999 sales: $3.4 million. IPO in March 2000.
Caliper	Caliper Technologies makes lab-on-a-chip micro-fluidic devices. 1999 sales: $12.1 million. IPO in December 1999.
Cronos	Cronos Integrated Microsystems owes its origins to MCNC, a research center in North Carolina. Cronos benefits both from MCNC's long-standing involvement in MEMS technology and status as one of the world's leading centers for both R&D and manufacturing of MEMS devices. Cronos produces MEMS components for telecommunications (optical and RF), biomedical, pharmaceutical, micro-instrumentation and intelligent surface technology applications. Cronos, which has 52 patents and pending patents, has 67 staff members and annual sales of about $10 million. JDS Uniphase recently acquired Cronos for $750 million.
i-Stat	i-STAT Corporation develops, manufactures, and markets medical diagnostic products for blood analysis providing critical diagnostic information to health care professionals accurately and immediately at the point of patient care. 1999 sales: $45.2 million.
Intellisense	Rapid and cost effective development and manufacturing of total MEMS solutions. Expertise includes Silicon Micromachining, Software tools for MEMS, and Integrated Optics. Sales estimated at under $5 million. Corning, which held an equity stake in Intellisense, purchased the rest of the company in June 2000 at a valuation of $750 million.
Microvision	Microvision is developing a virtual retinal display (VRD) technology that uses a small, wearable projector to cast moving images directly onto the eye's retina. 1999 Sales $6.9 million.
Nanovation Technologies	Nanovation Technologies develops customized integrated optical devices and discrete components for fiber-optic communications. Its product portfolio is based on integrated, high performance optical components including switches, splitters, couplers and monitoring. Nanovation has laboratories at the Massachusetts Institute of Technology and Northwestern University as well as a domestic development and manufacturing facility located in Northville, Michigan.

Standard Microsystems/Iota	Standard Microsystems Corporation is a worldwide supplier of MOS/VLSI circuits for the personal computer industry. SMSC has the leading position in I/O circuits for PCs. SMSC supplies integrated circuits for PC connectivity, local area networks, embedded networking, and microprocessor core logic chipset technologies.

B. LARGE COMPANIES

These include publicly held companies with multiple operating divisions. While these companies are not exclusively Microsystems-focused, Microsystems play a significant role in their operations.

COMPANY NAME	BRIEF INFORMATION
Honeywell	Conglomerate. 1999 sales: $23.7 billion.
Lucent	Switching, transmission, and network systems for voice and data. Integrated circuits for wireless and wired communications, optoelectronic components; optical fiber; cable; connectivity solutions. 1999 sales: $38.3 billion.
Motorola	Motorola is a global leader in providing integrated communications solutions and embedded electronic solutions. 1999 sales: $30.9 billion.
National Semiconductor	National Semiconductor combines leading-edge analog and digital technologies to create highly integrated solutions for the information age. From complete systems on a single chip to high-performance multi-chip products and basic building blocks, National provides optimized solutions for the information appliance, personal computing, consumer and communication markets. 1999 sales: $1.9 billion.
Philips	Electronics conglomerate. Philips has some 60,000 patent rights, 21,000 trademark registrations, and 6,000 design rights worldwide. Key patents are in such fields as optical recording, digital audio coding, digital video coding, and mobile telephony. 1999 sales: $31.7 billion.

Rockwell International	1999 sales: $7.0 billion. The Rockwell Science Center, formed in 1967, has annual sales of around $500 million.
Samsung	Conglomerate. 1998 sales: $28.4 billion.

C. RESEARCH INSTITUTIONS

These organizations are much more likely to be MEMS Tech's partners than its competitors. Generally, these institutions have a mandate to encourage Microsystems research with the intent of making its findings public through licensing or patents. This category includes universities, not-for-profit government research centers, and various industry consortia. Examples include:

- Cornell University
- DARPA (Defense Advanced Research Projects Agency)
- Massachusetts Institute of Technology
- Microelectronics and Computer Technology Corp. (MCC)
- Rensselaer Polytechnic Institute
- Sandia National Laboratories
- Stanford University
- University of California (includes Berkeley and UCLA)
- University of Cincinnati
- University of Michigan
- University of Washington

VI. STATUS AND MILESTONES

A. CORPORATE IDENTITY

We are currently working with a firm to create a new name, logo, and tagline for MEMS Tech. We expect to complete this process in September 2000.

B. FABRICATION FACILITIES

We have had involved discussions with three "centers of excellence" in Microsystems research. It is our intention to build an Industry Accelerator facility at one or more of these locations:

Ann Arbor, Michigan – The University of Michigan is leasing approximately 10,000 square feet of space including lab, service area, and office areas. This facility is referred

to as the "EML" and is not the primary research facility for Microsystems professors and students. In fact, the facility is not currently being used for Microsystems-related activities, but it does support some of the research needs of several university professors. We have toured this facility and have found it to have a very good infrastructure for our short term needs. Much of the equipment in the facility would not serve our purposes and we would need to purchase several new pieces.

The total cost of this equipment ranges from $5 to $10 million depending on whether we acquire it new or used. The lease runs for another four years and monthly operating costs, including rent, are estimated to be $50,000. Our intention is to negotiate a deal with the University and the landlord of the building (E.R.I.M., a non-profit organization interested in a cooperative effort with MEMS Tech).

This facility may also be used to serve our long-term needs if we can scale it with additional lab facilities and equipment.

Albuquerque, NM – We have had several discussions with Dr. David Williams, the Director of Microelectronics and Photonics at Sandia National Laboratories. Dr. Williams is responsible for all Microsystems activities at Sandia, one of the major players in the industry. As an offshoot of the lab's research activities, Albuquerque has seen an increase in Microsystems startups. Sandia actually offers an "entrepreneurial leave" for researchers interested in commercializing technology developed at the Laboratories. We believe that there is an opportunity for MEMS Tech to assist in providing business startup services and capital to this growing area. In addition to high-level interest at Sandia, we are also in contact with professors at the University of New Mexico, the UNM Office of Science and Technology, the City of Albuquerque, and local Microsystems businesses.

Dr. Williams has indicated to us that within a very short period of time, he will enter into an agreement with a qualified third party to assume responsibility for design, prototyping, and low-volume Microsystems manufacturing activities at Sandia, work that is currently being handled entirely by the Laboratories. MEMS Tech is a leading candidate to be this partner.

Berkeley, California – We have presented the concept of an Industry Accelerator to Burton Sage, Executive Director of the Berkeley Sensor and Actuator Center ("BSAC") at the University of California at Berkeley ("UCB"). Mr. Sage has indicated to us that the concept of a Microsystems incubator has been discussed for the last couple of years, but hasn't moved forward.

The UCB is one of the nation's most prolific Microsystems research and development centers. There are nine Directors at the BSAC, and over 90 Ph.D. students.

C. TALENT/RECRUITING

We are currently focused on identifying and hiring a key executive from the executive recruiting industry whose role will be president of the recruiting organization. We intend to have this individual identified by November 2000.

In the meantime, we will begin work on a Talent and Recruiting Database, which will serve to track and sort key prospects in the Microsystems industry.

D. MARKETING/MEDIA

We have performed significant business planning surrounding the MEMS Tech Marketing/Media group. Major accomplishments to date include:

- Development of a "Publication Plan" that details the contents, positioning, costing, revenue model, and competitive analysis for a Microsystems-related publication. Through comparisons with similar publications and industry sizing, we estimate our likely circulation to be near 20,000 readers.

- Meetings with a number of high-level publishers, journalists, and industry consultants.

- Identification of potential advisors, employees, and business partners, including printers, mail-houses, and design shops. Our focus has been on the Ann Arbor area, which has all the critical elements for a growing publication.

- Development of a business plan for the tradeshow business, which includes positioning of the tradeshow, revenue model, costing, and potential partners in hosting these events.

- Our next step is to hire an editor-in-chief and a publisher. We intend to fill this position by October 2000 and have a verbal commitment in place.

E. LOCATION

As described above, MEMS Tech has identified three "centers of excellence" in the Microsystems industry, located in Michigan, New Mexico and California. Given that this is a young industry and there are no centralized areas of commercial activity, MEMS Tech intends to defer our decision on where to locate our headquarters for two years. After two years, we intend to revisit this issue and select a location that is most appropriate given the growth trends and our own business activity.

F. INVESTMENT OPPORTUNITIES

To date, MEMS Technology, Inc. (who will assign its interests to MEMS Tech) has investor relationships with the following Microsystems companies:

MICRONICS
Micronics develops in vitro diagnostic systems based on disposable, microfluidic cartridges. MEMS Tech was the lead investor in their recent financing, and holds a seat on its Board of Directors.

Investment	$ 2,000,000
Total Round	$ 5,000,000
Pre-Money Valuation	$ 15,000,000

HANDYLAB, INC.
MEMS Technology, Inc. has invested in HandyLab, Inc. HandyLab provides point-of-care diagnostic tools and other lab-on-a-chip capabilities including DNA sample preparation and analysis. Strategic advantages of the products will be portability, ease of use, and high-quality testing with small sample sizes. The primary applications will be in the area of in-vitro diagnostics and the clinical research market.

Investment	$ 300,000
Total Round (1st)	$ 1,800,000
Pre-Money Valuation	$ 1,900,000

In addition, MEMS Tech has been working closely with the following two startups:

SENSATION
SENSation will develop chemical sensors for use in devices such as water purity monitors. MEMS Tech co-wrote the business plan and intends to launch this company in Q4 2000.

NU-EN, INC.
Nu-En is a Microsystems-based wireless technology company. We have completed Nu-En's business plan and are currently negotiating for the appropriate IP. We intend to launch this company in Q4 2000.

G. MILESTONES AND RISK FACTORS

MEMS Tech has identified a number of milestones that we need to reach in the coming year. As with any startup business, there is always a risk that one or more of these tasks may prove difficult to complete. By identifying these risks early in the process, we intend to maximize the likelihood of achieving our goals.

YEAR 2000 MILESTONES

Complete business plan and structure. This plan will continue to evolve over the next few months, as we identify new opportunities and strategies.

Raise $20 million now with commitments for an additional $130 million. (See "Financial Needs and Opportunities")

Complete two or more deals with major research institutions. MEMS Tech is establishing relationships regarding intellectual property.

Identify, acquire, and occupy shared office space facility. We intend to have an incubator facility fully operational by mid-year 2001.

Launch one interim MEMS Tech Fabrication Facility. Lay groundwork for a permanent facility in early 2001.

Make initial hires for the Marketing and Media affiliate. We intend to launch the magazine in early 2001 and start tradeshows after midyear.

Launch two Microsystems startups

Make minority investments in two additional Microsystems companies
Finish hiring core MEMS Tech personnel: (See "Targeted Positions")

FUTURE MILESTONES

Incubate 12 Microsystems companies by 2003.

Minority investments in a total of 10 Microsystems companies by 2003.

Develop Microsystems recruiting company in early 2001.

H. ADDITIONAL RISKS

In addition to the risks inherent in fulfilling the milestones discussed above, we have identified other risks associated with building MEMS Tech (in addition to the other Risk Factors described in the within Memorandum):

- Sandia National Laboratories may not choose MEMS Tech as partner with which to work to commercialize Microsystems research.
- Universities and Research Institutions may choose not to work with MEMS Tech.
- MEMS Tech may have difficulty finding enough qualified personnel, either in terms of management or in terms of Microsystems expertise, to staff its offices and new companies at a pace that matches MEMS Tech's rate of growth.
- Some Microsystems research that looks promising today may not translate to commercializable products as quickly as we expect.
- Some Microsystems devices that work in the laboratory may not be practical in non-laboratory conditions.
- Microsystems are sensitive to temperature, contamination, and other physical conditions. Some of these problems may be too difficult to practically overcome.
- Microsystems is still a fairly new field, and there may be poorly understood physical phenomena that could affect microscale devices in ways we do not expect.
- Microsystems-based solutions may be too slow to market, allowing competing technologies that address similar problems to dominate. Furthermore, Microsystems-based solutions may have difficulty displacing existing solutions.
- Because IP is so important in the Microsystems world, some of our work may be stymied by organizations that refuse to license key pieces of intellectual property.
- MEMS Tech's patents and licenses may not provide adequate protection for its companies' products.
- Technologies superior to Microsystems may be developed or discovered, which may materially decrease the value of our patents.

EXHIBIT 1

MICROSYSTEMS: A PRIMER

Bob is in a hurry. He just finished putting the last touches on a proposal, and has to be on the other side of town in 20 minutes to deliver it to a client. He saves his work, clicks the print icon on his computer, and his inkjet printer begins to shoot out pages in full color. He slips the copy into his briefcase, dashes out the door and walks briskly out to his car. Traffic isn't bad, and Bob's thoughts turn to work. He doesn't notice the truck backing out of an alley until it's too late.

The airbag deploys at the moment of collision and inflates fast enough to protect Bob from the impact of the crash. Shaken, bruised, but feeling for the most part unhurt, Bob is at first surprised to hear sirens approaching so quickly, but then remembers the GPS communications system built into his car. It must have called 911 as soon as the airbag deployed. Despite his protests, Bob is put on a stretcher and placed in the back of an ambulance; paramedics perform some basic tests on the way to the hospital.

A couple of hours later, Bob is seated in the hospital's lounge, talking to a patient while he waits for his wife to come pick him up. The patient's an older man, and he's telling Bob about his new pacemaker. "Between that and this hearing aid, I'm practically bionic," he chuckles. Bob smiles, glad to be in one piece. The proposal doesn't seem so important now, but when he needs it, he knows it will be stored safely on his computer's hard drive.

In just a few hours, Bob interacted with 7 Microsystems Devices. Ten years from now, that number will have increased more than tenfold.

Microsystems technology is in widespread use throughout technologically advanced countries, and its pervasiveness is growing. In a decade, Microsystems will be as ubiquitous as Integrated Circuits are today. We won't notice them any more than we notice the computer chips in our watches, phones, cars, and microwaves, but they will be everywhere. They will transform our society on a scale to match the current Information Revolution.

This primer will introduce the reader to Microsystems. After reading it, you will have a good sense of what the term means, what the market for Microsystems looks like, both today and in the future, and the academic and commercial organizations currently active in this exciting field.

WHAT ARE MICROSYSTEMS?

What we refer to today as Microsystems actually encompasses several fields, related to each other by their focus on the world of the very small. These include, but are not limited to, ***Microelectromechanical Systems (MEMS), Micro-Fluidics*****,** ***Micro-Magnetics*****,** and ***Micro-Optics*****.** Further complicating matters, the field that we call

Microsystems is given different names depending on geography. For example, in Europe, the acronym ***MST*** (Microsystems Technology or Microstructures Technology, depending on whom one asks) is widely used, whereas Japan refers to the field as ***Micromachines*** or ***Mechatronics***. In the United States, ***MEMS*** is usually used to refer specifically to silicon-based Microelectromechanical Systems, but at times to Microsystems in general. Here is how these various terms have been defined:

MEMS:
"Integrated microdevices or systems combining electrical and mechanical components, fabricated using integrated circuit (IC) compatible batch-processing techniques, and varying in size from micrometers to millimeters. These systems merge computation with sensing and actuation to change the way we perceive and control the physical world."

(MCNC, 1996.)

"Microelectromechanical systems (MEMS) are specialized silicon microdevices that combine microprocessor circuitry with tiny three-dimensional machine structures no larger than a grain of sand."

(MEMS—Powerhouse for Growth in Sensors, Actuators, and Control Systems, 1999.)

Strictly speaking, a Microsystems device is a MEMS device if it includes moving or deformable parts (gears, pumps, etc.) and is integrated on silicon. Many Microsystems devices (e.g. sensors, mirrors) do not possess moving parts and so are not MEMS devices *per se*. Likewise, many Microsystems devices are fabricated in something other than silicon.

MICROMACHINES/MECHATRONICS:

"Micromachines are composed of functional elements only a few millimeters in size and are capable of performing complex microscopic tasks."

(Micromachine Center, 1996)

This definition is a bit broader, but isn't very specific.

MST:

"A microsystem is an intelligent miniaturized 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 or multichip hybrid."

(Microsystems in the 4th Framework, IT, Sept. 1996.)

MST comes closest to encompassing the scope of what we mean by Microsystems. It doesn't limit its definition to components such as moving parts or fluidic channels. Rather, it describes devices in terms of their functions (sensing, actuating, etc.).

Each of these definitions accurately describes aspects of Microsystems, but to really understand the field, it helps to see some examples of Microsystems that are currently in use.

EXAMPLES OF MICROSYSTEMS

In silicon-based Microsystems devices, integrated circuit fabrication techniques are used to reduce the size of mechanical features to the miniature dimensions of microelectronics (*millions* of features per square inch!). Integrating these mechanical features with electronic circuits on the same chip offers a wealth of product opportunities not possible with conventional design and manufacturing approaches. These devices can contain mechanical, optical, fluidic, and thermal mechanisms in various combinations, all integrated with electronic components.

As illustrated in Bob's story, Microsystems are already components of much of the technology that we take for granted today:

Inkjet printer cartridges. These integrate *micro-fluidics* and *microelectronics*, to apply extremely fine individual droplets of ink, which are "flash evaporated," leaving pigment behind on the page.

Accelerometers. These devices sense changes in the rate of motion along a path. Commonly used in automobile airbags, MEMS accelerometers can sense an impact and trigger the airbag quickly enough to protect people from the force of a collision.

Pressure Sensors. These devices are currently used in the medical arena. Many blood pressure devices use pressure-sensing Microsystems to achieve higher degrees of accuracy in measurement. Air pressure sensors are commonly used to monitor cabin air pressure in airplanes.

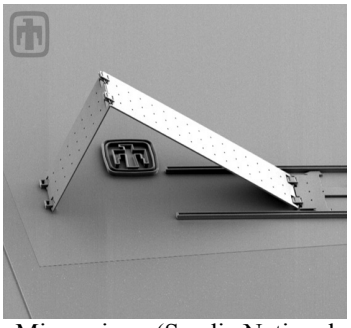
Gyroscopes. MEMS gyroscopes are beginning to be used in automobiles as part of automotive ride-control systems and Global Positioning Satellite (GPS) sensing systems.

Microphones/Speakers. Microsystems are used in devices such as hearing aids, for which a small form factor is of the utmost importance.

FUTURE MICROSYSTEMS APPLICATIONS

While current Microsystems activity is interesting, perhaps more exciting is what lies just around the corner, in the two-to-ten year timeframe. Here are a few examples of work being done in Microsystems, with expectation of commercial results in the near future:

Micro-optics. Some digital projectors use arrays of tiny moveable mirrors to pinpoint rays of colored light onto a screen, creating a crisp, high-resolution projected image. Recently, a number of companies have announced research that involves using similar mirrors to route and switch individual wavelengths of light through optical fibers. Faster, cheaper Microsystems-based switches will enable networks to keep up with the bandwidth demands brought about by the Information Revolution.



Micromirror (Sandia National Laboratories)

"Lab-on-a-chip" devices. Researchers are working on micro-fluidic devices, consisting of chips that contain tiny channels through which minute amounts of fluid are propelled by MEMS micro-pumps. These devices can separate a fluid (such as blood) into its more basic components, allowing for rapid chemical analysis. Similar devices could be used to quickly analyze strands of DNA.

Information storage. As computer hard drives become smaller while the amount of information they store grows, Microsystems components are beginning to replace larger conventional components. Currently, hard drive read/write heads are made using micro-machined processes, and complete Microsystems information storage devices are expected in the next few years.

"Smart" pills. Capsules containing MEMS devices could, when swallowed by a patient, release medication dosages at timed intervals, thus reducing the number and frequency of pills a patient needs to take.

Inertial Guidance Systems. By combining various micromachined sensors and actuators into a single system, Microsystems devices can be used as guidance systems for aircraft, rockets, satellites, and other airborne vehicles. The United States military and aerospace industries have done extensive research on this application of Microsystems technology.

Air Quality Sensors. Microsystems devices can monitor air quality, and give precise measurements of impurities. These devices may be used in factories, automobiles, and industrial areas.

Cellular Telephones. Many of the components of cellular phones will be replaced with Microsystems devices, including transceivers, switches, microphones, speakers, and antennas. While this is still a few years off, incorporating Microsystems into cellular

telephones will make them smaller (think of the "Dick Tracy watch"), and require much less power to operate.

WHY MICROSYSTEMS?

As the examples above illustrate, Microsystems technology is and will continue to be used for a wide range of applications. However, some of the aforementioned products (e.g. gyroscopes, accelerometers, and sensors) exist already on the "macro" scale. What advantages does microsystem-degree miniaturization offer over comparable large-scale systems? There are several:

Cost. Microsystems, once designed, are not expensive to produce. Most Microsystems devices are manufactured using materials, tools, and techniques derived from integrated circuit design and production. As hundreds or thousands of Microsystems devices can be "stamped" onto a single silicon wafer or polymer substrate, manufacturers can produce a Microsystems device at a fraction of the cost of its macro-sized counterpart.

Size. The smaller a device is, the more places it can be used, and the more likely that it can be used in ways considered impractical on the macro-scale. For example, it doesn't make sense to put a traditional gyroscope on a video camera—the gyroscope is simply too big. A MEMS gyroscope, however, can be invisibly incorporated into the circuitry of a video camera, and is quite useful for counteracting the normal movements of the user to keep the camera image stable.

Low Power. Microsystems devices use a fraction of the power required by their macroscale counterparts. This allows them to function semi-autonomously with an embedded power source. It also makes it cost-effective to place millions of Microsystems devices on a single device.

Disposability. Microsystems can be made in huge quantities at a low cost, so that it becomes practical to use them in ways that wouldn't make sense for larger, more expensive, less easily-replicable devices.

Interactivity. Microsystems can be designed and integrated with traditional integrated circuits to sense a stimulus (*microsensors*), process it (*integrated circuits and software*), and then respond (*microactuators*), thus cost-effectively closing the feedback loop with the real world. For example, a Microsystems sensor might be injected into a patient, where it would continuously monitor her blood chemistry. Electronics and software on the same chip could analyze the sensor data and provide signals to a portable micro-pump to release the appropriate amount of a drug (e.g. insulin) over the course of a whole day.

THE MICROSYSTEMS MARKET

There are countless potential applications for Microsystems, but descriptions of things to come, while exciting, don't tell a complete story about the overall Microsystems market. Fortunately, in the last ten years, a number of organizations have published Microsystems market studies:

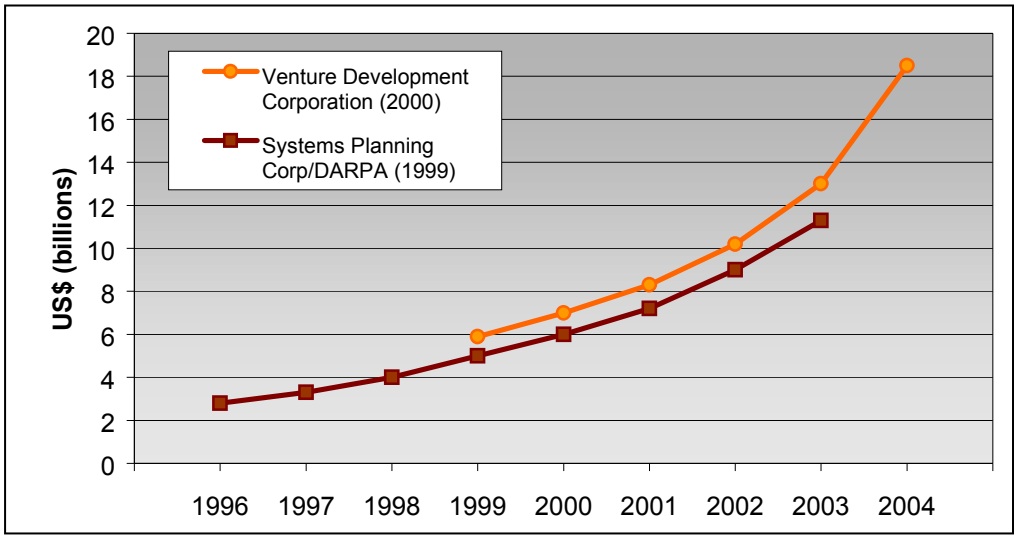
- Battelle (1992)
- Systems Planning Corp./DARPA (1994)
- Semiconductor Equipment and Materials International (1995)
- SGT (1996)
- Intelligent Microsensors Technology (1996)
- SRI Consulting (1997)
- NEXUS (1997)
- Frost and Sullivan (1997)
- Systems Planning Corp./DARPA (1999)
- Venture Development Corporation (2000)

These studies have varied greatly in both their mission and methodology. Likewise, the size and composition of the Microsystems industry has been the subject of much debate. If a Microsystems component enables an entire product, what is the market size for the Microsystems component– the retail price of the product or the cost of the component? Furthermore, products often span multiple segments. For example, optical switches that are used to transmit data via fiber optics networks might be classified as either "Information Technology" or "Communications".

For these reasons, the studies mentioned above vary dramatically in their market projections. Much of what we present below comes from the May 2000 Venture Development Corporation (VDC) study. We chose this study because it is the most recent, it has a sound methodology, and it is comparatively conservative in its projections.

Venture Development Corporation predicts that the market for Microsystems components will reach $18 billion by 2004. *Figure 1* below shows the projected growth from both the VDC study and the SPC/DARPA study from 1999.

Figure 1 - Market Size of the Microsystems Industry



There are several ways to divide the market— by technology, product, or industry. We'll take a quick look at the technologies and products and then focus on the industries they'll impact.

SEGMENTATION BY TECHNOLOGY

In the near future, we expect to see commercial activity in the following Microsystems areas:

Micro-Machined Passive Elements. Currently, hard disk drive heads are the only devices using this technology.

Inertial Measuring and Sensing Devices. Used to detect changes in inertia, such as in car airbags.

Process and Environmental Sensors. Gas leak detection, gene sequencing, microphones for hearing aids, etc.

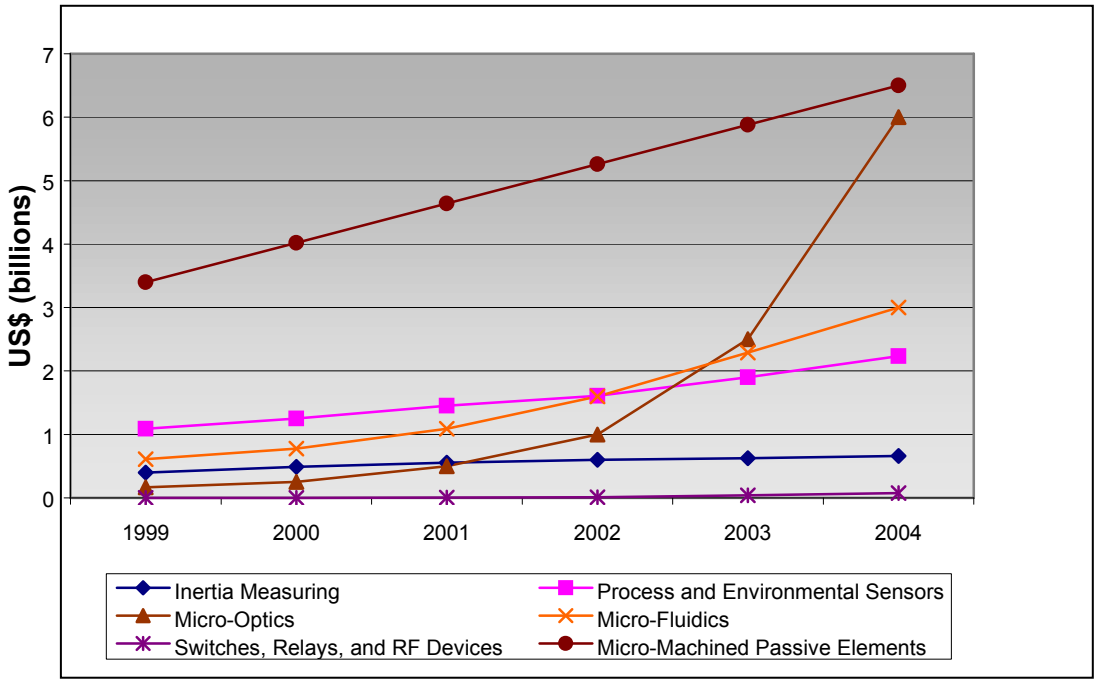
Micro-Optics. Used in fiber-optic networks.

Micro-Fluidics. Micro-pumps, such as those used in inkjet printer heads and fuel injection nozzles.

Switches, Relays, and RF Devices. Used in cellular telephones and telecom switches.

Figure 2 represents the current activity and projected growth in these areas.

Figure 2 – Segmentation by Technology



While the proliferation of hard drives is driving steady growth in the passive element category, the micro-optics category is by far the fastest growing segment, mainly due to growth in fiber-optic networking. Although the market for inertia measuring devices looks fairly flat, the real story is somewhat more complicated. Downward pricing pressure and simplified designs are expected to slow growth of airbag sensor revenue, while the incorporation of other types of inertia sensors into automobiles makes up the difference.

SEGMENTATION BY PRODUCT

Given time, Microsystems technologies will impact every commercial sector and will appear in thousands of products in all walks of life. We've tried to identify the product areas with the most promise in the near future:

Gas and Smoke Sensors. In the next few years, low priced gas and smoke sensors should be available for widespread use in commercial and home alarm systems.

Pressure and Flow Sensors. Used in industrial automation applications such as machine and process control and quality assurance.

Hard Drives. Most of today's hard drives use Microsystems devices.

Computer Displays. Flat panel and projection displays for laptops and desktop computers and large-screen televisions.

Printheads. Used in Inkjet Printers.

Optical Networking Products. Optical switches and crossovers.

Cellular Telephones. Continuing to shrink the phone's form factor.

Pacemakers and Blood Pressure Sensors

DNA Analysis and Gene Sequencing Devices

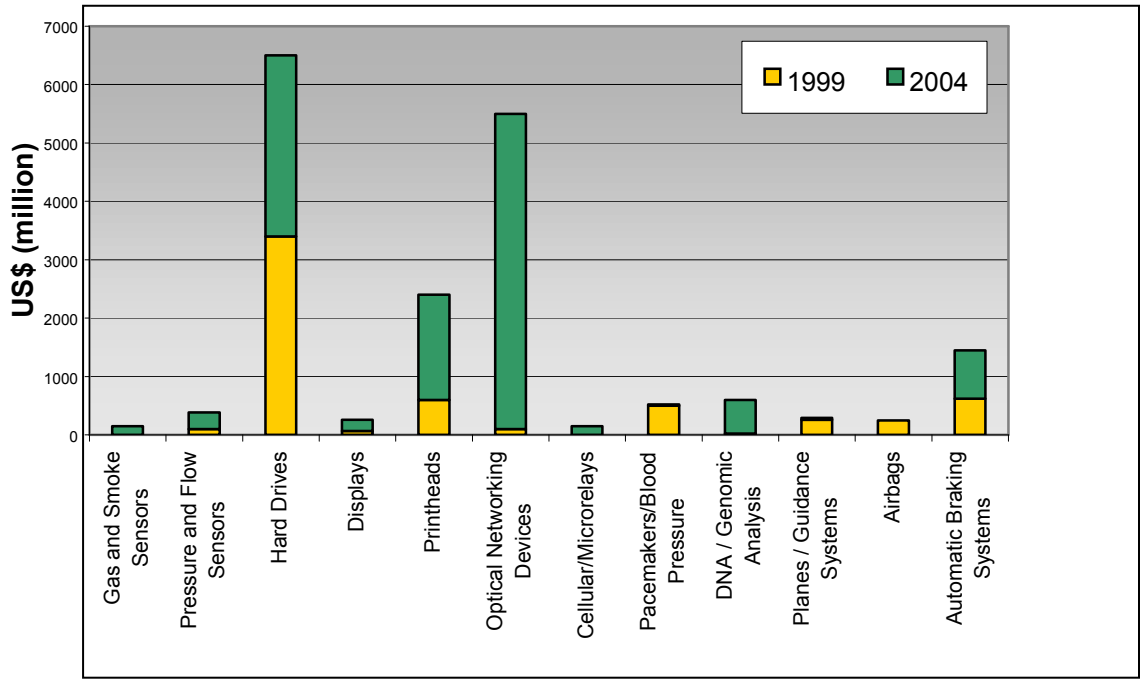
Military and Aerospace Applications

Airbag Accelerometers

Other Automobile Sensors. They provide skid-detection for Antilock Braking Systems and vehicle stability management.

Figure 3 describes the anticipated growth in each of these product areas:

Figure 3 – Segmentation by Product

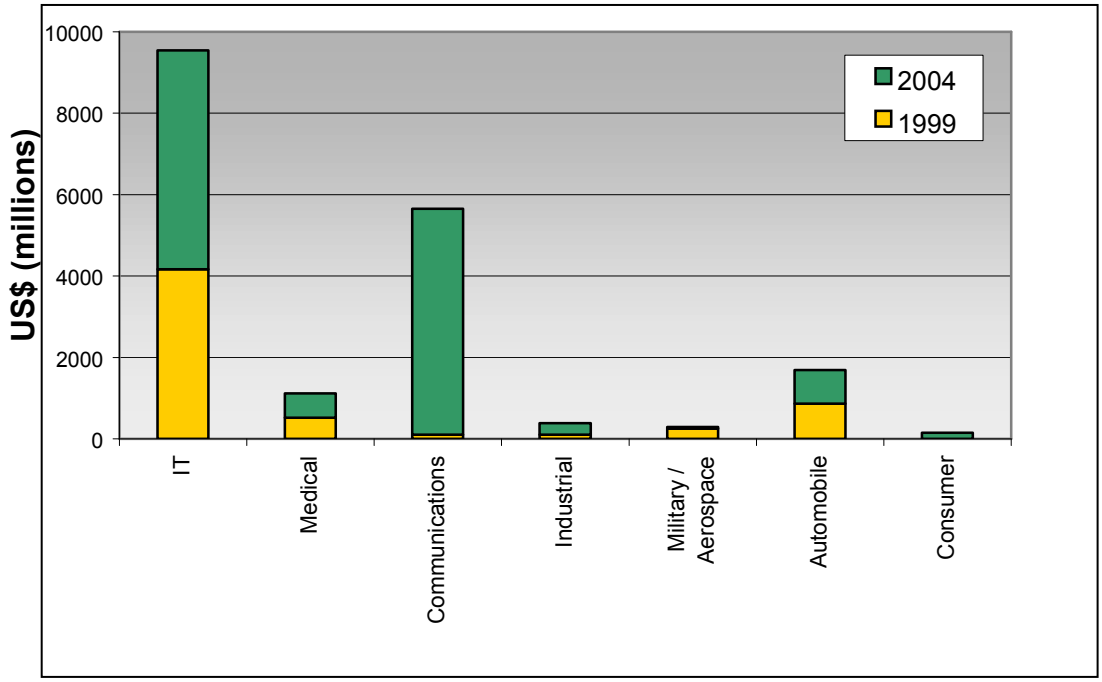


Again, hard drives and printers are growing as computer technology spreads and digital cameras drive demand for inkjet printer heads. Optical networking growth will be dramatic. We also expect exciting growth from gas and smoke sensors, pressure and flow sensors for industrial automation, computer projection displays, large-screen televisions, tools for DNA and genomic analysis, and automatic braking systems.

SEGMENTATION BY INDUSTRY

Finally, let's take a detailed look at the industries these technologies are impacting. Figure 4 describes the anticipated growth in each segment:

Figure 4 – Segmentation by Product



INFORMATION TECHNOLOGY

Information Technology (IT) is a broad category estimated to top $1 trillion by 2002. Typically, IT includes software, hardware, services and support.

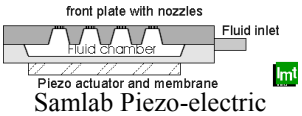
Microsystems opportunities in IT will be in the area of continued miniaturization, integration and cost reduction of various components. Specifically, growth areas for MEMS include data storage, displays (both flat panel and projection), bar code readers, and printers. In addition, Microsystems is used in wireless applications for RF modems, mice, keyboards, and networking.

VDC estimates that the Microsystems-IT market will grow from just over $4 billion in 1999 to $9.5 billion in 2004, making IT the largest market for Microsystems technologies.

MEDICAL

The $2 trillion healthcare market continues to grow, driven by an increasing population and improved technologies and services. Two of the largest segments include the $300 billion pharmaceuticals and biotech market, and the $100 billion medical instruments market.

Continued demand for higher accuracy, reduced cost, miniaturization and advanced technologies make Microsystems an integral part of the medical industry's future.



Samlab Piezo-electric "smart inhaler"

MEMS enables inexpensive "sensing", the first step in diagnosing and monitoring a patient. In-vitro diagnostics is a $19 billion market. It encompasses large laboratory analysis and disposable assay devices. The market for disposable blood glucose sensors totals $1.3 billion alone. Further opportunities exist for detection of heart attack enzymes, infectious agents, drug screening, and DNA testing.

An estimated one billion blood tests are given each year in the U.S. Forty percent of these tests involve routine analysis. In the traditional blood analysis process, blood is sent from the phlebotomist to a central lab for analysis. However, "point-of-use" whole blood analysis is beginning to replace the traditional way of doing routine tests. "Point-of use" analysis gives caregivers in any setting an instant look at their patient's blood vital with a mere finger-prick of blood, enabled by inexpensive, disposable Microsystems sensors.

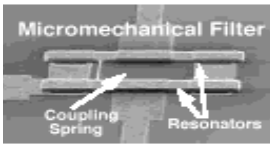

Tricumed Implantable Micropump

With the advent of Microsystems-enabled inhalers, implantable pumps, intelligent pills, less invasive surgical and diagnostic technologies, laboratories-on-a-chip, hearing aids, pacemakers, and even artificial organs, the medical products future is rich. However, some of the most exciting Microsystems opportunities exist before the technologies even reach the patients, in the fields of drug discovery and pharmaceutical manufacturing. Highly automated, high-throughput screening and production equipment requires the ever-increasing precision of such specialized components as well plates, micro-reactors and micro-spectrometers. Products in these categories don't require extensive FDA-approval process and are poised to show returns in the next few years.

VDC expects increased competition in the blood pressure sensors sector to cause price erosion in the next few years, but growth in the DNA and genomic analysis sector should more than take up the slack. While there was almost no revenue in this area in 1999, we expect it will be a $600 million business by 2004, with compound annual growth rates between 100% and 150% into the foreseeable future.

COMMUNICATIONS

The communications industry is exploding, fueled mostly by the fantastic proliferation of wireless and fiber optic devices. Still in relative product infancy, wireless handsets are rapidly becoming feature-rich, more powerful, smaller, and more efficient. Fiber optic cables provide the backbone for Internet and e-commerce data. With an average annual growth rate of 7%, the communications industry is expected to reach $1 trillion by 2003.

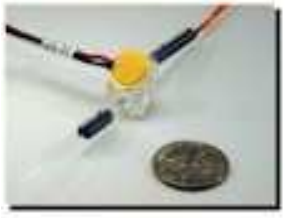


A MEMS Wireless

Microsystems plays a huge role in this industry in both the hardware used by consumers and the infrastructure of the service providers.

One specific application for this technology is in the wireless sector. Many see the year 2000 as a breakout year for wireless. 160 million new handsets were sold in 1999 and 600 million wireless phones are in use worldwide. Cellular phones have won public acceptance more quickly than any other consumer electronics product in history, including color and cable TV, fax machines, and VCRs. The opportunity for widespread integration of Microsystems into wireless devices is enticingly close. A hefty 15% of a cellular phone's total cost consists of its wireless transceiver and many of its sub-components, such as micro-mechanical filters. Microsystems enable smaller, cheaper, and more efficient alternatives to many of these components, resulting in overall improvements in size, cost, and performance.

An even greater opportunity than wireless is fiber optics, which will drive staggering growth in the next few years. Fiber optic networks can transmit terabits per second of information across great distances, but are limited by the speed of the electronic switching and routing components required for the data and voice streams. Today's electronic switching hubs are bottlenecks, many times slower than the main-line fiber optics they connect.



A fiber optic switch

Microsystems applications in this area involve optical connections, beam splitters, switches, and multiplexers. Optical connectors require significantly increased assembly precision over today's electrical connectors. While considerable technical challenges still exist, optical switching has the potential to be one of the largest single Microsystems applications, reaching $5 billion by 2004. The recent scramble by telecommunications companies to acquire Microsystems technologies indicates the level of activity expected in this area. In just the past six months, two noteworthy deals have been made: JDS Uniphase's acquisition of Cronos, and Corning's purchase of IntelliSense. Each acquired company was valued at $750 million.

INDUSTRIAL AUTOMATION

Microsystems will have a significant impact in the area of industrial automation over the next few years. Microsystems devices are used for monitoring and controlling machines and machine tools. Inertial measuring and sensing devices, such as accelerometers or micro-gyroscopes, will be used to provide feedback to a machine's controller for six-axis (X, Y, Z, Pitch, Roll, and Yaw) movement. Such feedback is essential for today's complex machine tools. Pressure and flow sensors are also used to monitor conveyors while Microsystems-based sensors are used to monitor fluids, gases, and ambient air to guard against contaminants.

VDC anticipates that the industrial automation Microsystems market will grow from $100 million to $385 million by 2004.

MILITARY

"Military" products are often products classified in another sector, but sold to governments for their military use. While there are some very specific military applications for Microsystems, VDC feels that the primary products and technologies are well captured in the other areas. They do not anticipate significant growth in this area.

AUTOMOTIVE

The effect of Microsystems on the automotive arena has been tremendous. Automotive airbag deployment systems, which use silicon micro-accelerometers, had estimated sales of $245 million in 1999. Other applications include:

- Fuel injection micro-nozzles
- Navigational systems
- Communications systems
- Air flow
- Fuel flow
- Exhaust gases
- ABS Systems
- Crash avoidance
- Obstacle detection
- Noise
- Driver ID
- Alarm Systems

Some predictions put sensors and electronics at an estimated 30% of a car's value in a few years. Microsystems components alone are projected to reach $1.7 billion by 2004[5].

CONSUMER PRODUCTS

Many of the products already discussed apply to the home consumer; however, additional consumer opportunities center on making the home "smarter." As sensors become less expensive and more capable of diverse abilities, they will proliferate within microwaves, coffee makers, toasters, ovens, refrigerators, lighting, hot water heaters, furnaces, and air conditioners. These devices will become networked together, with the central hub being the home computer or a central processor located within the refrigerator, telephone, or television set.

Additionally, recreational consumer products offer fertile ground for MEMS. These include portable and home stereos, DVD, video games, televisions, VCRs, and cable hook-ups. There are also calculators, cameras, camcorders, clocks, watches, answering machines, and hand-held "smart" tools. The hunting ground for consumer applications seems endless.

[5] Venture Development Corporation, May 2000

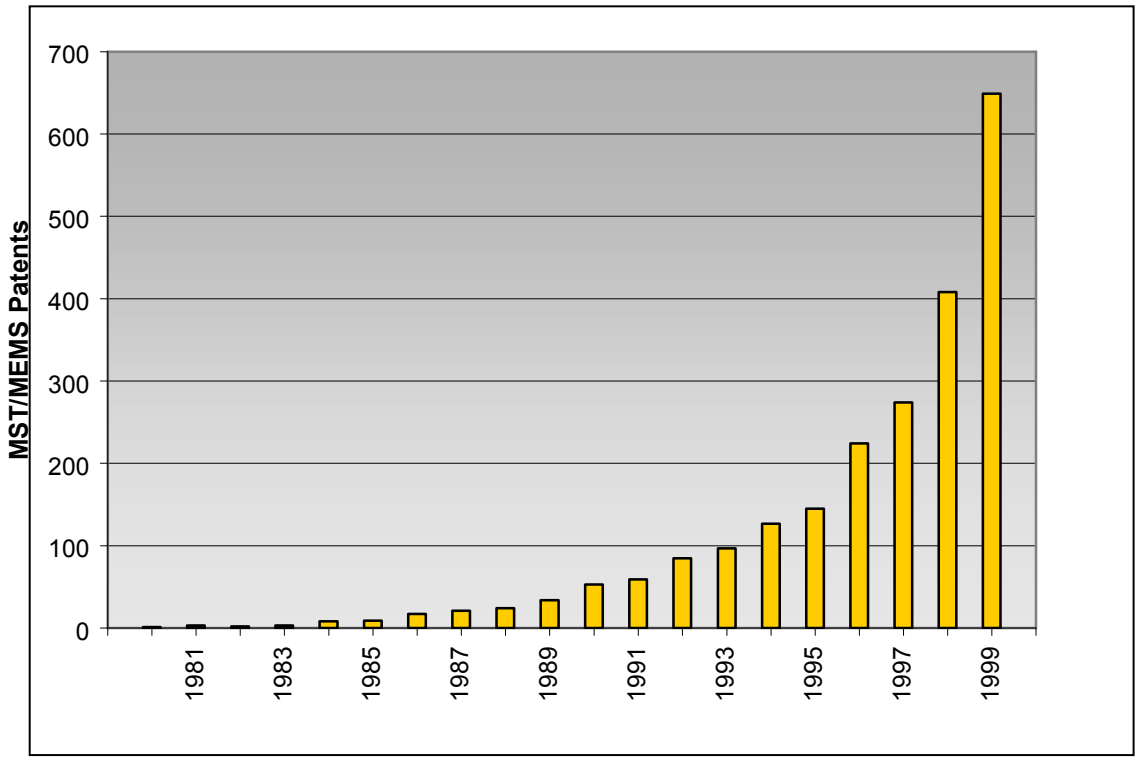
As exciting as the consumer market is, VDC does not expect it to reach its full potential until Microsystems have become fully entrenched in some of the sectors mentioned above. Widespread consumer applications for Microsystems are still some years away, but a good Microsystems strategy should keep the consumer sector in its longer-range sights.

KEY PLAYERS IN MICROSYSTEMS

Activity in the Microsystems arena has been fairly well distributed between the United States, Europe, and Japan, with the most exciting developments traditionally occurring in academia. More recently, patent registration has begun to explode, indicating an intention to commercialize these technologies.

Figure 5 shows the growth in patent registration over the last 20 years:

Figure 5 – Worldwide Microsystems Patent Assignees



The major research institutions ranked by total Microsystems patent registrations are:

- The University of California
- Massachusetts Institute of Technology
- Stanford University
- Cornell University
- Wisconsin Alumni Research Foundation
- The University of Michigan
- Cal Tech

COMMERCIAL PLAYERS

There is no single "center of excellence" for the Microsystems industry in the United States. While there are hundreds of companies that design and build Microsystems devices, they are located throughout the world. These range from large Fortune 500 companies, like Honeywell and Texas Instruments, to smaller startups that focus on specific Microsystems designs and applications. Following is a list of some of the more visible players in the Microsystems field:

- Analog Devices
- Cronos
- Daimler-Benz's Temic
- HEI
- Hewlett Packard Semiconductor
- Honeywell Transducer
- Hughes Electronic
- IntelliSense
- JDS Uniphase
- LSI Logic
- Lucent
- Motorola
- National Semiconductor
- Northrop Grumman Electronics
- Philips
- Raytheon
- Standard Microsystems
- STMicroelectronics

CONCLUSION

This is an exciting time for Microsystems. After more than two decades of research, the technology has moved out of the laboratory and into the "real world." The National Research Council attests that "[this] technology is now poised to enter a second phase of product realization, which is marked by the creation of entirely new markets." Over the next few years, there will be an explosion of new applications and new companies focused solely on Microsystems, and by the end of the decade, some Microsystems companies will be as well known as Intel and Cisco are today.

RESOURCES

The following resources might be useful, to learn more about Microsystems technology:

WEB SITES

The MEMS Clearinghouse
http://mems.isi.edu/index.html
Maintained by the University of Southern California's Information Sciences Institute, this is a good site for current information about Microsystems-related news, announcements, and conferences. It also provides a good introduction to MEMS.

Homepage of NEXUS, a European Microsystems Organization
http://www.nexus-emsto.com/
Links to Microsystems Resources

http://www.trimmer.net/
Maintained by William Trimmer, a MEMS consultant.

BOOKS

Travels to the Nanoworld: Miniature Machinery in Nature and Technology, by Michael Gross.
Copyright 1999 Plenum Trade, New York, NY

An Introduction to Microelectromechanical Systems Engineering, by Nadim Maluf.
Copyright 2000 Artech House, Inc., Norwood, MA

Fundamentals of Microfabrication, by Marc Madou.
Copyright 1997 CRC Press LLS, Boca Raton, FL

EXHIBIT 2

MICROSYSTEMS PUBLICATIONS

In the Microsystems space there are currently several publications. Most of these are "journals" of technology:

- Applied Surface Science
- Journal of Applied Physics
- MST
- Micro
- Sensors & Actuators
- Thin Solid Films
- Journal of Nanoscale Science and Technology (web only)
- Journal of Microelectromechanical Systems
- Journal of Smart Materials and Structures
- Journal of Micromechanics and Microengineering
- Materials Research Society Bulletin

There is also a 16-page industry newsletter called *Micromachine Devices*, published by Cahners Business Information, a division of Reed Elsevier.

EXHIBIT 3

MICROSYSTEMS TRADE SHOWS

A recent listing of Microsystems conferences in the MEMS Clearinghouse shows the following:

- 2000 Solid-State Sensor and Actuator Workshop 04-08 Jun 2000
- Actuator 2000 19-21 Jun 2000
- Microsystems: Mechanical, Chemical, Optical 24-28 Jul 2000
- Introduction to MEMS and the Multi-User MEMS Processes 31 Jul 2000
- IEEE International Conference on Optical MICROSYSTEMS 21-24 Aug 2000
- IBC: Early Stage Production & Purification Development for Biologics 21-23 Aug 2000
- IBC: International Symposium on Production Site Transfer 21-23 Aug 2000
- Materials Technology for Piezoelectric and Pyroelectric Microsystems 11-14 Sep 2000
- IBC: 5th International Conference on Biomolecular Diversity 11-13 Sep 2000
- 6th International Symposium on Magnetic Materials, Processes and Devices 22-27 Oct 2000
- IBC: 7th Annual Chips to Hits 2000 06-09 Nov 2000
- Introduction to MEMS and the Multi-User MEMS Processes 13 Nov 2000

This is by no means an exhaustive list of Microsystems conferences, but is presented to give a flavor of the technical nature of existing conferences.