STARTING FROM SCRATCH: CREATING AN INFORMATION TECHNOLOGY INFRASTRUCTURE FOR MEMS-RELATED RESEARCH AND DEVELOPMENT

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Abstract: Micro Electro Mechanical Systems (MEMS) have already revolutionized several industries through miniaturization and cost effective manufacturing capabilities that were never possible before. However, commercially available MEMS products have only scratched the surface of the application areas where MEMS has potential. The complex and highly technical nature of MEMS research and development (R&D) combined with the lack of standards in areas such as design, fabrication and test methodologies, makes creating and supporting a MEMS R&D program a financial and technological challenge. A proper information technology (IT) infrastructure is the backbone of such research and is critical to its success. While the lack of standards and the general complexity in MEMS R&D makes it impossible to provide a “one size fits all” design, a systematic approach, combined with a good understanding of the MEMS R&D environment and the relevant computer-aided design tools, provides a way for the IT architect to develop an appropriate infrastructure.

Keywords: MEMS, Information Technology, Computer-Aided Design

INTRODUCTION

Micro Electro Mechanical Systems (MEMS) are highly miniaturized microscale structures, devices or completely integrated microsystems that are comprised of electrical and mechanical components fabricated using modified integrated circuit (IC) batch-processing techniques. The promise that MEMS holds is remarkable, from implantable devices for sensing, monitoring and control of bodily functions [1], to miniature positioning systems [2], accelerometers [3, 4], microfluidic pumps [5-7], microactuators [8, 9], etc. Many comparisons have been made between the early days of the Very Large Scale Integrated (VLSI) semiconductor devices and circuits industry, and the MEMS industry of today [10]. Certainly, MEMS-related research and development (MEMS R&D) has the potential for a similarly, if not even more, spectacular growth, but the realization of such progress and growth is hampered by the lack of standardization in design, fabrication and test methodology, another characteristic of the early VLSI industry

MEMS R&D covers a wide and diverse range of application areas. However, with the limited standardization between MEMS fabrication facilities, it is typical for each facility to be specialized in particular, and sometimes proprietary, techniques or technology. This means that, in general, no single facility is capable of handling the fabrication requirements for every MEMS application. As with the VLSI industry of yore, this is changing as the industry and technology matures, but reflects the reality facing MEMS researchers today.

On the surface it may seem best for an organization considering initiating and developing a MEMS R&D program to also consider developing their own MEMS fabrication process and facility. However, the cost of setting up such a facility is very high (a basic MEMS fabrication facility can cost upwards of $15 million, just for the initial equipment outlay), and if the MEMS industry continues to follow the trend that the VLSI industry has laid out, then “private” state-of-the-art MEMS fabrication facilities will not be viable in the long term, except for very specialized cases. The most practical and cost effective alternative for most organizations, and particularly in academia, is shared access with other organizations to a MEMS fabrication facility (and typically to more than one, based on the current specializations of these facilities).

By its very nature, MEMS R&D is a domain in which collaborative efforts between organizations and individuals are a necessity. The classical boundaries between various research areas are non-existent in MEMS R&D, and it is not unusual for a project to require the input and collaboration of experts in a wide range of classical areas of both science and engineering, including microbiology, chemistry, electrical engineering, mechanical engineering, chemical engineering, physics, material sciences, computing sciences and others. As with the individual, it is impractical, if not impossible, for an organization to have all the necessary expertise in house. This often leads to the need for communication and collaboration between non-collocated individuals and organizations.

The collaborative and geographically distributed nature of MEMS R&D, establishes the need to interface with a wide range of external organizations, and the computationally intensive nature of the work, makes selection of an appropriate information technology (IT) infrastructure a critical element of a successful MEMS R&D program. However, as with much else in the MEMS industry, there is an identifiable lack of standardization when it comes to the design and deployment of the associated IT infrastructure. The very nature of the industry prevents a “one size fits all” type of approach, but, as will be shown, a thorough understanding of the needs of MEMS R&D programs allows the IT architect to employ a standard systematic approach to the design and deployment of an appropriate IT infrastructure.

The aim of this paper is to provide IT architects with a better understanding of the complex requirements of MEMS R&D in order to assist them in such design efforts.

MEMS DESIGN PROCESS

The Concept or Idea

In addition to the number of different device areas where MEMS is being applied, it also encompasses a wide range of application areas including aerospace, automotive, military, storage devices, biology, medicine, etc. The wide range of application areas and types of devices makes for a rather diverse range of research ideas.

The process of determining the feasibility of any particular research idea involves sketching out the concept at a high level, assessing the basic functionality, and confirming the availability of appropriate resources (design tools, collaborators, fabrication facilities, testing tools, IT infrastructure, etc.). Although more directly relevant in the commercial environment than perhaps the academic environment, the additional factors of market potential, competitive landscape and organizational capabilities must also be taken into account.

Literature search into existing work in an application area can often eliminate months, if not years, of preliminary research. As more and more of the published literature is becoming available over the Internet, one of the first requirements on an IT infrastructure is that it provide researchers with the ability to do on-line literature searches, and save, sort and manage the results. Various bibliographic tools exist, including EndNote [11] and Reference Manager [12], to support such tasks. Extensive utilization of research databases such as Medline, Compendex, Inspec, ACM Digital Library, CISTI Source, and IEEE Xplore (see e.g., http://www.ucalgary.ca/library/gateway/indabs.html) is essential. For more industrially oriented research, patent searches (see e.g., http://www.delphion.com) are also a necessity.

Modeling

The ability to work and design with standardized high level abstractions based on process-independent design elements has been one of the instrumental reasons for the accelerated growth of the VLSI industry [10]. Unfortunately, with limited exceptions, such standardized high-level abstractions are lacking in the MEMS industry today, and thus the MEMS researcher must not only consider overall device functionality, but also take into account how the complexities of the fabrication processes, and its impact on the design. However, in many cases this information can only be obtained at the end of the fabrication and testing phases, requiring a time consuming reiteration through the whole design process.

Although standardized abstractions are lacking, it is still necessary for the MEMS designer to model MEMS designs at various levels of abstraction. Common abstraction levels are variously referred to as System, Network (or Link) and Geometry (or Physical) [13, 14]. The geometry level is the closest to the “real” device, and modeling at this level requires numerical solvers such as Finite Element Analysis (FEA). IntelliSuite [15], CoventorWare [16], Ansys [17], Abaqus [18] and others, are software tools available for this purpose. Modelling at this level is very computationally intensive [19].

Modelling at the Network level is commonly done by describing the design as systems of differential algebraic equations representing circuit equivalents of the various design elements. There are also a number of software tools available for modeling at this level, including MEMS Pro [20], SPICE, PSPICE, Sugar [21] and MATLAB [22]. Processing power is still highly important for network level modeling, although typically not as computationally intensive as at the geometry level.

System level modeling involves representing the design as a combination of various functional blocks and applying system level simulations. The biggest difficulty facing the MEMS designer is that there is no general systematic way of creating system models from physical models [14]. This means that the MEMS designers must work at all levels of abstractions and iterate between them in order to fully model and adequately simulate their design [23].

Design, Analysis and Simulation

Design of a MEMS device consists of the definition of structures that physically represent the device. The outcome of the design process is a set of masks and fabrication steps that will be used in the fabrication process. As with any Computer-Aided Design (CAD), MEMS design is highly graphical in nature. However, MEMS design must also take into account fabrication details, and so iteration between design, analysis and simulation is very common. This puts requirements on the associated computing resources for high computing performance, as well as for high performance and quality graphics processing. There are several software CAD tools available for MEMS design which also provide analysis and simulation capabilities, including MEMS Pro [20], IntelliSuite [15] and CoventorWare [16].

Iteration back to modeling, and even to the original design idea is not uncommon, as design fabrication limitations may make it impossible to implement a particular design that was initially considered feasible. This re-emphasizes the importance of taking into account fabrication details and material considerations early in the design, and of modeling these fabrication details and material properties at the geometric level.

Another point that is often missed is the need to test the final device. Test considerations must be part of the design at all phases, since fabricating a design only to find out that it doesn't work without being able to find out why, essentially means having to start the whole design process over again.

Implementation

Transfer of the final design to a fabrication facility is typically done by electronic means (in file formats such as CIF, GDS and DXF) although physical transfer of files is also a possibility. In either case secure and reliable transfer is a requirement. IT architects must fully understand the nature and the availability of various communication alternatives (which are typically set by the MEMS fabrication facility) in order to determine which one is best suited to their particular requirements.

The MEMS fabrication facility will return the final product to the designer once the fabrication steps have been completed. This could be a complete silicon wafer, a wafer that has been diced into individual chips, or chips that have been packaged in some manner depending on the abilities of the fabrication facility and the desires of the designer. In some cases a fabrication facility will not be able to package a chip to the designer's requirements, and so the designer must transfer the chips to another facility for packaging or perform the task him/herself if local facilities are available.

Testing

Once the final packaged device is available, it must be fully tested and characterized. Testing environments for MEMS devices are as diverse as their application areas. The IT architect must work closely with the MEMS researchers to fully understand their testing needs, and the implications on the IT infrastructure. In a general sense there will be one or more sets of testing equipment, frequently under computer control, and thus it is necessary for the computing resources to be able to support the various control interfaces that will be present. Testing and evaluation to assess operational reliability and safety are critically important to the potential deployment of MEMS devices focused on in vivo applications.

INFORMATION TECHNOLOGY (IT) INFRASTRUCTURE FOR MEMS

Functional Breakdown

Due to the lack of standardization in MEMS R&D and the variety of tools that may be used, it is necessary to tailor the associated IT infrastructure to suit the needs of the individual program. However, evaluation of these needs at a functional level allows for a systematic approach to such customization.

Functionally a MEMS R&D IT infrastructure can be broken down into general purpose workstations, modeling workstations, design and analysis workstations, testing workstations, license servers, file servers and network. Each of these may represent one or more physical entities, or may be combined together on a single physical machine, depending on the needs of the MEMS R&D group.

Functional Entity Descriptions

General-purpose workstations handle literature search, sort and management as well as general administrative tasks such as email, documentation creation, etc. These workstations must have Internet access, as well as word processing, bibliographic, 2D or 3D drawing and diagramming software and other related tools.

Since modeling tasks are usually very computationally intensive operation, modeling workstations must be optimized for performance. It may be desirable in such instances to use high end multiprocessor workstations for modeling tasks. In many instances modeling software will represent derived models in a graphical manner, placing a strong need for high quality graphical interfaces on these machines as well.

Requirements for the design and analysis workstations are very similar to those for modeling workstations, and in a small MEMS R&D group, one set of workstations is often used for both purposes. Emphasis is again placed on the provision of high performance and high quality graphical interfaces, both in resolution and speed.

Testing workstations must interface to the equipment used in the testing. The selection of such workstations relies heavily on the interfacing needs of the test equipment. High performance can be a requirement for certain types of test environments, especially when large quantities of data are being sent or received.

While it is necessary to purchase sufficient copies of each software tool to correspond to the simultaneous use expected, frequently the number of workstations will exceed the number of concurrent users of any one such tool. The most cost effective method of dealing with this is through the use of a license server. Provided that appropriate security measures are taken in the network design, this also has the advantage of allowing remote users and casual users to use the software tools, without having to provide each of them with their own licensed copy.

Performance requirements on a license server are typically fairly low, although consideration must be given to the input/output (I/O) performance if many simultaneous users are expected.

The need to share files and access the same files from many different workstations points towards the need for a file server. From a system administration viewpoint, having a single location for all design and personal files, makes backing up and archiving the data much simpler as well.

Obviously, storage space and file access speed are important considerations for a file server. In addition I/O performance and appropriate sizing and speed of backup capabilities must be considered.

As every IT architect knows, network design is critical to a smoothly running operation. Due to the often proprietary nature of MEMS R&D, security of data and systems is paramount. Use of a hardware firewall and/or proxy server with a software firewall can be considered a general requirement.

If remote users will need to access internal resources, secured access through the firewall, through such means as a Virtual Private Network (VPN) connection, will be necessary. Higher end hardware firewalls support VPN serving directly, but use of a computer as a VPN server is also an option.

Where the need exists to connect multiple labs together through a network with traffic unrelated to the MEMS R&D work (common in an academic environment) several options are available. Each lab may have its own firewall, with IP tunneling set up between them. Although slightly less secure, if intelligent switches (which support Virtual Local Area Network (VLAN)) are used to connect the labs to a common backbone, then a firewall can be established in one lab, and other labs can “share” its security. Physically connecting networks between labs is the most secure option, although in many cases difficult to implement in practice.

Example

An example of an IT infrastructure which could be used for a smaller sized MEMS R&D group is shown in Figure 1. This infrastructure was designed for multiple general purpose workstations, shared workstations for both the modeling and the design and analysis of MEMS devices, a combined license/file server, multiple test workstations and a combined Web/VPN server. The environment is academic, with a general-use backbone and intelligent switches. A port-based VLAN is set up between the various switches enabling secured access with a single firewall. Using such a configuration the physical locations of the two MEMS R&D labs and of any non-collocated collaborators becomes irrelevant, providing a truly distributed collaborative research and development environment.

DISCUSSION

Micro Electro Mechanical Systems (MEMS) is an emerging area of research, which holds the great promise of combining electrical and mechanical macro-system features on a miniature scale for a wide variety of applications ranging from microfluidics to process monitoring and control.

Since this novel research area is quite dynamic and at the same time highly technological, establishing an adequate information technology (IT) infrastructure for it represents a challenge, both structurally and financially. However, properly conducted preliminary assessment of the technology and prospective design needs reveals that relatively modest IT investment can quickly lead to an adequate MEMS design environment.

For an academic unit such a modest investment may be sufficient, as design and simulation is usually enough to penetrate the global market of ideas. However, a broader-range ambition of creating a corporate or academic MEMS laboratory capable of delivering industrially-viable MEMS products is inevitably related to the availability of adequate MEMS fabrication and testing facilities. To some degree the creation of a MEMS testing facility may be easier in an academic environment than in a corporate environment, as most academic establishments have micro and macro electronic and material testing capabilities that may also be adequate for MEMS testing. However, there is a significant difference between just exploring ideas in MEMS, and producing actual MEMS devices, and the work and commitment involved in implementing this should not be underestimated.

In any case, building, or even simply utilizing, a MEMS fabrication facility represents a substantial financial and logistic challenge and could be a major stumbling block in the completion of a full MEMS development cycle. This re-emphasizes the importance of exploring various avenues for collaborative distributed research, and fully considering the impact on the MEMS-related IT infrastructure.

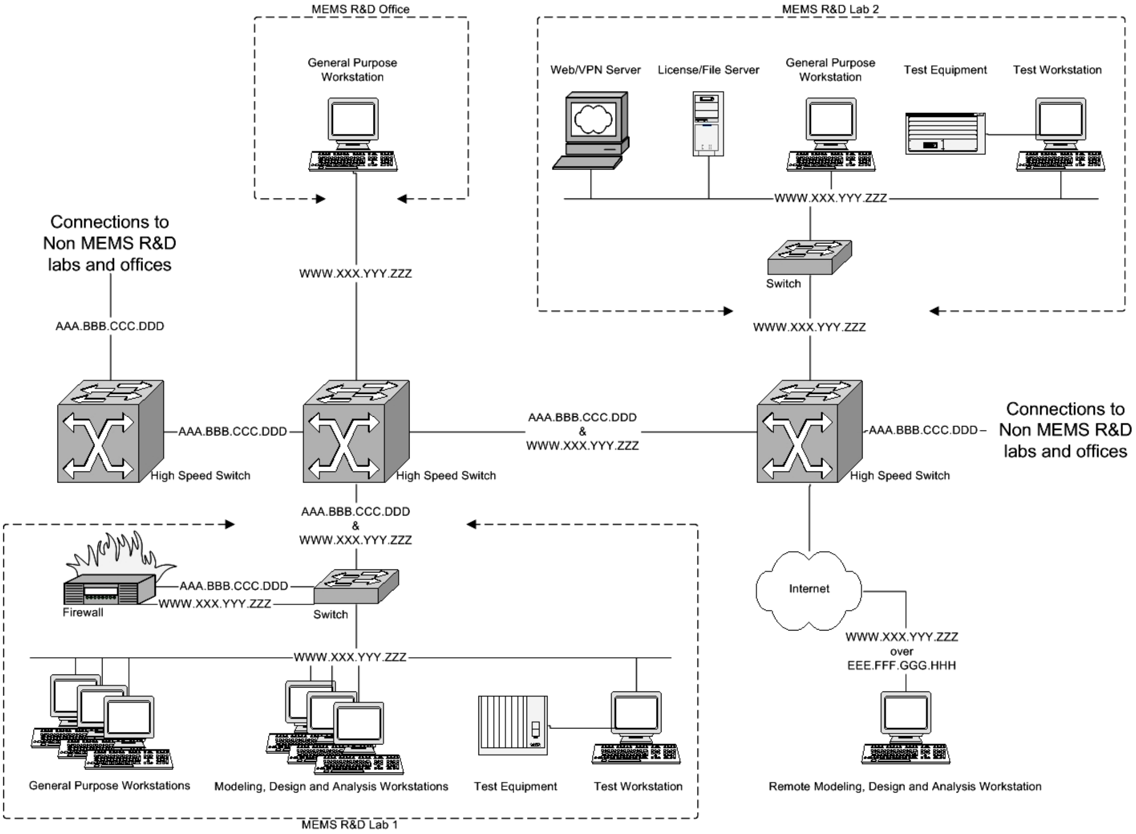

Figure 1: Example of an Academic IT Infrastructure for MEMS R&D

CONCLUSIONS

Creating and supporting a MEMS R&D program in a corporate or academic environment can be a substantial financial and technological challenge. Establishing a proper IT infrastructure for such a program is critical to its success.

While the MEMS industry suffers from a lack of standardization in design, fabrication and test methodologies (preventing the ability to utilize a “one size fits all” approach to deploying the associated IT infrastructure) a systematic approach, with a detailed understanding of the MEMS R&D environment, provides a way for the IT architect to develop an appropriate infrastructure.

A distributed collaborative environment, incorporating standard design and modeling software systems, can be regarded as a quick and efficient method of providing MEMS design exposure in an academic environment. However, industrially-viable MEMS products can only be developed with access to appropriate MEMS fabrication and testing facilities and this must be taken into account when developing the associated IT infrastructure.

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