MEMS Commercialization: Ingredients for Success

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ABSTRACT

The commercialization of most new technologies has traditionally taken many more years than pundits predict. MEMS are no exception to this rule. Five-year predictions of explosive growth often turn into 20-year marathons of endurance.

The adoption of new technology often requires overwhelming evidence of superiority before displacing an established technology. As a rule of thumb, if one can't see a tenfold advantage in some parameter of importance, such as performance or cost, the likelihood of successful adoption is low.

Several MEMS devices have emerged that have significant commercial importance. Several others appear to be on the threshold of commercial success. The characteristics of some of these MEMS devices will be examined, the ingredients for success distilled from this group, and some predictions for the future will be offered.

INTRODUCTION

Commercialization is a frequently heard word in association with MEMS. There is even a yearly meeting devoted to the subject. For the purposes of this presentation, commercialization will be defined as "contributing to the **creation of value**", which is the primary objective of commerce. Value can be created in a variety of ways. In one case, the technology might enable a device, which is sold directly, contributing sales and profits directly to those involved in its manufacture and distribution. In another case, the technology might enable a device that further enables a higher-level system that generates sales and profits. Hundreds of millions of **pressure sensors** and tens of millions of **accelerometers** fall into the first category.

Hundreds of thousands of Digital Light Processors fall into the latter.

What are the characteristics of devices that create value and fall into the classification of commercial success?

One characteristic is that the device must provide a **compelling reason for adoption**. Unless the application is totally new, there is an existing solution to the problem any new device attempts to address. The producers of the established solution have the advantage of an established infrastructure. The device or system is fully characterized in the end application. Reliability has been proven. The supply chain is in place. All the unspecified characteristics have been shown to be under sufficient control to keep the customer's production line moving smoothly. The end customers, suppliers of expensive systems, must see sufficient advantage over the existing solution to accept the risk of change.

EARLY SUCCESSES

Compelling reasons come from a variety of sources. The first and foremost reason one might be compelled to adopt a new technology for an established application is **reduced cost**. If a new technology effects a significant cost reduction in the end system directly by lowering the cost of an established component type, a substitution will result. Pressure sensors, the first MEMS devices to be successfully commercialized, followed this path. Pressure sensors, before the advent of the micromachined parts that emerged in the 1980's, were assembled from several parts and handled individually throughout their production flow. MEMS enabled a simpler construction, batch fabrication, better uniformity and ultimately lower costs. These factors caused a slow and steady displacement of older technology.

Another commercialization success story is that of **airbag accelerometers**. In this case there were two established mechanical switch technologies that had been deployed in high volume before the development of viable micromachined acceleration sensors. It is interesting to note that the technology for airbags existed for twenty years before their adoption began in automobiles. Only after legislation was passed by the United States Government mandating supplemental restraint systems did airbag installations proliferate. Furthermore, they only grew in popularity after the less expensive, wrap-around, non-optional shoulder harnesses were bitterly rejected by consumers. With a non-intrusive airbag available, safety began being a factor that sold cars.

The first micromachined acceleration sensors cost the same as the mechanical switches that they sought to replace, $10-$20. The real value added by the accelerometer was that a single accelerometer in the electronic module of the airbag control, correctly mounted to the module and to the frame of the car, was sufficient to detect the severity of a crash. This meant that one accelerometer in the end application could replace 3-5 switches. Additionally, the single-point-sensing module eliminated the need for a wiring harness and a supplementary diagnostics module. Conservatively, the use of an accelerometer saved $100 on each car that used one, instead of several mechanical switches. Single point sensing was the real valuable contribution enabled by a continuous analog acceleration sensor.

The rate at which micromachined accelerometers were introduced into automobiles was remarkably fast. In a four-year period between 1995 and 1999, the accelerometer went from <20% of the market to >80% of the market. The rapid rate of introduction was a direct result of the huge economic advantage that accrued to the automobile manufacturer. Even $50 per car savings on twenty million passenger cars amounts to $1B in savings.

Far less of the value accrued to the manufacturers of micromachined acceleration sensors. Over the last five years some one hundred million or more accelerometers, at an average selling price of around $5, went into automobiles. The total sales are less than the annualized savings of the automobile companies. Hence, while the accelerometer has been a major commercialization success story, the value accrued more to the consumer than to the supplier.

A very analogous application to the airbag problem is a **crash data logger** for packages or containers. In this application, additional information is provided to the shipper for additional cost. This application has been slow to develop.

Low g accelerometers enable a new and more intuitive input means for games players. Initial performance data on MEMS based game controllers showed ease of use and general pleasure from the users, but again, it represents improved capabilities for higher cost. This application is taking additional time to grow.

In the case of the Texas Instruments **Digital Light Processor**, the technology took over twenty years to come to market. This commercialization success had a very long gestation period. The original work was aimed at defense applications where it never matured. About eight years ago it became refocused on display applications. The high volume application, a CRT replacement for televisions and computer displays, had cost requirements below the cost capabilities of the DMD (<u>D</u>igital <u>M</u>irror <u>D</u>isplay). The solution for TI was to integrate the device into the core of a business video projector where a premium would be paid for the performance improvement of the display that their high brightness component enabled. With modest volume of tens of thousands, from the sales of this more expensive system, the cost might very well be reduced to the point where much higher volume applications can be addressed. When the display can go into TVs it could see volumes into the tens of millions.

Fluid handling systems are the next area where MEMS have found some major applications. The ink-jet printer head is the oldest and highest volume product where MEMS techniques have been used, some debate whether they are truly MEMS. There have certainly been hundreds of millions of them sold and at least parts of many designs have micromachined elements within them. They shall be MEMS for the purpose of this talk.

The **ink-jet print head** demonstrates the kind of application where MEMS fluidic devices can be successful. The application demands the projection of microscopic quantities of fluid material. The device is relatively simple in construction, amenable to the batch processing techniques used in the IC industry and used in very high volumes as the system is thrown away often when the reservoir is empty. The performance-limiting feature on the device is a simple orifice whose dimensional control is easily within the range of photolithographic tolerance. In the case of the bubble-jet printer, thermal management is also needed and MEMS technology facilitates this property.

The ink-jet printer has had a big impact on the commercial world. It has brought high quality printing to the home computer user. I personally own three. The print quality is very high and allows the completion of many office projects conveniently at home.

More **general use fluidic components** have had more of a struggle emerging out of Research Laboratories and into the commercial marketplace. Redwood Microsystems has built and sold micromachined valves and more complex flow control systems for several years. Their struggle is indicative of the application of a microscopic component into a market generally concerned with moving macroscopic quantities of material. When moving a big rock, one usually uses a big crowbar or a powerful machine. MEMS will have no impact on that kind of problem. Only when a small object is moved a very small distance, are MEMS solutions viable. Additionally, for a general purpose device to be incorporated into a large number of applications, the complete set of compatible components need to be in place. It is not enough to offer a valve if the plumbing and the sensing components the pumps and the connectors are not available in the same flow range and compatible with the fluid of interest.

DEVICES ON THE THRESHOLD

We have emerged from the stage of mere promise in MEMS, which characterized the 1980's, to real commercial use and significant volumes in selected cases that has characterized the 1990's. It is hard to be more than a kilometer from a MEMS device in the United States or Europe. A billion or more MEMS devices have been sold and they are in most cars, hospitals and computer peripherals. As is the case with many disruptive technologies, the ultimate high value and high volume applications often take another decade or two to emerge and are often unexpected. Computers were developed to replace adding machines and file cabinets, but they have emerged as the controllers of most of our sophisticated communications and transportation in much larger numbers.

Where will MEMS end up with the biggest commercial successes?

One of the important new applications for MEMS is in the manipulation of photons. Photons have little mass and can easily be moved by microscopic devices. Many years ago I said that the most useful things to do with MEMS were to measure motion and move photons. Neither requires exposure to the outside world nor the performance of a significant amount of Work in the physics sense. The moving of photons will emerge as a big application area in my view. TI has pioneered their application in displays at the high end. Simpler displays will emerge.

The larger application of optical MEMS is likely to be in the area of **optical communications**. With the development of Wavelength Division Multiplexing (WDM) and with the explosion of the Internet, large increases of optical communications bandwidth have been both created within the fibers and demanded by consumers. While the bandwidth exists in the fiber that has been strung around the US, the components at the ends of the fibers are lagging the explosion of bandwidth within the fibers. Such mismatches or bottlenecks in supply and demand inevitably drive advanced technology as well as its adoption rate. Three recent businesses have developed new switches and routers for this optical bottleneck, Nexabit, Monterey Networks and Sycamore Networks. As of the writing of this paper, they are each about two years old and they have a cumulative market value of over $20B. They offer optical-electrical-optical construction. MEMS optical connectors and switches an miscellaneous other developments will steadily reduce the power and improve the performance of such systems and enable the **all-optical switcher and router** configurations such as one recently disclosed by Lucent Technologies.

Another emerging application for MEMS is in the area of electrical **switches and relays**. Physical switches have some significant advantages over the solid state devices we have seen make the continuous progress for decades described by "Moore's Law". Microscopic switches that MEMS enable have higher isolation, lower leakage and lower parasitic capacitances than transistors and this difference becomes even more significant as the dimensions of solid state devices get smaller and smaller. MEMS switches have begun to emerge that offer high isolation, low feed through capacitance. The devices typically operate at a point on the "Paschen Curve" that mitigates arcing, the primary failure mode of macro-assembled devices. Will every wireless phone soon have a MEMS switch in place of the current macro-fabricated Transmit and Receive (TR) switch? This is exactly the kind of high volume and high value added application that can jump-start a new area of MEMS technology.

Another emerging area for MEMS commercialization is **passive electronic components**. Similar to the switch and relay application, MEMS allow the development of passives that mitigate the limitations of the planar IC and enable the construction in modern form of devices from the earliest days of electrical devices and circuits. IC's with complementary devices have emerged as the dominant technologies both in Bipolar and MOS IC technologies. These technologies were the most prevalent in the days of discrete circuits too. Will inductors reenter the bag of tricks for circuit designers, enabled by MEMS? They very well might. Additionally, higher density capacitors and electrically controlled variable capacitors will similarly benefit from the MEMS technology progress.

Fluidics is a more slowly emerging area of MEMS commercialization. There are several MEMS-enabled commercial success. Affymetrics has used microscopic quantities of reagents and biological materials to dramatically increase the pace of drug discovery and genetic research. The direct commercialization wherein the technology produces a product which is sold as and end product has been slow to emerge. Several companies like Cyrano Sciences Inc. for example, are developing simple MEMS like sensors for chemical and biological detection. The fluidic applications demand that the materials of the device construction interact with an often hostile world of chemicals and varied material compatibility issues raise the question of whether there will ever exist a dominant driving application. Disposable applications are numerous and attractive which might profit from micro-fluidic devices, but each application has cost constraints, material compatibility issues and input output interface issues that make each application a unique experience. Many applications like the "lab of a chip", being developed by Sandia National Labs, also require the development of a large suite of components before the applications becomes practical.

SUMMARY

The requirements for rapid commercialization of any new technology, MEMS included, is that a compelling value proposition needs to drive the progress. Historic commercialization successes have occurred where technology offers overwhelming evidence of superiority over the established way. MEMS pressure sensors offered significantly lower construction costs over the assembled sensors that preceded them. MEMS accelerometers offered $B savings to the automotive manufacturer for the risk of adopting radically new MEMS solutions. Smaller isn't always better. Less expensive is the more compelling reason. Once a compelling reason has been found to forge a beachhead for new technology, the follow on applications can often be developed driven by a less compelling reason. Applications where a new capability is created for an additional cost are much more slow to develop into businesses.

MEMS are all around us. New applications in optical communications and other areas are emerging. **The future looks bright.**

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