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INTRODUCTION

Chapter Leaders

Robert Giasolli
Xcom Wireless
robert.giasolli@xcomwirless.com

Steven T. Walsh
University of New Mexico
walsh@unm.edu

Job Elders
C2V
job.elders@C2V.nl

Carl Steele
Univerity of South Florida
csteele@seas.marine.usf.edu

Jane Niall,
Department of Innovation, Industry &Regional Development Government of Victoria, Australia
jane.niall@iird.vic.gov.au

Contributing Authors

James Wylde
Bookham Technology
james.wylde@bookham.com

Kees Eijkel
Mesa + Institute
c.j.m.eijkel@el.utwente.nl

Dave Tolfree
Technopreneur Ltd
d.tolfree@dl.ac.uk

Henne van Heeren
EnablingMNT
henne@enablingMNT.com

Srikanth Varma
University of New Mexico
srikanth@unm.edu

Bruce Kirchhoff
New Jersey Institute of Technology
kirchhoff@njit.edu

Numerous MANCEF members have contributed to this chapter this group along with the leaders were the authors

1 The Purpose of the MANCEF Roadmap Effort

The purpose of the 2nd edition MANCEF International Micro-Nano Roadmap (hereinafter also referred to as "our roadmap," "the roadmap") is to assist in the commercial development of products and systems based on the micro and nano enabling technology base. The roadmap is designed to assist firms in developing their own strategic roadmap, thereby improving their own chances for competitive advantage.

The Roadmap in particular aims to:

1 "speed-up" the process of commercialization of products based on Micro and Nano technologies through the pre-competitive sharing of information between the firms and contributors involved in this roadmapping process.

2 assist decision makers and their staff members to understand the industry, its technology, markets, and potential for future growth.

3 guide corporate strategists, technologists, investors, policsts, marketing professionals, and entrepreneurs in conceptualizing the reality of the technology and its potential applications, thereby providing value to the entire stakeholder community, operating in relation to this technology.

4 provide a roadmap that allows companies, regions and individuals to develop a roadmap suited to their own needs

5 ensure representation by many stakeholders including:

1) micro and nano based product users and potential users (i.e. systems integrators, entrepreneurs)
2) micro and nano suppliers
3) micro and nano manufacturers
4) MEMS researchers and research institutes

5) Policy makers
6) the capital investment communities (Angel, Venture, M&A, Investment Banking)
7) industrial and academic institutions
8) all entities seeking to join these technology and its markets

2 The Nature of the Micro-Nano Roadmap

The popularity and efficacy of the road mapping process has led to a wide range of definitions and purposes of and for roadmaps. The success of road mapping as a strategic managerial tool has spawned the creation and acceptance of other techniques that are similar to road mapping such as technology foresight, technology forecasting, data scanning and the like. The roadmap committee collectively understands the unique nature of the emerging and enabling Micro and Nano technology as either being disruptive in nature, going through a transformation from a disruptive to sustaining, or having recently become the sustaining and the resulting and the basic issues they convey to our road mapping process.

The Micro-Nano roadmap process is based on traditional technology roadmaps, but varied to meet the needs of the emerging, enabling and often disruptive technology/ product roadmap. This type of roadmap differs from a traditional road mapping process in many ways some of which we provide here:

1) The focus of the Micro-Nano roadmap is on forecasting the development and commercialization of a new, emerging, enabling and often disruptive technology base which does not have, for the most part, dominant technology product architectures within solution sets they provide.

2) The fragmented nature of the markets that Micro and Nano technology based

product paradigms tends to provide value.

3) The flexibility required of firm based Micro / Nano technology product platform that companies need to develop in order to be robust and address the uncertainties of different markets .

The roadmap process cannot focus solely on current or future specifications derived from a particular market application space. It must also include a review of the traditional technology product paradigm that the community often attempts to replace with our solution sets but other new paradigms as well.

4) The roadmap process must address the reality of competing technology product paradigms from within the Micro /Nano technology solution space in addition to others providing value based on other technologies.

5) The roadmap process must address not only the technological hurdles that face an emerging industrial solution set, but also be a source of confidence for all in the emerging technology solution set value chain acting: thereby acting as a bridge to overcome customer fear of change, the essence of the physiological hurdles involved in managing solutions based on disruptive technologies.

3 Why is a Global Community Effort Important?

Roadmaps were born of an interest in inserting technology into the strategic process of a company and now are designed to have a strategic and tactical value. Developing a living road map document for a company large or small in an enabling

technology like Micro and Nano technologies is a daunting task for a strategist or road mapping team. These technologies can be applied to almost any product arena but the road mapping space can soon exceed the scope of any one group or region. Simply put, a global community like MANCEF, focusing on diverse technology product applications benefits all the volunteers and users of the document (see our testimonials).

Further, companies that use technologies like Micro and Nano technologies to develop products that seek to change the manner of technology- product- manufacture-paradigm in a given application space, often face technological, infrastructural and philosophical barriers to market entry. This is true and no less disrupting, even, when the new technology product paradigm, as in our case is based on Micro / Nano technology that provides solutions with better performance, cost characteristics and trajectories etc. A huge resistance still exists to the adoption of a new technology based solution. These issues can be limited or reduced by a committed community.

4 Why This Roadmap?

We as a community learned from the first road mapping efforts. MANCEF continued these to improve the base knowledge of the road mapping process. The Road Mapping Committee has put that experience into action and provided an even better document than the first one, highly acclaimed by the global community. Our first print-run (200) roadmaps was completely sold out which was an indication of its success. We have received numerous accreditations and positive responses (not a single negative one).

For additional information we include as evidence of the value and usefulness of the first roadmap by copying some testimonials from those who purchased and use it.

"Bookham Technology has been using the First Edition of the MANCEF International MEMS and Top-Down Nano Roadmap since it's introduction in 2002. Given the tumultuous nature of the telecom market in the last 4 years, developing and maintaining a MEMS strategy has been challenging to say the least. I just wanted to write a quick note to thank you and the rest of the MANCEF Roadmap Committee for providing a resource and an international perspective. We have been able to identify key vendors, process technologies, and improved our integration strategy using this document." Ryan M. Hickey, MEMS Design Prime, Bookham Technology Ottawa

The MANCEF Roadmap was of vital assistance to the development of our own roadmap and strategic direction, providing a global perspective that we apply to the Canadian context. CMC looks forward to contributing to and utilizing the next Edition, in support of our vision to accelerate Canada's competitiveness through Microsystems." Dan Gale, Vice-President, Canadian Microelectronics Corporation

"*The roadmap and the process which I was involved in (to generate it) was hugely important in our firm's foundation and strategic formulation*." Dr. Doug Elerath President HT Micro

"We used the roadmap was used to help us through a series of questions in developing our own company direction " Advanced System Automation, Singapore

3. Third, your roadmap effort was recognized by road mapping professionals as an exemplar for emergent and disruptive technology road mapping.

"As the editor of the international journal ***Technological Forecasting and Social Change*** *I encouraged the development of a double issue devoted to (disruptive and emergent vs. sustaining technology) Road mapping and the issue was published early this year. Two articles derived from the MANCEF International Roadmap Committee were included in this issue, which has been well received. These articles reflect well on the work of the professionals and your efforts in the area. We look forward to your continued work and use of the knowledge generated in your reports*." Hal Linstone

5 How Did We Improve On Our First Document?

MANCEF's Roadmap Committee members listened to the road mapping experts and to the MNT community. We are fortunate to have on our Committee road mapping experts as well as a number of the communities' commercial and technological

stakeholders.. The Committee reviewed all suggestions for new chapters from colleagues, customers and practitioners in the community. These are outlined below.

- The one area where many of our customers wished improvement was in the media presentation. The customers wanted it electronically so we have produced it in digital form.
- To meet new demands for the expanding technological areas we have produced the follow five new chapters ; Nanotechnology Informational roadmap, RF MEMS, MEMS patent analysis , Process and Equipment for MNT, and Equipment and Tooling for MNT.

6 Why Now?

It has been approximately 18 months since MANCEF, SEMI, Sandia National Laboratories, and IVAM collaboration generated the first international Microsystems, MEMS, Micromachining, Top-down Nano Roadmap. Since then MNT has advanced significantly.

We have outlined below the some of the reasons why we thought it timely to o provide an updated Roadmap.

1) The RF MEMS challenge is upon us, the community is facing problems of barriers to commercialization that include perception, technological trajectories, change, other promising technological substitutes, in general; the problems plaguing enabling, emergent disruptive technology product paradigms.

We provide a strategic technology roadmap document that addresses these issues just when they need to be addressed.

2) The overwhelming hype that is saturating the Nanotechnology and giving out misguided information raising public concerns has to be addressed now so as not to deter investment and lower public support.

We provide an informational roadmap which examines atomically precise manufacturing from both top down and bottom up while providing and exceptional patent analysis of the field. It reviews the economic and societal impact issues in relation to health and the environment and regulation being considered by Governments.

3) The Nano bubble is strong but NanoSys has just withdrawn its IPO – could the bubble burst?

We investigate the bubble by providing a time line of real products in three strong Nano market segments.

4) The reality of MEMS and NEMS foundry activities are changing rapidly

We directly address the fast changing NEMS and MEMS foundry issue providing foundry players, definitions and statistics.

5) While most enabling MEMS technologies are still disruptive some like the accelerometer as automotive airbag subsystem, ink jet print heads, pressure sensors and light projections have become a sustaining industry standard

We provide an analysis of MEMS standard equipment processes and toolsets that

directly support firms in all three technology categories.

6) The optical MEMS bubble has bust but more optical MEMS devices for telecommunications are being sold into telecommunications than ever before

We investigate a new chapter on MEMS patents while revising the packaging and assembly to see how the new realities of effected the research and productization of MEMS and NEMS devices

7) It been 18 months, now the time is right for the production of the additions and update to the original international Road

.

7 Who?

The MANCEF roadmap committee is comprised of leading professionals from all three actors in the "triple helix" of sustaining and developing industries "Government, Industry and Academia." The roadmap is designed to utilize professionals from each part of the Micro and Nano technology commercialization value chain to develop an encompassing effort. In every effort here we have people that span the industry value chain including: Specifically those stakeholders include:

1) MICRO / NANO based product users and potential users (i.e. systems integrators, entrepreneurs, etc.)
2) Suppliers to MICRO / NANO manufacturers
3) MICRO / NANO manufacturers
4) MICRO / NANO researchers and research institutes
5) Policy makers interested in MICRO / NANO
6) The Angel, Venture, M&A capital community
7) Industrial and Academic entities seeking to institute facilities in MICRO / NANO

8 What's New?

The roadmap committee is trying to keep "Riding the wave" and as such we have promised new sections in the roadmap that responded to the requests of roadmap users. The five new chapters represent an understanding of the increasingly dual nature of Micro and Nano technologies as both a disruptive technology (where we are trying to dislodge the current traditional technology used to produce a product) and as an emerging technology in those industries and applications where it now forms the dominant technology product paradigm (i.e. automotive accelerometers, DLP) and is the sustaining technology product paradigm.

The New2nd Edition Chapters are:

1) ***INTRODUCTION for second edition***
2) ***RF MEMS***
3) ***NANOTECHNOLOGY***
4) ***MEMS PATENT ANALYSIS***
5) ***PROCESSES AND EQUIPMENT FOR MST***
6) ***EQUIPMENT AND TOOLING FOR MNT***

The Revised 2nd Edition Chapters are:

7) ***STATUS AND FUTURE OF MICROSYSTEMS / MEMS FOUNDRIES***
8) ***MEMS PACKAGING AND ASSEMBLY***

New Media:

Electronic

9 Why Develop a Process?

Technological road mapping is important in the process of rapid technology commercialization. Methods tailored to road mapping nascent enabling disruptive technologies did not exist when we initiated our early effort. Yet these very same enabling disruptive technologies portend to be the future economic engines for companies, countries and regions, so we went forth into this process armed with the "Science of Muddling through". Our first effort shed some light on the process to be followed when embarking on an industrial enabling technology roadmap which is a living document. We accomplished this by focusing on the fundamental differences between sustaining and enabling disruptive technologies. Much of our process came from this knowledge base. This roadmap in particular aims to "speed-up" the process of Micro and Nano based product commercialization through the pre-competitive sharing of information between the 400 + firms that have assisted in this living process document.

Road mapping is a strategic process that was developed to better insert technology when it is not a firm's strategic paradigm. Micro and Nano technologies are emergent (nascent) enabling and often have a disruptive technology base. They form the basis for both replacement and radical or discontinuous innovations that, if successful, revolutionize the manufacturing methodology for existing industries or create new ones. These then become the sustaining technology of the new industry paradigm.

Commercialization of this type of technology is the cornerstone of the "Winds of creative Destruction" that is the basis for extreme wealth and job creation it is also typically an extremely lengthy process. The average time to full commercialization of disruptive technology based products varies but has never been reported less than 14

years on average and is on the usually stated to be in excess of 17 years on average. The commercialization of air bag accelerometers, medical pressure sensors, digital light projection devices an other devices as shown in version one ion the roadmap have progressed from disruptive technology to full commercialization standard from 17 to 22 years so we know that Micro and Nano technologies fit this paradigm.

We learned from this effort and from interactions with the Micro and now Nano community to improve our process. The emergent Micro and Nano industries are enabling "era of ferment" with new processes heralded routinely. There are a few dominant designs or standards and the Micro / Nano technology's applications and these applications span a plethora of industrial settings. Managers, entrepreneurs and technologists with great Micro and Nano based ideas are enabling the initiation of companies or redirecting the commercial focus of existing firms. Often these companies have value propositions that change midstream and the resultant product platforms, Micro and Nano manufacturing base or target industries change radically. Yet as an industry we search to emerge, to provide suppliers a pathway, users an expectation and Microsystems manufacturers with key targets that they can obtain. Here we provide a selection process for roadmap development and how stakeholders might effectively use the information provided here.

We utilized the process of roadmap selection to define our task and help other to utilize information for their efforts. This process originates from the management of technology literature. This process assists both us and other nascent roadmappers to get their "hands around" the challenges they face when road mapping technologies especially Microsystems technologies.

10 MANCEF's Roadmap Process

Further based on our development of the first roadmap and our committees and contributors own experience, we highly emphasized two separate issues in our road mapping process.

The first is that for the most part Micro and Nano based solutions are trying not only to displace a current technology product paradigm but are also trying to provide the best value solution as compared to other technology product paradigms which are also trying to provide value too the same application space. Therefore our roadmaps must investigate multiple technologies for any specific solution application market. The roadmap when following any "Killer app" must not only project Micro or Nano technology progress against a traditional technology product projection but also investigate others as well. We show in figure 2 how we utilize the projection of a set of traditional technologies versus MEMS based technologies along one application space generated critical dimension .

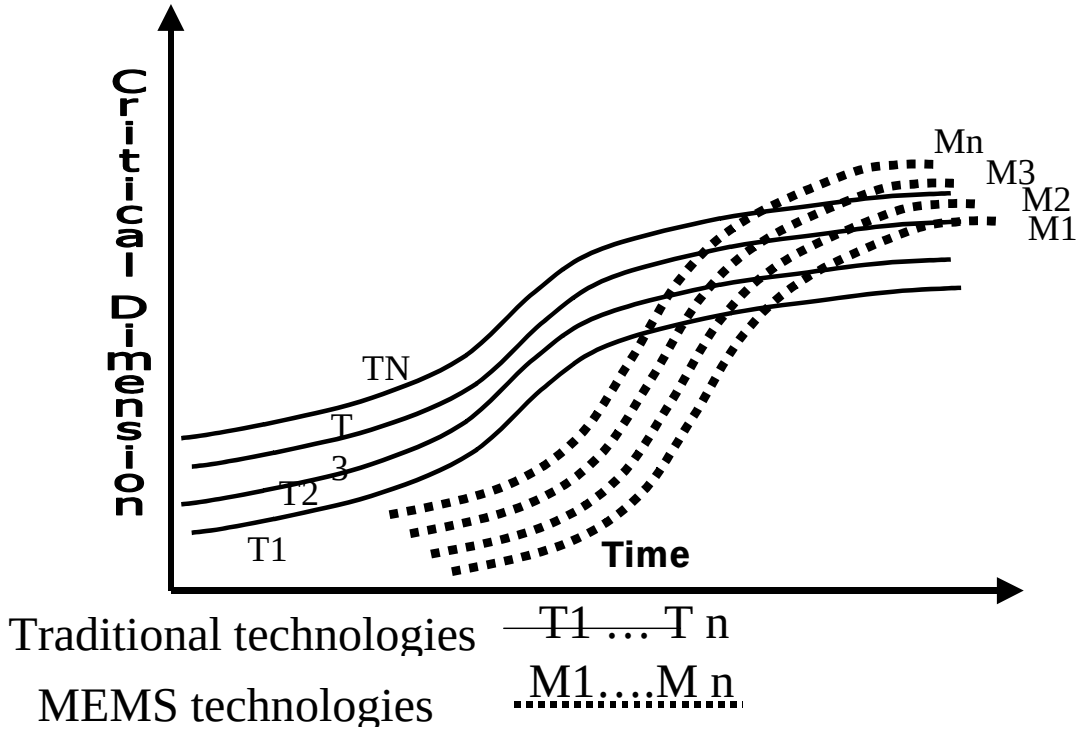


Figure 2. Emergent Disruptive technologies versus many traditional options

Finally when an emergent enabling technology product solution is trying to replace and existing technology solution the roadmap chart should be modified to include defined and well understood steps. We must be able to show the market that there is a great deal of value embodied in our technology product paradigm at all those levels. Here we provide our generic effort that we provide our roadmapers (Figure 3) and a finished effort for RFID MEMS (Figure 4). We show in Figure 5 Atomically Precise Manufacturing for Nano technology.

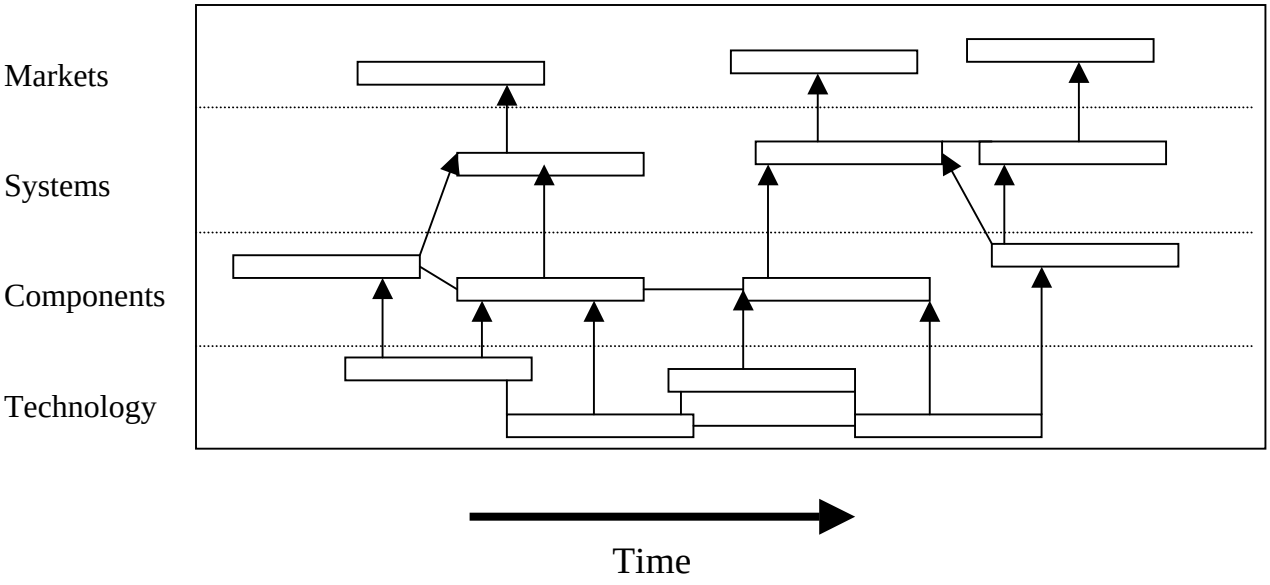
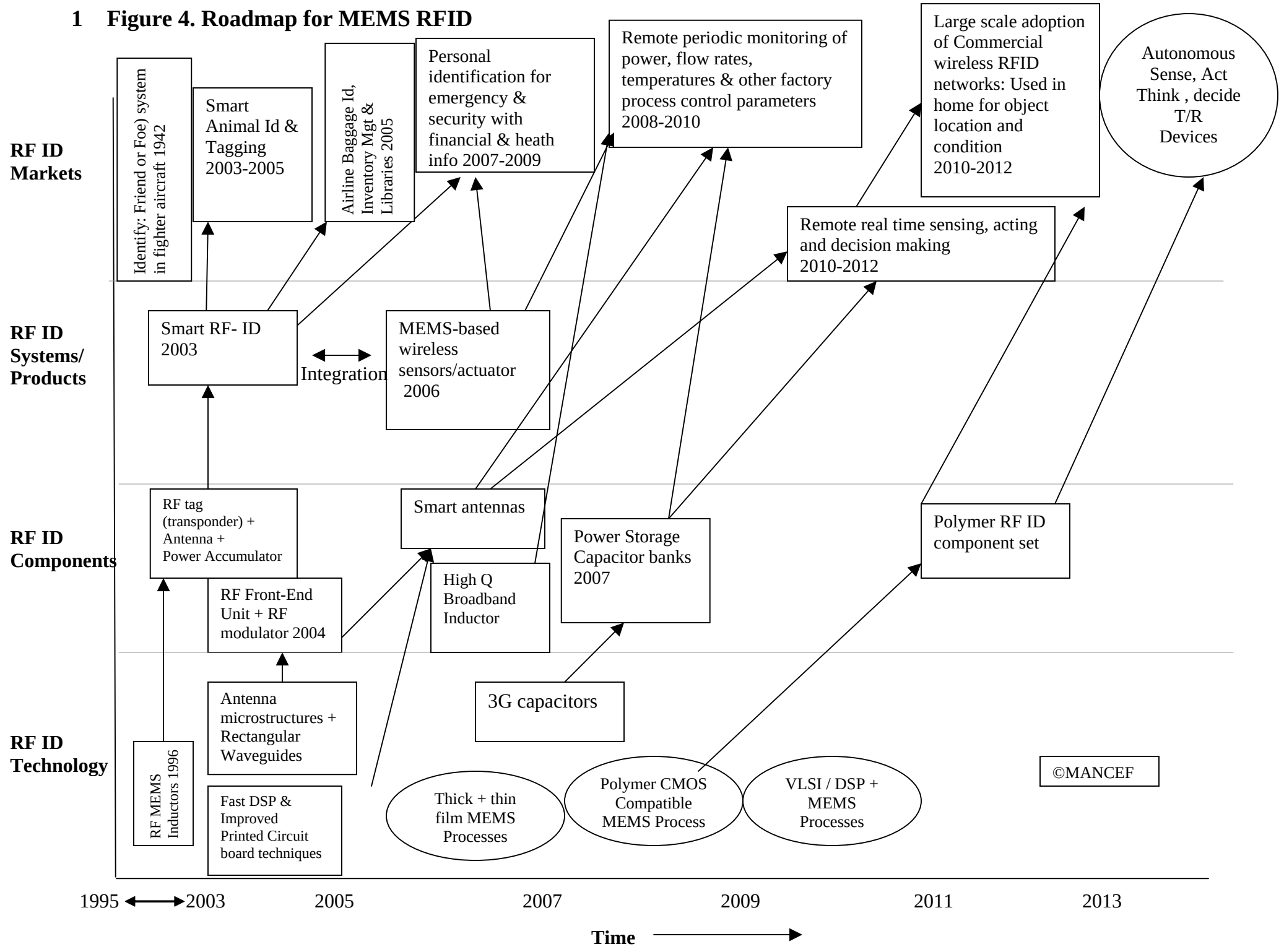
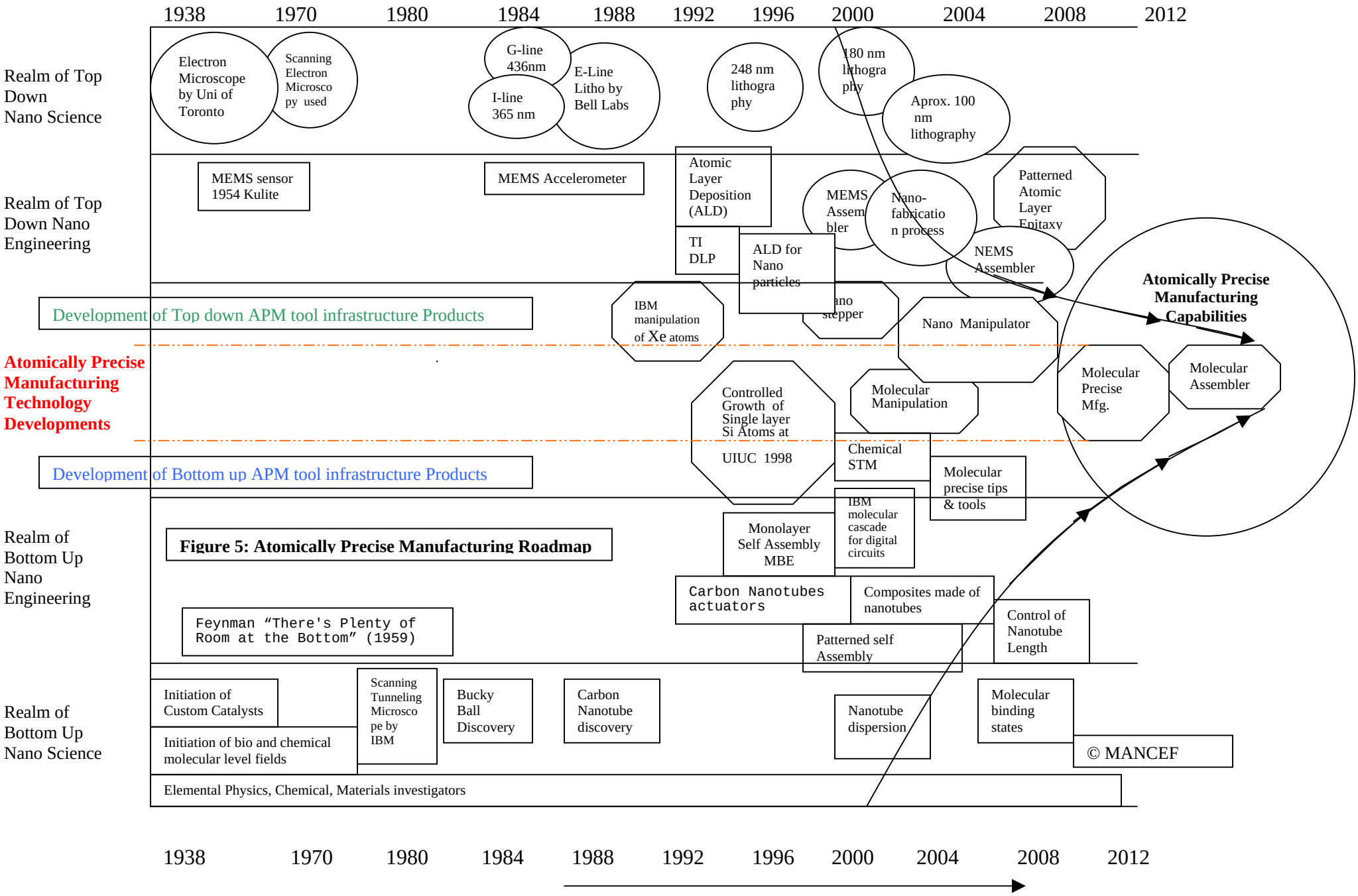


Figure 3. A Multi-tiered Visual output of a Technology Roadmap

1 Figure 4. Roadmap for MEMS RFID




1938
1970
1980
1984
1988
1992
1996
2000
2004
2008
2012
Realm of Top Down Nano Science
Realm of Top Down Nano Engineering
Atomically Precise Manufacturing Technology Developments
Realm of Bottom Up Nano Engineering
Realm of Bottom Up Nano Science
Electron Microscope by Uni of Toronto
Scanning Electron Microscopy used
G-line 436nm
I-line 365 nm
E-Line Litho by Bell Labs
248 nm lithography
180 nm lithography
Aprox. 100 nm lithography
MEMS sensor 1954 Kulite
MEMS Accelerometer
Atomic Layer Deposition (ALD)
MEMS Assembler
Nano-fabrication process
Patterned Atomic Layer Epitaxy
TI DLP
ALD for Nano particles
NEMS Assembler
Development of Top down APM tool infrastructure Products
IBM manipulation of Xe atoms
Nano stepper
Nano Manipulator
Atomically Precise Manufacturing Capabilities
Molecular Precise Mfg.
Molecular Assembler
Controlled Growth of Single layer Si Atoms at UIUC 1998
Molecular Manipulation
Chemical STM
Molecular precise tips & tools
Development of Bottom up APM tool infrastructure Products
IBM molecular cascade for digital circuits
Monolayer Self Assembly MBE
Figure 5: Atomically Precise Manufacturing Roadmap
Carbon Nanotubes actuators
Composites made of nanotubes
Control of Nanotube Length
Feynman "There's Plenty of Room at the Bottom" (1959)
Patterned self Assembly
Initiation of Custom Catalysts
Scanning Tunneling Microscope by IBM
Bucky Ball Discovery
Carbon Nanotube discovery
Nanotube dispersion
Molecular binding states
Initiation of bio and chemical molecular level fields
© MANCEF
Elemental Physics, Chemical, Materials investigators
Year

11 The Nature of Roadmaps in General

Firms routinely perform roadmap processes as well as countries, regions, agencies, national labs, and industries. Yet, almost all of these roadmaps arte performed on sustaining sometimes rapidly changing and even high technology industries such as semiconductor micro fabrication. How does one then roadmap effectively for Micro or Nano based solutions which are emergent, enabling and often disruptive technology? Other than the fact they are both high tech and fast changing they share little with sustaining high technology. The task of road mapping the Micro and Nano technology base is daunting.

The roadmap selection process logically follows from the content question of "Why roadmap?" The process provides a series of questions and constructs that logically bound and defines the task. The roadmap selection process is driven by the nature of the technology under consideration and modified by the strategic nature and scope of the roadmap project. The roadmap selection process defines the parameters for the roadmap effort under question.

The broad nature of a roadmap is defined by the nature of the technology under question. The following sets of constructs help to define the nature of the technology under consideration for road mapping.

(1) Potentially disruptive versus a sustaining technology
(2) Dominant versus multiple manufacturing technology pathways.
(3) Meta systemic innovation versus singular industry innovation

The terms disruptive and sustaining technologies are ubiquitous in the literature they have taken on an "all things to everybody" nature and are therefore somewhat

ambiguous. Here we provide a definition an example that emphasizes their utility as a construct central to the issue of Microsystems road mapping. Disruptive or potentially disruptive technologies such as Microsystems are technologies that set up a new production platform based on new set technological competencies. They create product technology paradigms that challenge and if successful render useless the currently utilized manufacturing competency base or the sustaining technology base. A disruptive technology base usually provides a substantially better (factor improvement or better) value proposition along at least one critical dimension to be considered commercially viable. As these disruptive technology become and industry standard they two become sustaining in nature.

The nature of a roadmap is further modified and bounded by its strategic purpose. The following sets of constructs help to define those bounds. These constructs include the following bifurcations:

(4) Corporate versus industrial in nature
(5) Market versus technologically concentric
(6) Regional versus international in scope.

Perhaps the biggest strategic modifiers of any road mapping effort are the purpose of the roadmap. There will be a difference in the strategic focus and bounds of the roadmap dependant on the stakeholder group that is developing it. A industry based roadmap differs from one done by a national laboratory or a state agency. A firm based roadmap, for example, provides a bound to the roadmapping effort due to a firm's competency or market interests. National or regional roadmaps for international markets have not had a history of success, however bounding the geographic scope often provides a focus to a dominant technological pathway for that region. Similarly, a concentric

market focus or a concentric technological focus either by a firm or industrial effort will provide a bound to an effort.

Finally, this roadmap required a lot of work from the community to become a reality and congratulations to the volunteers are always in order for a job of this magnitude attempted. Here we had the good fortune to not have one but three key measures that demonstrate the effectiveness of their work. In particular we wish to thank all volunteers for the hard work of all our volunteers over the last 6 years. We look forward to providing you value in this document and please contact MANCEF if you wish to be part of the next process.