IMPLEMENTING THE

EUROPEAN RESEARCH AREA FOR

SMART SYSTEMS TECHNOLOGIES

STRATEGIC RESEARCH AGENDA

OF

THE EUROPEAN TECHNOLOGY PLATFORM

ON SMART SYSTEMS INTEGRATION

VERSION 1.3

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1. Preface

European industry is a world leader in microsystems and related advanced technologies. The further enhancement of product capabilities and services through evolving complexity, integration and interconnectivity will help to ensure Europe's global competitiveness. Future innovations and market success will depend on intensifying technical developments and infrastructure investments.

The key success factor is to shorten the time between research in basic technologies and the transfer of these technologies into innovative products. In early 2005 a group of industry stakeholders - convinced that progress in research and development of smart systems and techniques of their integration is crucial for European competitiveness – launched EPoSS, the "European Technology Platform on Smart Systems Integration".

The document in hand is the result of the activities of the newly initiated working groups of the Technology Platform EPoSS.

EPoSS also involves public research institutions and, particularly, small and medium-sized companies, which play a crucial role in the smart systems value chain. Public authorities in the EU member states are also addressed in order to mobilise resources on the broadest possible scale.

I would like to express my sincerest thanks to everybody that contributed to this document and to the initiation of the new European Technology Platform.

Dr. Klaus Schymanietz
CTO Defence & Security, EADS Deutschland GmbH

EPoSS Chairman

2. EPoSS High Level Group

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Tomasz Dembski	President and Director General, Bumar
Giancarlo De Angelis	Director Innovation, Magneti Marelli
Nevio Di Giusto	CEO and General Director, Fiat Research Centre (CRF)
Klaus Egger	Member of the Executive Management, Siemens AG
Aimé Flesch	CEO and President, Vermon
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Jean Pierre Tual	Director Industrial Relations, Gemalto
Dominique Vernay	Corporate Technical Director, Thales Group
Richard Wenham	Global Product Group Director, Ricardo Consulting Engineers Ltd
John R. Wood	Managing Director, MIRA Ltd.

3. Executive Summary

Strong international competition calls for rapid product change, higher quality, lower cost and shorter time to markets. Smaller and smarter by transdisciplinarity will be the key issue in the future, innovative systems integration will pose a major challenge. The evolution of the critical dimension of technologies into the nanometer scale together with the exploitation of completely new phenomena at the atomic and molecular levels has opened opportunities for groundbreaking solutions to old and new problems in bioengineering, environment, human-machine interface, etc. The ability to miniaturise and integrate intelligence and new functionalities into conventional and new components and materials is particularly relevant for the implementation of the vision of ambient intelligence and to extend this vision towards 'ambient assisted living' in general.

Today's miniaturised systems go beyond monolithically integrated or hybrid systems which combine measurement, data processing, and storage functions. The future of microsystems will consist of integrated smart systems which are able to sense and diagnose a situation, which are predictive, and therefore are able to decide and help to decide. Smart systems address and identify each other and enable the products in which they are incorporated to interact with the environment and with other smart systems. Furthermore, they are able to exchange data between one another.

These systems, which can be described as perceptive and cognitive technical systems, are miniaturised and highly reliable, they are often networked, energy-autonomous, and implantable.

4. Introduction

4.1 Intention of the Strategic Research Agenda

This Strategic Research Agenda (SRA) has been created by the working groups of the European Technology Platform on Smart Systems Integration. "Technology Platforms" were initiated by the European Commission to "*…provide a framework for stakeholders, led by industry, to define research and development priorities, timeframes and action plans on a number of strategically important issues where achieving Europe's future growth, competitiveness and sustainability objectives are dependent upon major research and technological advances in the medium to long term*".[1]

The overarching aim is to address the European Union R&D investment target of 3% of the GDP, as defined at the Lisbon European Council in 2000. Europe has to achieve higher economic growth through increased competitiveness, product innovation and productivity, whilst ensuring a sustainable future. Taking the globalisation of markets and the ever-faster pace of technological changes into account, it is of outmost importance to introduce adjustments to the economic realities.

In the face of these challenges, Europe must continue to develop its knowledge and skills. It must master the key technologies that will allow people, businesses, and governments to succeed and to seize the opportunities of the future. Innovative technologies such as Smart Systems Integration have a crucial role to play.

The aim of this Strategic Research Agenda is to show the importance of Smart Systems and to illustrate their outstanding technical and economic potential.

This Strategic Research Agenda formulates a shared view of the medium-term to long-term research needs of the smart systems integration sector. It has been prepared by the European industries involved in the most important application fields of smart systems, namely automotive, aerospace, medical technology, telecommunications and logistics.

[1] CORDIS service on European Technology Platforms (http://cordis.europa.eu/technology-platforms/)

4.2 Vision of Smart Systems Integration

Smart systems integration addresses the trend toward miniaturised multifunctional devices and specialised connected and interacting solutions. Multidisciplinary approaches featuring simple devices for complex solutions and making use of shared and, increasingly, self-organising resources are among the most ambitious challenges.

EPoSS proposes a multilevel approach incorporating various technologies, functionalities and methodologies to support the development of new visionary products. Rather than solving problems piece-meal at the components level, systems approaches offering comprehensive solutions are to be preferred. EPoSS will build upon new multidisciplinary technologies and concepts following a problem-solving approach: it is not dedicated to any specific research discipline nor will it restrict its activities to a certain scale or size of devices.

The visionary goal is smart systems able to take over complex human perceptive and cognitive functions, devices which frequently act unnoticeably in the background and intervene visibly only when human capabilities to act and to react are reduced or cease to exist.

Examples for such smart systems and related integration challenges are, for example, object recognition devices for automatized production systems, devices for monitoring the physical and mental condition of vehicle drivers, or integrated polymeric RFID systems for logistics packaging.

The technological priorities identified by EPoSS are described in the following chapters.

4.3 Market impact of smart systems and SME integration

In 2004 the world market for microsystems technology amounted to an estimated 36 billion USD. A market analysis by NEXUS projects an increase of this market to 52 billion USD by the year 2009[2]. Another scenario predicts an increase from 48 billion

[2] NEXUS Market Analysis for MEMS and Microsystems III, 2005-2009

USD to 95 billion USD for the total MEMS supply chain[3].

However, these values are merely a lower boundary of the whole market for smart systems integration. A top-down approach to estimating the share of smart systems in, for example, the automotive value chain, may give a more reasonable idea of the true size of the smart systems market:

A rough estimate for the share of electronic systems in the automotive value chain is 20 percent. Recognising that a major part of this value chain concerns wiring and non-intelligent electronic systems, one can safely assume that a share of at least 5 percent of the total automotive value chain can be targeted by smart systems. This amounts to a market of approximately 45 billion USD for smart systems in the automotive sector alone. Taking into account other possible fields of application for smart systems, the total market may soon exceed a 100 billion USD.

Europe needs to raise its game in order to exploit its existing potential and to keep and increase its share in the world market for smart- and micro-systems.

Several sources[4,5] predict a rising share of suppliers in the value chain in, for example, the automotive market in coming years. This is because OEM manufacturer more and more search for partners with the ability to integrate knowledge across the classic segments of the value chain. Specialised suppliers are able to provide this expertise needed for an integration of such complex systems.

These effects and a change in the OEM strategy are already starting to become visible in several industry branches. Thus smart systems integration plays a crucial role in strengthening the ability of OEM manufacturers and suppliers to stay ahead of the market.

SMEs play a major role. With their increasing importance and influence within the value chains of the different application fields, specialist SME suppliers will be important partners in fostering the promotion of smart systems and in advancing technological developments in Europe.

4.4 Technological Priorities

The following chapters present an overview on R&D priorities in an application horizon of ten to fifteen years. These research topics and areas were defined with the objective of achieving European added value in terms of strengthened economic competitiveness and benefits for the society.

The sectoral areas which are most relevant for smart systems applications are[6]:

- Automotives
- Aeronautics
- Information and Telecommunication (ITC)
- Medical Technologies
- Logistics/ RFID
- Cross-cutting Issues

Each chapter outlines the vision for the specific priority followed by a detailed concept, including technological requirements, to reach the goal set. Where appropriate, a preliminary roadmap is presented.

[3] "The MEMS Supply chain size 2005-2010", Yole Développement SARL 2006

[4] HAWK 2015, VDA 2003

[5] FAST Studie, Mercer Management Consulting 2004

[6] A further working group dealing with Smart Systems for Safety and Security is currently under examination

5. Smart Systems for Automotive Applications

5.1 Vision

The automotive industry is amongst the most important industries in Europe. It relies strongly on ever improving functionalities to cope with increasing mobility, trade and customer requirements. The emerging challenges will need comprehensive and interlinked action; at the vehicle level this is the domain for smart systems.

The automotive industry represents 3% of Europe's gross domestic product and 8% of EU government's total revenues. The vehicle and equipment manufacturers provide employment for more than 2 million Europeans and support an additional 10 million indirect jobs in both large companies and SMEs (7% of total European manufacturing employment). The importance of the automotive industry is reflected in a number of high-level policy initiatives, such as the European CARS21 scheme, to which EPOSS relates in accordance with the EUCAR and ERTRAC guidelines on the critical research sectors necessary to sustain this European sector's competitiveness. The automotive industry makes a central contribution to providing the European public and economy with increased mobility: In 1970, the average European travelled 17 km daily, while today the corresponding figure is 35 km. In addition to mobility and flexibility in general, the automotive industry underpins the lifestyle Europeans enjoy by facilitating safe social interaction and access as well as the reliable distribution of goods across the continent. The automotive sector is the largest R&D investor in Europe (20% of total manufacturing R&D) and constitutes a major driver for the development and diffusion of new technologies and innovations throughout the economy.

While the automotive industry is a pillar of the European economy, it is also facing the much discussed globalisation challenges from growing dependence on primary energy and primary materials (steel, aluminium) as well as being subject to significant societal demands, particularly in terms of the environment and road safety. Stronger European partnerships and visions are thus required, associated with design innovation in functions, materials, and technologies. Smart system integration solutions as targeted by EPOSS are key to tackling the new challenges by improving vehicle performance while reducing negative side-effects.

In the field of emissions, progress has been impressive. The industry has been a key partner in continued efforts to reduce greenhouse gas emissions from the transport sector. The signing of the voluntary agreement between the automotive industry and the European Commission to reduce new cars' CO_2 emissions to 140 grams per kilometre by 2008, with a further EU target of 120 grams per kilometre by 2012 (-30% from 1990 to 2012), is testimony to this intention. Similarly, noxious emissions are expected to decrease by 80% from 1997 to 2010 and there are visions of zero-emission vehicles as the long-term target.

Road safety remains a high priority for Europeans as the human and economic costs of road fatalities and injuries remain significant (road accidents are the main cause of death in the under-45 age group). Again, much progress has been made by the automotive industry, and cars have never been safer than today. While European road traffic has tripled over the last 30 years, the latest programmed expectation is a 50% reduction in fatalities from 2001 to 2010. The automotive industry plays a significant role in achieving casualty reductions by enhancing the vehicle safety. The long-term vision is to achieve zero fatalities on European roads while retaining the liberty of individual driving.

Other challenges include improving the vehicle capabilities, the interaction between driver and vehicle as well as the passenger comfort. EPoSS is designed to deliver all technologies, processes and components needed for highly innovative smart vehicle systems and therefore to contribute to the international competitiveness of the European automotive industry.

5.2 Rationale and Objectives

The following considerations are based on strategic objectives defined by EUCAR, the European Council for Automotive Research, and ERTRAC, the European Road Transport Research Advisory Council.

The European Platform on Smart Systems Integration focuses on the development of complex systems and solutions to fulfil future vehicle functional demands. The multidisciplinary integration of technologies and competences as well as the linkage of different scale solutions are among key elements. The technological requirements call for comprehensive

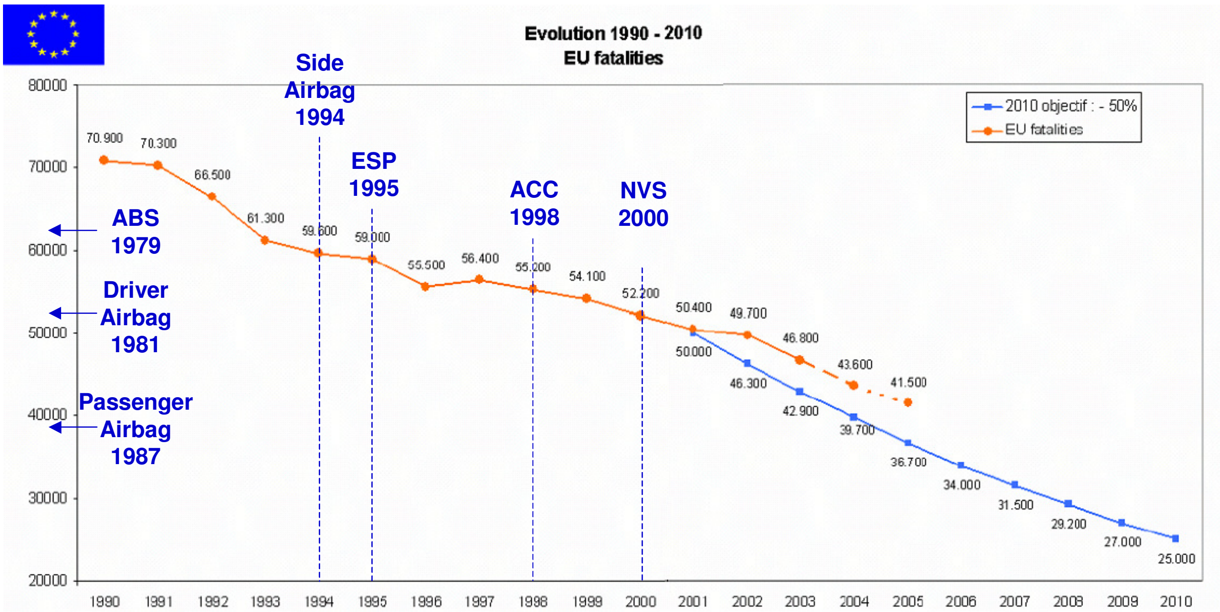


Figure 1: *From 70000 to 40000 fatalities in 15 years. From 600 to less than 200 fatalities per million vehicles. Micro technology has played a crucial role for this achievement.*

approaches beyond the capabilities of single components – the challenge for Smart Systems Integration. Sensors and actuators as the nerves and arms, controllers and power semiconductors as the brain and muscles of smart vehicles are of special interest for EPoSS.

EPoSS addresses the various challenges facing the automotive industry from both the technological and the process sides, e.g.:

- Increasing number of automotive systems (e.g. a three digit number of control units)
- Demanding development challenge of multi-domain systems
- Complex interaction between components (and systems)
- Permanently increasing functionality
- Very high quality demands compared to other consumer goods
- Many safety-critical issues
- Harsh environment
- Decreasing time to market
- Permanent pressure on cost
- Growing global competition

EPoSS therefore focuses on the R&D in the following fields: intelligent materials, sensors and actuators, interconnect technologies, management methodologies for the integration of technological and human resources, production methodologies for fast and efficient manufacturing, standards and rules for global knowledge sharing and systems interoperability. This requires close attention to the systems scales and integration levels relevant to automotive applications: More than 2 km of wiring, 80 - 100 sensors, 50 - 80 processors, 80-100 actuators are common in cars, nowadays. The overall engine efficiency has improved by an average of 1% per year over the last 20 years, mostly because of electronic management and the related microtechnologies which allow a precise control of fuel injection.

Simultaneously, adding on new functionalities has lead to an average 15% weight increase of all car segments as well as growing electrical power demand of an average of 100W/year over the last 15 years.

Rather than solving a problem at the component level, a systems approach is envisioned and a comprehensive solution is targeted.

At an integration level, this means bringing together representatives of the whole value chain to discuss and analyse an issue in order to decide on the appropriate level for suggested technologies and methodologies. Improved engine efficiency, convenience and safety might then, for example, be linked to a substantial decrease in the use of primary energy and materials.

Overall car-system complexity together with the critical importance of the cost and reliability of components and subsystems means the automotive industry is set to be a reference for advanced micro- and nanotechnology developments in general.

EPoSS in particular intends to build upon new multi-disciplinary technologies and approaches with a specific focus on:

Materials and compounds
Starting with and going beyond silicon. Working with Si, SiC, polymers, ceramics, powders, functional materials etc., and with combinations of these.

Miniaturisation and integration
Miniaturising systems and addressing the right scale for systems solutions so as to ensure appropriate integration measures (starting from nano via micro and mechatronic systems to functions)

Interoperability and networking
All scales (including redundancy and fusion concepts, and addressing robustness, systems networks with modular and shared resources)

Converging technologies
Using and combining technologies from optics, mechanics, fluidics, thermodynamics, electronics, computer science, chemistry, biology, etc.

In line with the industry requirements, the priorities of R&D in smart systems for automotive applications are clustered into: safety, driver assistance, convenience, smart power train and cross-over topics.

5.3 Research Priorities

EPoSS takes up the general challenges formulated by the European automotive industry, which are to be addressed by combining national and European efforts. At national level, there are already relevant R&D support programmes (e.g. dedicated to innovations for sensors, electronics, software and manufacturing). At European level, the first choice will be the instruments of FP7. Coordination and support actions across the technology platform will be needed to deliver European solutions in terms of instruments and measures and to organise the interaction of all relevant stakeholders. Furthermore, concerted actions among the Member States involving industry stakeholders will have to be initiated.

The definition of research priorities is an ongoing process. Therefore, the suggested clustering as well as the emphasized topics reflect opinions at the time of this document's preparation. An important aspect for Smart Systems Integration is to provide a framework for taking account of future technologies and approaches.

The research priorities suggested by EUCAR and the ERTRAC ETP, i.e. energy, environment, information and communication technologies, nanoscience-nanotechnologies, materials and production, are clustered within EPoSS into three dimensions: technologies, functionalities and methodologies. Technologies and functionalities need to be combined to build automotive applications. Methodologies are the process-oriented dimension to build applications as well as technologies and functionalities. The following list identifies selected R&D topics of high relevance for Smart Systems Integration:

Technologies

- Materials (Si, SiC, SiGe, non-Si semiconductors, ceramics, polymer, glass, textiles, etc.)
- Nano-scale devices (surface functionalisation, nano-electromechanical systems e.g. sensors/resonators/arrays, nano-characterization tools and methodologies)
- Technologies for micro/nano-scale integration
- Packaging (wafer-level packaging, 2,5/3D integration, heterogeneous integration)

(Common) Functionalities

- Sensing (nano-sensors and MOS-detection devices, multidimensional sensing technologies like sensor arrays, data-processing including data fusion and model-based techniques, low-power platforms)
- Energy (advanced energy scavenging techniques, energy storage, energy management etc.)
- Communication (Micro- and nano-devices e.g. filters, nano-resonators, RF-MEMS, antennas, EM modelling and simulation, low-power components, wireless networks)
- Human-machine interface and visualization (µ-displays, flexible displays, carbon nanotube displays, large-area display technologies, speech recognition and communication)
- Security (low-power cryptography, multi-sensor technologies etc.)
- Privacy
- Robustness
- Quality and reliability

Methodologies

- Design tools and approaches (system-level modeling and design tools, multi-scale design tools e.g. from system to IC design and mechanical functions, from large-area to nanoscale through macro-, meso- and micro-scales, knowledge management)

- Manufacturing techniques (reliability, equipment, process management including e.g. data-flow management and manufacturing floor planning)
- Simulation of multi-domain systems and components on all levels of abstraction
- Standards

As already mentioned, from an automotive applications perspective the R&D field can be divided into five areas of particular interest: Safety, driver assistance, convenience, smart power train and crossover topics.

Safety includes active and passive vehicle systems to protect the driver, the passengers as well as road users. Here the major R&D objectives for the next 15 years are:

Driver information on vehicle dynamics limitations (e.g. traction, curve speed, ground clearance); adaptive human machine interface (HMI) systems to interact with the driver based on the specific situation; a personalised safety system adapted to characteristics of the individual (e.g. weight, age, size); driver drowsiness monitoring to sense and predict dangerous driver situations (e.g. sleep recognition); pedestrian protection systems including reacting and avoiding strategies; collision mitigation systems to automatically reduce impact severity; emergency braking systems for unavoidable accidents; vision enhancement systems including night vision and blind spot monitoring, and vehicle interaction systems to allow cooperative driving using car to car and car to infrastructure communication.

Driver assistance is support to the driver in guiding the vehicle. Consumer demands, technical limits, and legal issues all require the driver to retain full responsibility for the vehicle. Taking account of human ability to deal with complex situations, a synergetic solution aimed at extending driver abilities is the midterm perspective for vehicle control. The major R&D objectives here are:

Lateral and longitudinal vehicle guidance systems (including lane-keeping and lane-change support, ACC stop & go, and ACC for urban areas); later, semi-autonomous driving for defined situations (e.g. automated parking, automatic following and guided driving); personalised driving based on individual driving patterns, constitution, and appropriate vehicle adjustments; active load-management systems controlling chassis systems and the suspension based on the weight distribution in the vehicle; adaptive human-machine interfaces for situation specific interaction (using e.g. force feedback, HUD and speech recognition systems), and adaptive light projection systems for a better illumination of the vehicle's forward scene (using, e.g., turning lights, projection, automatic high beam).

The smart aspect of the mentioned systems is an adaptive approach, as compared to the kind of fixed solution which is common today. The objective is that the technical systems provide optimal driver support taking account of vehicle and driver capabilities and characteristics. EPoSS will build upon networked functionalities using numerous sensor inputs to collect information, (shared) computational power to analyse and interpret situations and decide on appropriate measures, and a variety of actuators for operations to assist the driver in a smart and situation-specific way.

Convenience, the third one of the proposed R&D clusters, addresses secondary driver and passenger requirements (beyond vehicle guidance). Convenience is one of the major decision factors for vehicle purchase. To feel good in a car, first of all the vehicle has to be safe. Therefore appropriate warnings and automatic interference for safety critical situations is one of the major R&D objectives. Second, a car should fulfil the transport requirements – maybe a challenging demand for an increasingly crowded traffic scenario. Individual dynamic routing and supporting overall traffic measures address this issue. The rue convenience functions follow only in third place.

Automated secondary functions (e.g. non-fogging windscreens, anti-dazzle systems and automated light and wipers), user-identification systems, adaptive control elements and human-machine interfaces (including situation specific interaction, scalable and auto-adjusting vehicle control elements), a personalised environment creating a feeling of comfort and convenience (including e.g. audio separation, personalised skins, adaptive climate, forming seats and redolence control), advanced multimedia systems based on wireless communication and digital broadcast technologies.

Here, too, the EPoSS approach allows for changing the automotive technology approach from vehicle static to user centric. It is not the user who will adapt to the car or learn how to operate the systems, instead the vehicle will adapt to the user's needs and capabilities. A first example that could employ the EPoSS approach is reported in Figure 2.

The potential of CMOS technology could permit the integration of further functionalities such as lane warning, pedestrian detection, and road-sign detection. By using smart illumination, the single detector can perform at both visible and near infrared wavelengths.

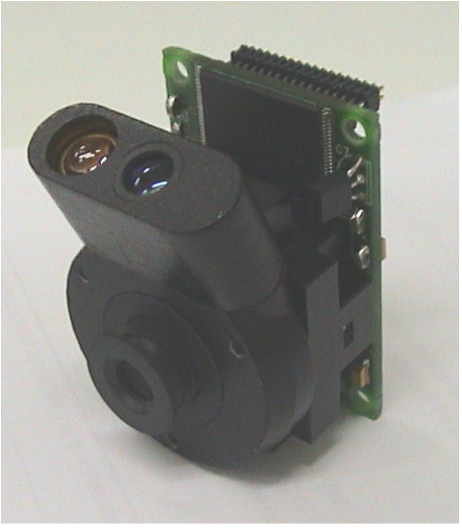


Figure 2: *A single CMOS sensor is used as a multi-functional smart system device which can detect crossing vehicles, the status of incoming traffic, tunnels, bridges, mist, fog, rain, and ambient light intensity while operating as controller of several actuators.*

Networking architectures, and related processing, with these sensors mounted at different locations around the vehicle to detect different areas in a multi-stereo and multispectral approach, could make it possible to reconstruct the road environment and obstacles, thus providing the basis for novel safety, driver assistance and convenience functions.

Micro-optics with novel materials, micro-mechanics, microelectronics, advanced packaging, advanced processing (data fusion) and wireless communication links underlay such developments.

A second example of a multidisciplinary approach for system integration design is the novel lighting system shown in Figure 3.

The comparison of the smart lighting system shown in **Figure 3** with a conventional LED taillight can be summarized as follows: thickness reduction (factor of 10), increased efficiency/power reduction (-70%), weight reduction (-50%), for-life operation, simplified installation, cost reduction, Further integration of embedded sensing and related processing unit will allow light control in different conditions of visibility.

In a mid-term perspective, the EPOSS approach envisages solutions integrating both solar energy converters and energy storage by combining hybrid inorganic and organic technologies.

Smart power train addresses the overall objective of a clean and powerful propulsion system. The R&D objectives are:

To develop a clean power train by e.g. high pressure direct injection and exhaust after treatment, smart energy strategies (including integrated starter /generator approaches, regenerative braking, and route planning), alternative fuel concepts (based on the use of natural gas, synthetic and bio fuels, hybrid vehicle concepts and hydrogen), adaptive power train solutions (e.g. scalable engines, self calibration and active friction avoidance), comprehensive energy management taking into account all loads, active wheel (to concentrate different functionalities like drive, braking, steering, suspension and diagnostics in a wheel system).

Especially, the last objective of an active-wheel concept, or the so called "quarter car", demonstrates the power of a smart systems approach – changing the perspective to solve vehicle requirements in a new context by exploiting advanced technologies.

Figure 3: *Lighting system based on solid state emitting sources, novel nanoscaled high efficiency phosphors and planar micro optics integrated directly on the external polymeric cover.*

The concept is illustrated in the "quarter car" assembly of Figure 4, including suspensions, tires, the actuating systems for steering and braking functions with related sensors.

The integration of smart actuation and of networked sensing systems will allow the complete overall control of a vehicle's dynamic behaviour. Electric actuators integrated in the wheel/suspension system will provide efficient and clean traction, completely controllable, with regenerative braking capability (active wheel). The vehicle control system and the driver will have a real-time detailed awareness of the vehicle status in every driving condition through the sensing distributed network.

These opportunities, coupled with a network of external sensing and communicating systems will provide a natural integrated platform for the development of personalized, autonomous driving functions, enabling the capability of managing vehicle interaction with the external world, including obstacle and pedestrian avoidance.

Scavenging-harvesting is important in a car for several reasons. Fuel-energy savings via heat recovery provide primary power to sensors and actuators thereby reducing complexity, (i.e. a scavenger is a possibility to either avoid or reduce the use of connectors and cables and allow wireless connection) and also yield primary power to the power train.

The integration of scalable micro and nanotechnologies is crucial for both efficient heat recovery and direct chemical to electrical conversion. An example of the potential of heat recovery by thermoelectric modules is shown in Figure 5.

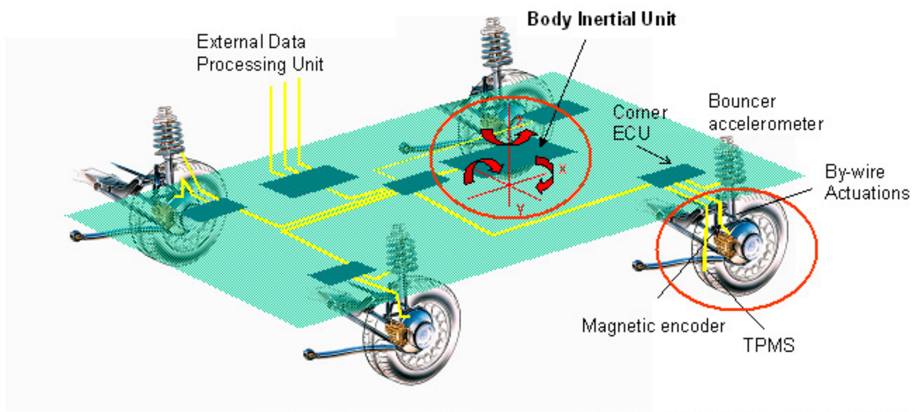
EPoSS envisages coordinated EU action to overcome the challenges in thermoelectric material design, components development and system integration that would allow moving from micro- and nano-scaled developments to large scale novel energy generation devices for automotive applications.

Current and future fuel savings roadmaps on engine development will require more:

- Sensing and Processing: to couple the operation of the ICE to the electrical motors
- Electrical motors and actuators, and
- Sensors (to improve engine performance including efficiency, from today's 12-15 sensors to over 30 in a few years).

An integrated approach including wireless and autonomous sensors/actuators will be necessary to handle this complexity.

The fifth cluster addresses the **crossover** functionalities and methodologies. These include data fusion and management, advanced human machine interface concepts, manufacturing and design methodologies, integration, security, privacy and robustness. Robustness, for example, can no longer be solved at the components level. Especially for safety critical systems a breakdown cannot be tolerated. New measures and comprehensive approaches will ensure function robustness far beyond today's possibilities. R&D topics to reach this objective include: A better understanding of failure scenarios and mechanisms, improved ageing and lifetime test procedures, failure tolerant component and systems, lifetime monitoring and failure prediction, advanced and robust networks, shared resources and flexible hard and software architectures together with robust component solutions and manufacturing technologies.



Sensors

- Braking force
- Vertical acceleration
- Wheel steer angle (duplicated)
- Wheel speed
- TPMS
- INERTIAL CLUSTERS
- Suspension position

Actuators and drives

- Wheel steering (fault tolerant)
- Braking
- Suspension dumping
- Wheel electric motor (option)

Local processing and control functions

- Wheel braking control (including ABS)
- Wheel steering control (fault tolerant)
- Dumping control
- Tire monitoring
- Communication (FlexRay and wireless)
- Diagnostics

Figure 4: *Integrated smart actuators and sensors for the comprehensive "quarter car" control.*

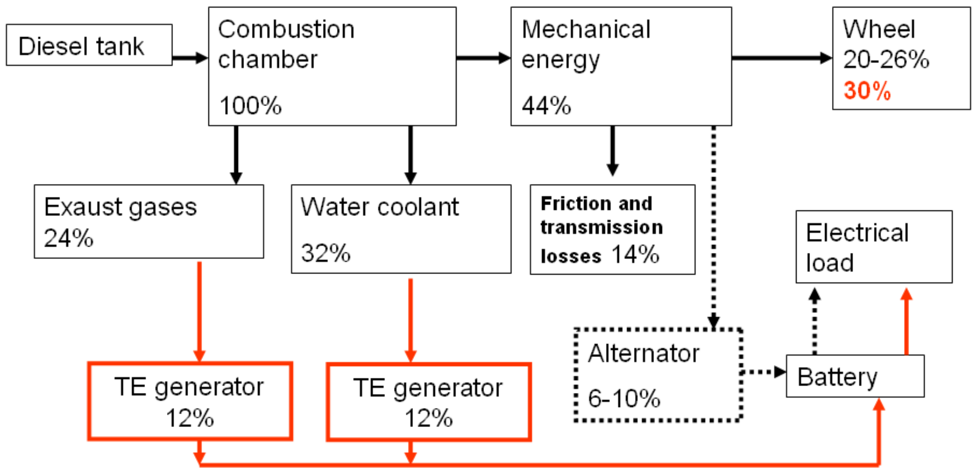


Figure 5: *Heat recovery based on indirect thermoelectricity which could lead to a typical 5-8% fuel saving*

Addressing these issues in a comprehensive way will allow to meet the future requirements of an increasingly complex technical environment. EPoSS considers robustness to be of high importance for all functionalities and that it needs to be addressed on the appropriate systems' level.

To fulfil the listed functional demands in the described five clusters, a challenging variety of technologies is needed. The overview shown in **Figure 6** proposes the most important ones from a today's standpoint.

Some very promising but also challenging technologies are: torque measurement, camera technologies, integration of antennas, energy scavenging, image and speech recognition, and 3D packaging and integration. Rather than single technologies and functionalities, a collection of specific solutions is needed to build the required advanced applications. In many cases it is not yet decided or known which technology or, better, set of technologies and functionalities will deliver the needed performance. EPoSS is broadening the horizon for finding the best solution by addressing the appropriate level and by following a systems approach.

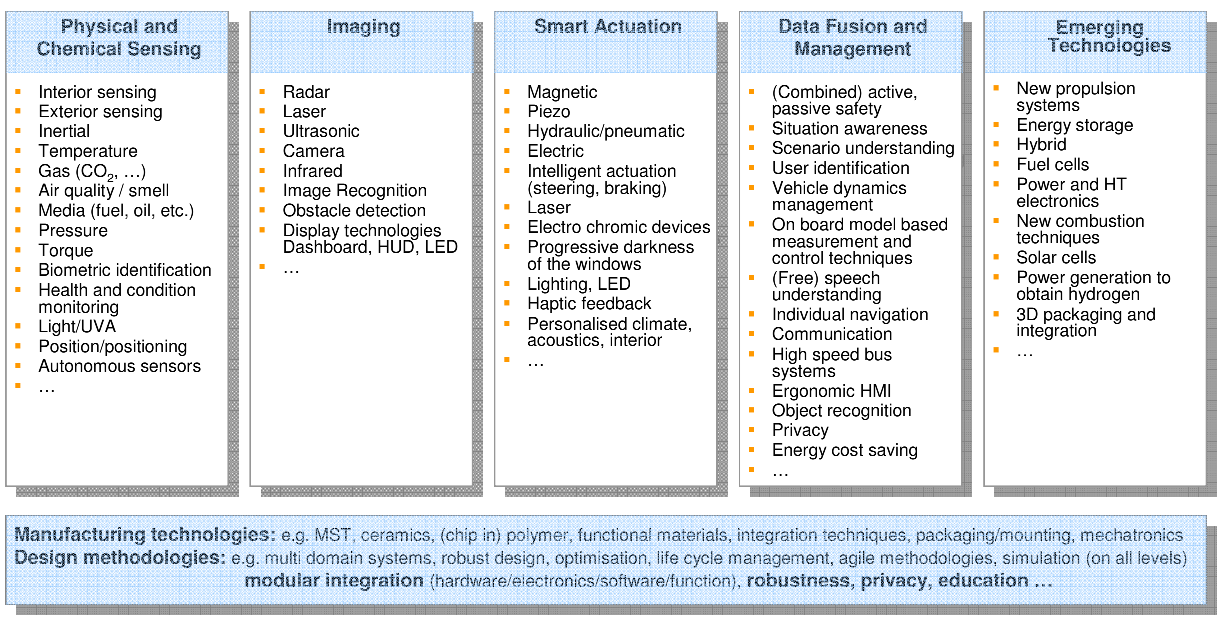


Figure 6: *Research priorities for automotive technologies, EPoSS WG Automotive*

5.4 Research Strategy 2005 to 2015 and Beyond

When discussing an automotive research agenda it is important to understand the connected timelines. Once a principle or idea has been detected or invented, several decades of development are necessary before an automotive application is made. The design of a new vehicle needs three to seven years depending on the availability of appropriate solutions and on the complexity and degree of innovation in the vehicle. The period in which the vehicle will be produced ranges again between three and seven years, which limits the scope for introducing new future technologies. The average age a vehicle reaches is about 10 years, which translates into a slow market penetration for newly introduced solutions, even if a 100% equipment rate is assumed. In sum, innovations in automotive technology have a rather long-term leverage effect.

The **short and midterm automotive R&D perspective (up to 2015)** is driven by customer, legislative and competitive requirements. The four (out of five) chosen application clusters safety, driver assistance, convenience and smart power train reflect these needs. To improve safety, three major approaches will be followed: a better understanding of the situation based on sensors to collect information about the environment; the merging of passive and active safety towards personalised and situation-specific accident mitigation measures, and the active interacting of road users towards a collaborative traffic approach. The underlying technologies are sensors to characterize the situation completely (traffic, vehicle and driver), computational networks to analyse and obtain decisions, communications protocols and infrastructure for interaction and smart actuators, and human-machine interfaces to act in a proper way. Driver assistance calls for comparable measures. Based on a comprehensive understanding of the traffic, vehicle and driver situations, appropriate supporting measures are chosen. Subsequently, the human-machine interface becomes of prime importance, aiming for an adaptive and individual system. In parallel, convenience aspects will gain further in importance. The objective is to develop personalised vehicles – adapted to the driver and changing their attributes to personal and situation-specific needs.

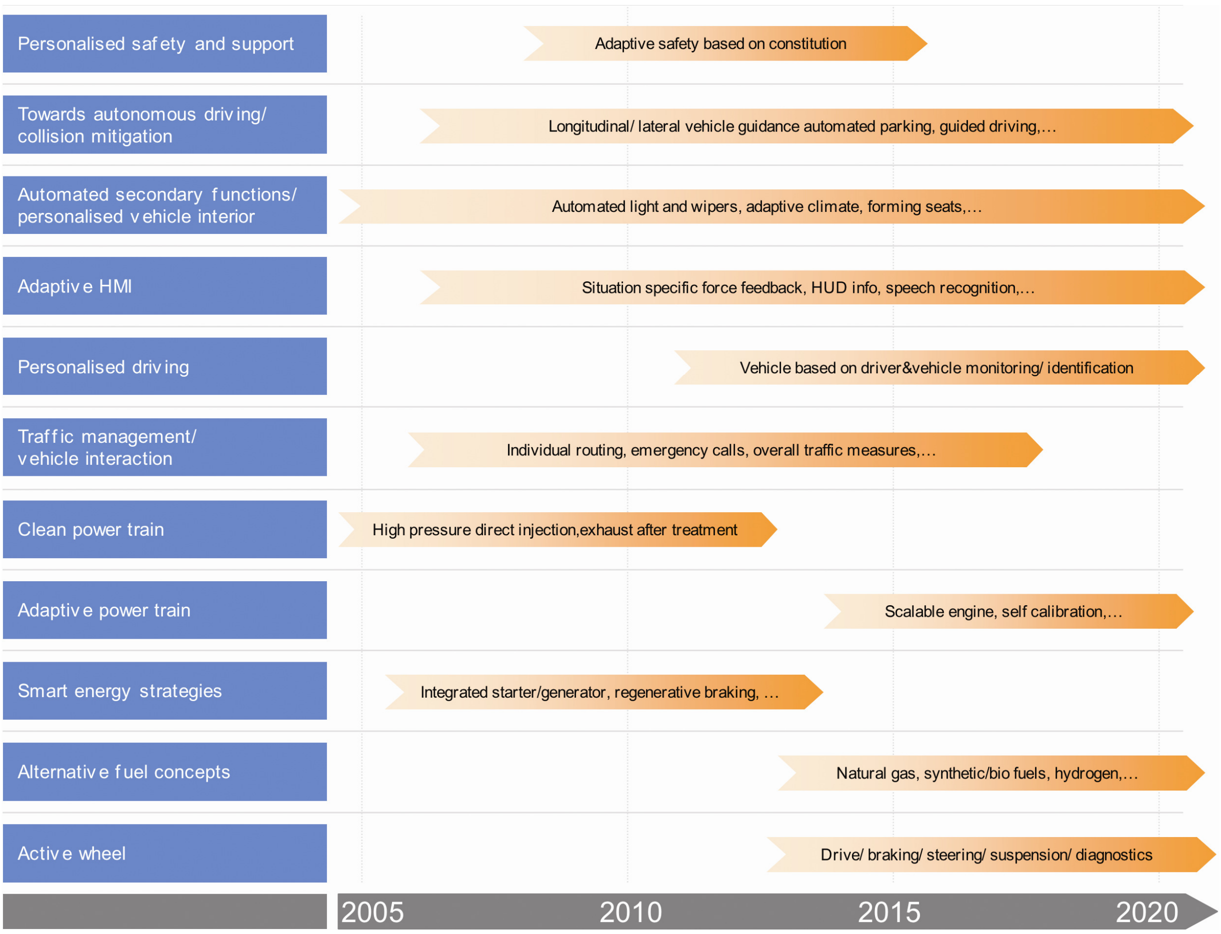


Figure 7: *Research priorities for automotive technologies, EPoSS WG Automotive*

Finally, yet importantly, smart power train applications are a major R&D focus in order to respond to the challenges of less fuel consumption and fewer emissions. It is a long road to a hydrogen infrastructure and new propulsion systems. Intermediate and competing solutions require further high attention. High-pressure injection systems and exhaust after-treatment are short term perspectives; advanced hybrid concepts (vehicles built around a hybrid philosophy) are a mid-term perspective. **Figure 7** highlights the major automotive R&D challenges from a functions perspective.

To meet short-term requirements the development of auxiliary systems is an appropriate methodology. This does not require change to established systems, while still promising potential benefits of high relevance. The second, more mid-term approach is optimisation of the original system, perhaps also including additional auxiliary systems. The EPoSS approach is to seek to solve problems and challenges at the specific level, ideally using the whole vehicle systems potentials. Thus the midterm R&D solutions which EPoSS focuses on are a combination of emerging technologies and existing functional approaches.

By contrast, the long-term perspective includes the development of completely new solutions like, for example, the development of hydrogen-based transport systems. EPoSS addresses this dimension, tackling the practical problems of these approaches.

To provide a **long-term R&D perspective (up to 2050)** two inputs are taken into account: first, the mid term R&D perspective visualised in **Figure 7** and, second, anticipated major societal trends. These trends are mega-cities with more than 10m inhabitants, pollution, ageing and fuel/energy shortage. Scenarios of never-ending traffic jams, unacceptable pollution in the cities and further accelerating global warming, isolated individuals in societies with an average age of 50 years, all leading to restricted personal mobility, are to be avoided. Possible solutions include:

- alternative zero-emission propulsion systems based on regenerative energies;
- communicating vehicles with electronic safety regions surrounding them and safety systems to avoid fatalities and to mitigate accidents;
- cooperative driving, reducing the number of dangerous situations and using the existing infrastructure as well as possible, including intermodal transport, and
- adaptive vehicles with advanced human-machine interface concepts including the ability for autonomous driving on demand to allow everybody to stay mobile.

It is evident that such solutions can no longer be based on single functions but need complex and interacting system solutions. EPoSS will, together with adjoining technology platforms, prepare and investigate such solutions for our future.

To summarise, EPoSS focuses on Smart Systems Integration starting from application requirements and addressing all needed scales and potential technologies. Rather than solving problems at component level, EPoSS supports new comprehensive and system-transcending approaches. The technology platforms ENIAC (nano-electronics), ARTEMIS (embedded systems), MANUFUTURE (manufacturing technologies), ERTRAC (transport technologies and approaches) and EPoSS - as the linking element on the way to future products and features - will provide the required solutions for sophisticated European vehicles. The linkage between the platforms will be ensured by individual stakeholder’s commitments in the various platforms, by co-ordinated activities through organisations like ACEA/EUCAR and CLEPA as well as by commonly supported activities among the European Technology Platforms.

6. Smart Systems for Aeronautics

6.1 Vision

Over the past century aeronautics, the art of "navigating" the "air", has evolved tremendously. Starting with the invention of simple machines capable only of flying, this field has created highly complex systems and devices making the distribution and exchange of goods and people worldwide possible. A modern world without aeronautics would simply not be possible. However, this enormous growth also poses problems that have to be dealt with. Aeronautics will experience a dramatic change in the coming years. In order to cope with the growing demand for air transport and air transport systems, completely new pathways have to be established.

As demand grows, air transport will have to become more individual, allowing for the fast, efficient and affordable transport of individuals and goods. Air transport will develop into a mass transport system, with increasing demands for speed, safety, security, environmental cleanliness and efficiency. In line with these forecast developments, the aeronautics industry has defined the following key objectives for the year 2020:

The highly customer oriented air transport system

The passenger will expect the same services and the same comfort that he is used to at home or in the office. In-flight entertainment will have to provide high quality video and audio on-demand. Passenger comfort will have to be improved by, for example, reducing the perceived internal noise and through personalized passenger climate control. In addition, the cabin will have to become a flying office offering high-speed data connections and mobile (video)-telephony communication options.

The highly time efficient air transport system

The time needed for boarding and de-boarding, cargo and catering operations, cleaning, and fuelling has to be reduced in order to decrease the overall passenger flight time and aircraft ground-time. This will reduce costs and increase customer satisfaction. The main goals that have to be achieved here are, first, to enable the air transport system to accommodate three times more aircraft movements by the year 2020 compared to 2000. Second, to reduce the time spent by passengers in airports to under 15 minutes for short-haul flights and to under 30 minutes for long-haul flights. Third, to enable 99% of flights to arrive and depart within 15 minutes of their scheduled departure time, in all weather conditions.

The highly cost efficient air transport system

Maintenance expenditures are among the main costs for air systems operation. Maintenance strategy will have to evolve from the present time-scheduled approach to a more cost-efficient on-demand maintenance or predictive maintenance, increasing aircraft availability and safety.

Air freight services are expected to grow by 2020 at 5-6% p.a. IATA has launched the e-freight project to eliminate paper documents in air cargo transportation and expects a cost reduction of approx €100m per year. Further costs could be saved by reducing the volume of misdirected baggage: IATA estimated a cost of €2,350m for lost baggage compensation in 2002. New approaches are needed to make baggage transportation and the whole cargo supply chain more efficient.

The ultra green air transport system

The main challenges to reduce the environmental impact of operating, maintaining and manufacturing aircraft and associated systems relate to fuel saving, noise reduction inside and outside the aircraft and fewer emissions of harmful substances. These objectives require a better understanding of flight physics, new techniques for flow controlling, new lightweight materials, improved propulsion, optimized aircraft handling etc.

The main targets may be formulated as follows:

- to reduce fuel consumption and CO_2 emissions by 50%
- to reduce perceived external noise by 50%
- to reduce NO_x emissions by 80%
- to make substantial progress in reducing the environmental impact of the manufacture, maintenance and disposal of aircraft and related products

The ultra secure air transport system[7]

The main points to address for increasing security in air transport are:

- detection of dangerous goods or risky events in cargo operations;
- detection of dangerous persons/passenger operations, e.g. through spectrometer analysis and automatic surveillance, and
- real-time and remote aircraft telemetry.

Smart systems will have a decisive impact on the development of aircraft structures, performance monitoring, engine operations, navigation and safety systems. They will enable more precise control of aircraft while reducing the size, mass and power requirements for operational and safety functions as well as energy efficiency. They will be decisive for diagnostics and predictive-maintenance management of engine, aircraft structure and electronic sub-systems.

ACARE (Advisory Council for Aeronautics Research in Europe) - the European Technology Platform of the aeronautics industry – has defined a series of technological challenges in order to obtain progress in the following areas: quality and affordability, the environment, safety, air transport systems efficiency and security.[8] Related to these objectives the following "taxonomy areas" are defined: flight physics, aero structures, propulsion, aircraft avionics, systems & equipment, flight mechanics, integrated design and validation, ATM, airports, human factors as well as innovative concepts & scenarios[9].

EPoSS has followed the logic of the ACARE consortium and identified those aspects where developments are likely to be affected or determined by smart systems integration.

Translating the ACARE requirements into the world of smart systems technologies, four major future scenarios were defined:

I. The Electrical Aircraft

II. The Connected Aircraft

III. The Intelligent Aircraft

IV. The Efficient Aircraft

6.2 Research Strategy 2005 to 2015 and beyond

I. The Electrical Aircraft

Within less than one decade – by about 2010 - the electrical aircraft scenario should have been achieved. This scenario envisages the replacement of, for example, pneumatic and hydraulic components with electrical actuators controlled by networked and flexibly managed devices. Smart sensors and actuators will permit by-wire functions. Within less than ten years, fuel cell APUs (Auxillary Power Units) are expected, using sensors, process monitoring and control. A new generation of optical components and optical sub-systems will then permit new by-light functionalities (see section II "The Connected Aircraft").

Research and development of new technologies is required in several distinct areas (see **Figure 8**).

Sensors:

Meshed sensor networks including optical sensors, sensors for load, pressure, fluids and gases, temperature, position and motion have to be invented, improved and integrated. These sensor networks will support the measurement and control of, for example, energy consumption during the flight.

Actuators:

Actuators will take over a variety of functions in the future aircraft, translating electronic or optical signals into physical action or motion. Smart actuators will integrate process monitoring and device control technologies. Actuators will also be necessary to switch optical filters, mirrors or other optical switches, and smart electric motors and actuators will be crucial for new by-wire functionalities.

Networks:

A key issue will be the implementation of auto-reconfigurable backbones, fault-tolerant, flexible and adaptive plug and play networks and system architectures by making use of polymer fibres and power line networks.

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7 ACARE, Strategic Research Agenda 2 , p.27

8 idem, p.16

9 idem, p.76

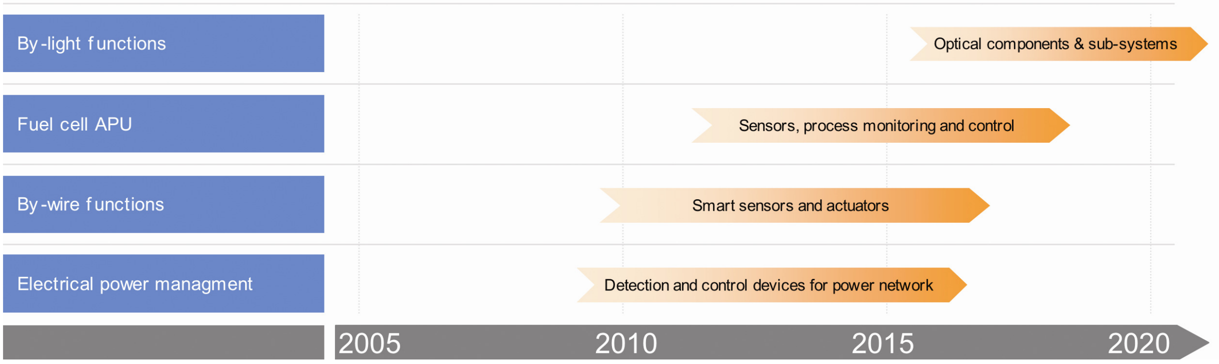

Figure 8: *Technological perspectives of the Electrical Aircraft*

II. The Connected Aircraft

The **connected aircraft** scenario is focused primarily on the integration of the aircraft into an overall and global communication system. Communications technologies for aeronautical applications and for space will be interoperable with terrestrial systems and span the communications arena from the physical, data-link and network layers to the transport communications layer.

The connected aircraft will very soon offer new features for passengers through bi-directional broadband links, e.g. the "Flying Office". Aircraft maintenance will be more efficient and costs will be reduced. Remote monitoring of structures and systems will be possible. Aircraft-to-ground communication will be affordable by high bandwidth low cost data links. With a 10-15 years time horizon ad-hoc networks with flexible routing capability may allow aircraft-to-aircraft communication.

The technologies required for these advances include monolithic microwave integrated circuits, travelling wave tubes, micro and nanotechnology based devices, ferroelectric devices for antennas, transmitters and receivers, modulation, coding and routing techniques for the physical layer; advanced switching methods for the data-link layer; protocols for the network layer and transport layers, and network security systems that span across all the OSI layers. These networks, together with the appropriate sensors, will create the basis for lifetime monitoring of all vital functions of an aircraft.

The following R&D issues will be addressed:

Communication:

Communication will include broadband access for short- and long-range connections, with low data rates with low power consumption available for short-range connections. Ad hoc networks with flexible routing and interference-free intra-cabin wireless and optical links will be provided. These network structures will add to the auto-reconfigurable backbone systems within the individual aeroplane.

Data management and processing:

Very important for the connected aircraft is the issue of data coding and compression, encryption, access management and data storage. This will be crucial for safety and security.

RF technology:

The connected aircraft will depend fundamentally on the development of conformal and low profile antennas with multi-frequency capability, (A)ESA-antennas, active RF-front-end satellites and smart antennas. These will guarantee a stable and permanent link, tracking and control possibilities. Apart from electromagnetic antennas, optical links and optical connections will also become of interest in the near future. This could relate to the issue of electromagnetic compliance, which is a critical factor in the design and development of RF-devices to be used in aircrafts.

The networks within a connected aircraft can be separated into three different layers:

1. The layer for body-area networks (inter-airplane connection, ground, satellite connections)
2. The network layer for the flying office (ensuring bidirectional broadband links and entertainment access)
3. The network layer for ensuring aircraft operation (towards an optical system)

III. The Intelligent Aircraft

The "intelligence" of the aircraft will develop gradually and will peak with the all-freight, fully automated aircraft. Over one decade a series of intelligent features will be realised of which the first will be cabin control functions achieved by applying new sensing devices. Innovations in maintenance and operation,

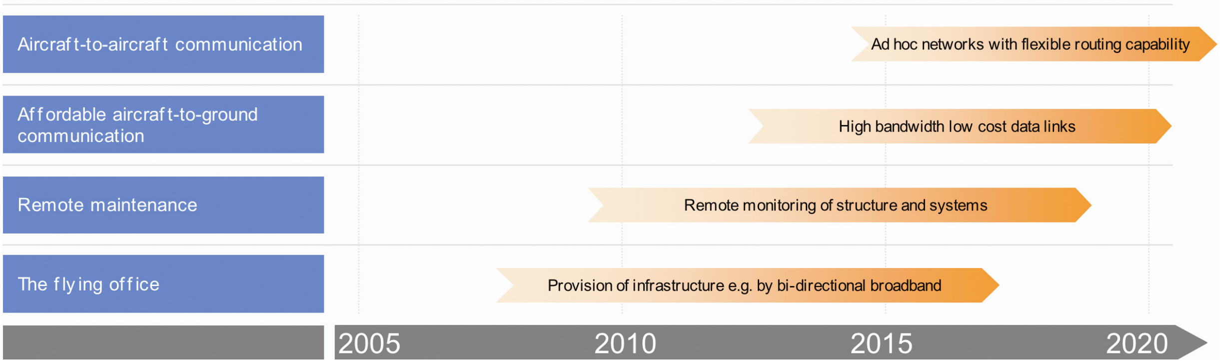

Figure 9: *Technological perspectives of the Connected Aircraft*

e.g. condition dependent maintenance based on sensing functions and data fusion, will follow. Combined sensor and actuator devices will help to realise defence assistance subsystems. Advanced ground operations will be possible by guidance, and a reduction of turn-around time will be achieved. Within one decade, it is expected to realise a fully situational awareness of the aeroplane, which includes all relevant information gathering and processing of the aircraft's environment and direct-coupled feed-forward control. The fully automated all-freight aircraft could technologically be realised towards the year 2017. Secure data links and position determination are key requirements for this.

Significant progress will have to be achieved in integrating the following components:

Sensors:

Sensors and especially smart sensors are a fundamental building block of any intelligent system. For the intelligent aircraft sensors will be required to monitor parameters such as load, shock, vibration, corrosion, cracks, pressure, temperature, humidity, fluids, gases and other chemical parameters or biological factors e.g. pathogens. Furthermore, information about position and motion of the aircraft and about the existence of wake vortices (CAT) has to be obtained. In terms of safety and security, the monitoring of luggage and passengers will be a further issue. Self protection and signature detection of approaching aircraft or other objects with the help of lidar or radar are also crucial.

Actuators:

In addition to the actuator devices already named in the section on "The Electrical Aircraft", intelligent security systems will require devices such as high energy laser and RF-devices for counter-action and jamming. Control devices for navigation and collision avoidance will ensure airplane safety..

New visionary HMIs (Human machine Interfaces) have to be developed and implemented to ensure extended reliability and intelligence of flight control,

Communication:

In order to add smartness to the "connected aircraft", wireless technologies, remote sensing, RFID systems for luggage and goods tracking, UWB, special fault-tolerant networks and again auto-reconfigurable backbone structures will have to be improved. To increase safety, firewall systems for integrated networks and other fallback strategies will need to be implemented.

Data management and processing:

Data handling and processing will be critical, in particular fusion, classification, and real-time processing for closed-loop and feed-forward operation. Collision avoidance systems on-ground and in-air for autonomous aircraft operation will ensure the safety of passengers and goods.

IV. The Efficient Aircraft:

The "Efficient Aircraft" describes the future of the aircraft in terms of cost and performance improvements. Significant breakthroughs will be obtained in the near future already in passenger monitoring and guidance and tracking of luggage and goods, based on wireless technologies. By the beginning of the next decade, significant progress in aircraft all-weather capability are expected by applying synthetic vision systems based on radar/lidar and by remote warning and stabilisation systems. New actuators and forward control will allow effective power control and hence power optimisation. Significant progress is expected in adaptive aerodynamics, resulting ultimately in morphing aircraft structures, particularly morphing wings. Flow control by integrated micro sensors and actuators will contribute to these developments. The development of active-material-based embedded actuators in the aerodynamic lifting com-

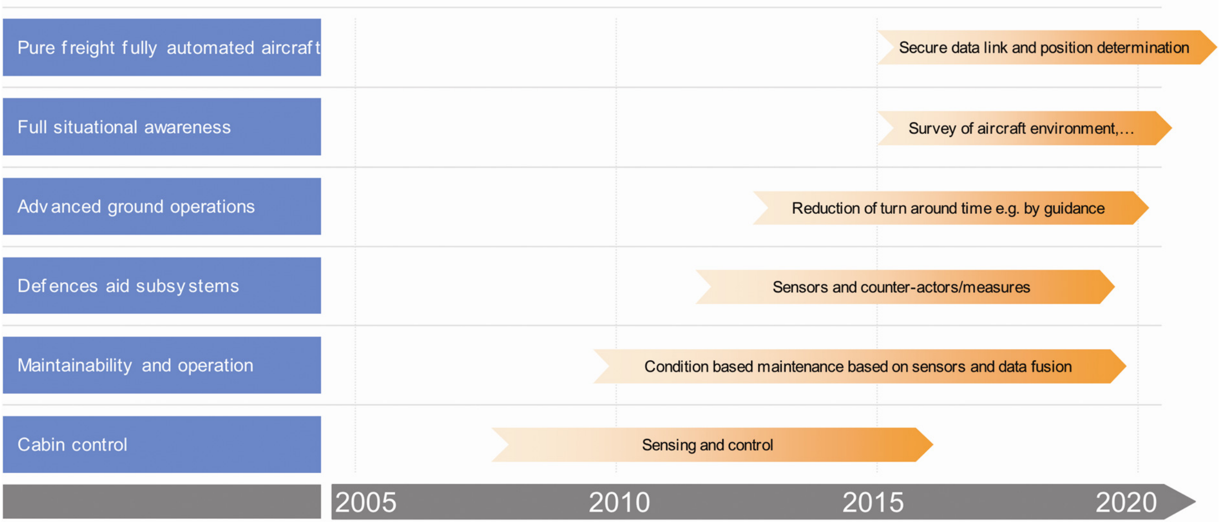

Figure 10: *Technological perspectives of the Intelligent Aircraft*

posite structure will enable effective load control devices for a series of new air vehicles.

The following issues are to be addressed:

Sensors:

In addition to the previously described sensing requirements, the future aircraft will require sensors for wireless position/localization and tracing, conformal micro airflow sensor arrays, load detection sensing devices, self-sufficient airflow sensors, and ice sensors. Wake vortex/CAT, lidar/radar and harsh-environment sensors will also be integrated in the envisaged future aircraft.

Actuators:

During flight micro-passive and active-flow control devices, EMAs, trailing-edge devices and adaptive aerodynamics, anti-contamination surfaces, adaptive functional skins realized through piezo elements, actuated polymer fibres or memory metals will all help to improve flight performance and physics and thus reduce fuel consumption.

Integrated de-icing devices will ensure a short ground time even in harsh conditions and will add to the all-weather capabilities. Moreover improved tracking of goods, e.g. by RFID technology, will also contribute to reduced ground time.

Actuators will increase passenger comfort, e.g. adjustable and self-adjusting seats and cabin climate control.

Data management and processing:

Travel time and fuel consumption will be drastically reduced through automated guidance systems, built-in environmental routing and active load control.

Power:

Under the constant pressure to increase the economic efficiency of aircraft, power management will be of foremost importance within the next years. Smart turbine control and the integration of fuel cells into aircraft will play a major role. Major issues are distribution, sensing, monitoring and control of fuel cells, high efficiency fuel cell reformers, water generation from fuel cells and knowledge in remote powering, power transmission by light, vibration, and energy harvesting.

6.3 Envisaged issues for future smart systems in aeronautics

Synergies can be derived from the various scenarios and development paths and specific technologies will serve multiple purposes. Summarising across the various functional areas the following smart systems issues related to aeronautics are key:

Communication:
Broadband for short and long range, low data rate with low power consumption for short range, ad hoc networks with flexible routing, interference-free intra-cabin wireless and optical links, auto-reconfigurable backbone structures, wireless network technologies (e.g. UWB), remote sensing, fault-tolerant networks.

Sensors:
Load, corrosion, cracks, pressure, humidity, fluids and gases, chemical parameters, temperature, position and motion, microsystem-based sensor networks, meshed sensor nets, optical sensors, lidar/radar, wake vortex/CAT; self-protection and signature detection, pathogen sensing, wireless position/localisation and tracing, conformal micro-airflow

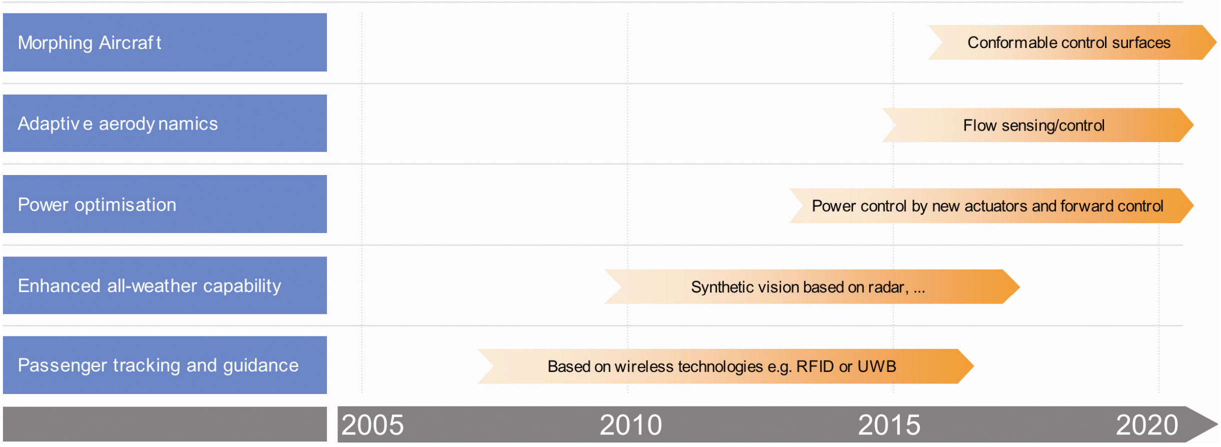

Figure 11: *Technological perspectives of the Efficient Aircraft*

sensor arrays; self-sufficient airflow sensors, harsh environment sensors

Actuators:
High-energy laser and RF for counter-action and jamming, control devices for navigation and collision avoidance, EMAs, smart actuators; micro-passive and active-flow control devices, trailing-edge devices/adaptive aerodynamics, de-icing devices, high efficient actuators, anti-contamination surfaces, adaptive functional skin

RF Technology:
Conformal and low profile antennas with multi-frequency capability, (A)ESA-antennas, active RF-front-end satellites, smart antenna linking, tracking and control, optical links

Power:
Remote powering; power by light, vibration; energy harvesting, process monitoring and control devices, optical filters, mirrors, switches, power management and distribution, sensing, monitoring and control of fuel-cells, water generation from fuel cell

Data management and processing:
Coding and compression, encryption, access management, data storage, fusion, classification, real-time processing for closed-loop and feed-forward operation, collision avoidance systems on-ground and in-air for autonomous aircraft operation, active load control; auto-reconfigurable backbones, fault-tolerant networks, polymer fibres, power line networks, fault tolerant architecture.

Summary

The four identified fields of application show a high potential for synergetic effects. They also show, that smart systems will play a vital role in future aeronautics. They will contribute to increased flight security, reduced environmental impact and raised performance of transport in general.

7. Smart Systems for Information and Communication

The European market for telecommunications, like the automotive technology market, continues to grow steadily. Both are driving forces in technology development.

7.1 Vision

In Europe, as in the USA, the ITC labour market was stable in 2005. Indicators suggest a positive trend for the next two years. ITC directly provided 5.9m jobs in EU15 in 2005 (source: Eurostat –New Cronos) with a turnover of €614 billion, an increase of 2.9% on 2004. European ITC growth was twice as high as economic growth in general. Further growth is predicted for 2006: the European Information Technology Observatory (source: EITO [1.1]) expects 2.8% (total turnover: €631.7 billion).

The biggest slice of the ITC market belongs to the EU with a trade off market share against profit margins of ~30.2% followed by the USA with ~29.4% and Japan with ~14.8%. The total turnover in the year 2005 was € 2,043 Billion compared to € 1,889 Billion in 2004. The growth rate amounts to 4.3% in 2005. EITO predicts up to the year 2010 a stable average growth rate of ~4.2% per annum. The predicted trend is strongly related to the incremental analysis with respect to the new EU Membership nations.

Advanced smart systems integration technologies will be the key element to secure a competitive advantage for European telecommunication players to fulfil the credo of the "seven fundamental right approaches" in telecommunication:

> To provide the right information in the right form to the right address in the right place at the right time to support the right transaction with the right security.

A range of technologies have to be combined to optimize solutions and allow innovative new product generations. These incorporate new

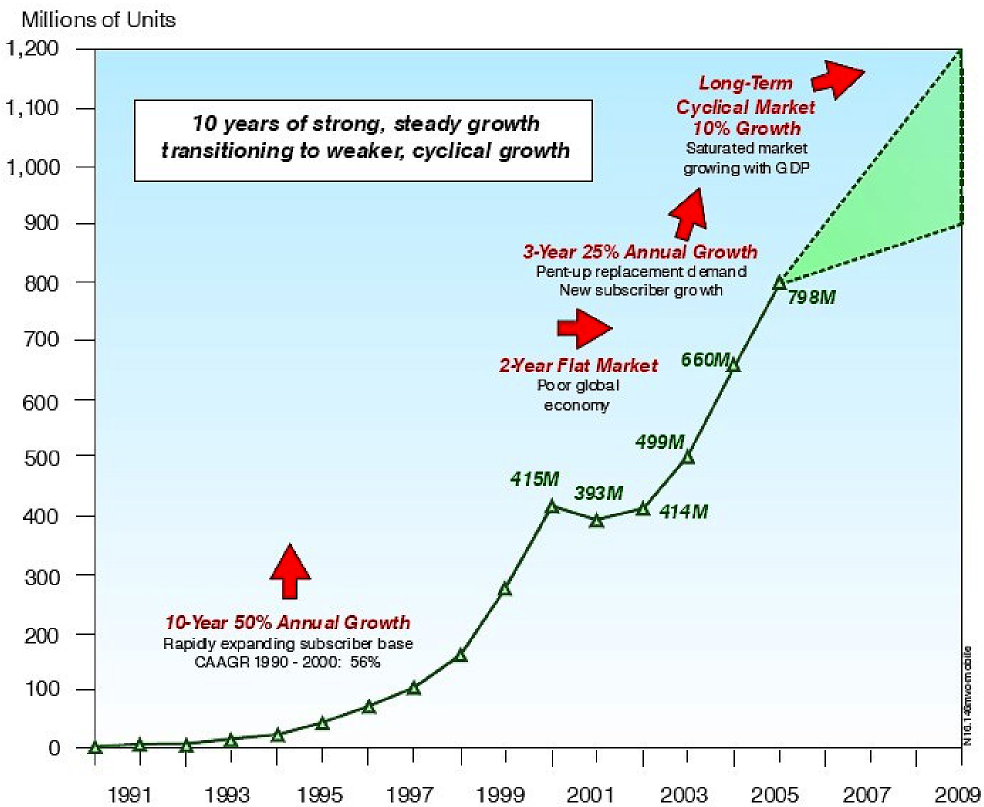

Figure 12: *An expressive example of the tremendous dynamics of the ITC market was given by Prismark WTR in 2006 with respect to the global cell phone market.*

- Materials
- Components
- Sensor and actuator technologies
- Smart packaging
- Signal conversion, transformation, adaptation, processing, computation, and protection
- Communication
- Position finding and localisation
- Energy scavenging
- Adaptive self control
- Modelling, design and test
- Security and environmental safety

IT and communication technology based on smart systems integration will drive future innovation and applications in many sectors, e.g. medical technology, wellness, automotive, aerospace, logistics, etc.

7.2 Rationale and Objectives

The telecommunication sector embraces many areas, including the distribution of data, audio, video and other information via cable or wireless.

The sector is of huge importance for the national finances of EU governments. The management and logistics of networks as well as service provision over networks have become significant elements of national economies. Production and distribution of radio and television programmes is one factor. But IT and communication infrastructure has also become a strategic factor essential for national economic competitive advantage. Telecommunication strongly influences the prosperity of other industrial sectors, e.g. aerospace, automotive, medical or logistics/retail etc. These are the most important sectors for European competitiveness currently and in future. Continuous product innovation cycles are important and essential for technological and economic progress. Developing innovative sophisticated products makes high demands on many different technologies (optical, electrical, mechanical, packaging, material, etc.) with the challenge of fulfilling a large bandwidth of requirements from the automotive, aerospace, medical and logistics etc. sectors.

EPoSS will focus simultaneously on technological, process and application issues critical for the telecommunication industry.

Figure 13: *Telecommunication strongly influences many industrial sectors* [10]

Technological Challenges:

- Increase of processing power
- Tremendous local mass storage
- Expanded communication bandwidth
- Power management
- Very short innovation cycles (< 0.5 a)
- Dramatic price erosion
- Hidden technology for the user
- Up/down compatibility
- Miniaturisation
- Continuous growth in complexity and functionality
- Tremendous number of different standards

Market Challenges:

- Smart devices
- Hidden technology
- Plug and play
- Human-machine interface - forget manuals!
- Safety of data, communication and transaction
- Environmental monitoring
- Personal health and integrity
- Health care
- Environmental control

Successful solutions must be sought on the system level from materials, components, miniaturisation and integration to converging technologies.

[10] Source: EPCOS

7.3 Research Priorities

The mobile communication market has evolved rapidly. Standards have been extended or replaced continuously by new generations of standards. More and more new products and features have been introduced, ranging from base station to mobile phone or WLAN. Concurrently, communication systems migrate to support more and more multi-mode, multi-in/multi-out radio functions. Technical challenges increase.

The ITC market demands very short innovation cycles and highly improved quality. The required R&D faces both technical and financial barriers. There is demand for new smart system technology in order to push innovation forward and create growth. The integration of the new EU member states is a great chance to create one of the biggest ITC markets in the world, and to leverage the technologies essential for economic success.

Forward-looking system development is needed to focus complex ambient conditions and anticipate smart system solutions. The technical complexities of highly interconnected systems can be mastered only by new highly sophisticated methods. Catchwords are flexibility, engineering for usability, and context of application. Cost benefit analysis and highly sophisticated technologies will be the factors of future success. Smart systems integration will not compete with integrated monolithic microsystems; it will complement them.

Reductions in size, weight, cost and power combined with shorter product life cycles and increasing complexity cannot be achieved without technical innovation. An example of an important technology enabling significant improvements in these parameters is System-in-a-Package (SiP) technology. SiP technology allows flexible integration of different elements such as MEMS, optoelectronics, active and passive components and bio-electronics into the packaging, improving performance and reducing system cost.

The key elements of SiP technology are:[11]

- system partitioning/modularisation
- chip-package co-design (on-chip, off-chip)
- integration of different functions in one package
- application of “add-on” technologies to increase system functionality
- high-density component integration

[11] Source: ITRS 2005

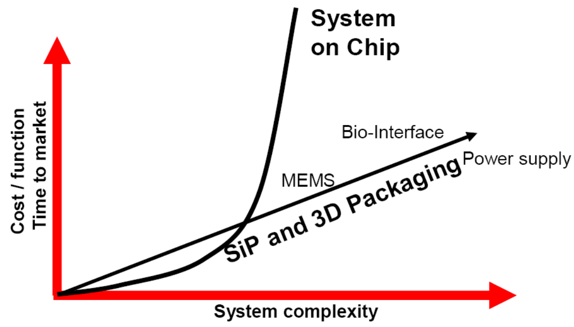

Figure 14: *SoC (System on Chip) and SiP (System in a Package) comparison for cost per function and time to market vs. complexity given by ITRS 2005*

- known good die
- test and reliability
- short time to market cycles
- low cost

A major challenge of SiP technology is the heterogeneous integration of different components using different technologies and materials. The system approach requires integrated co-design and manufacturing and has to merge interdisciplinary technological approaches and solutions.

Another important challenge to increase functionality and miniaturisation is the development and integration of new materials and components into systems of new architecture. With more and more air interfaces introduced into the wireless market the product spectrum becomes increasingly diverse. There is a need to shrink the product spectrum while still matching the different market expectations. To achieve this, frequency-agile radio must be developed requiring next generation RF-MEMS (Radio Frequency Micro-Electro-Mechanical Systems), tuneable capacitances and inductances. Sophisticated system design will have to deliver such a solution at less complexity and cost compared to classical radios.

The R&D field can be divided into the main areas of mobility and networking, against demands for increased performance and security. Some key issues and challenges are outlined below.

Mobile communication technology

The functionality and features of mobile phones, base stations and multimedia devices are dramatically increasing. The pace of innovation is immense, forcing integration technologies, new materials, power management, new system concepts, miniaturisation and cost reduction. Innovation cycles have shortened to half a year and are much shorter than in the automotive application field. Integration and embedding technologies must be able to handle a lot of heterogeneous technologies, e.g. different substrates, materials and components.

An important example is tuneable multi standard front ends:

The trends in the development of mobile phones include more and more multi-band, multi-standard (GSM, UMTS, CDMA, 3G, 4G, WiMax, …) operation for global communication and for global (GPS, Galileo) and local positioning applications. To tackle this challenge with respect to performance and costs, re-configurable, tuneable and frequency-agile front-ends are required. This will require the development of tuneable filters and duplexers, tuneable matching of antenna and power amplifier, frequency-agile filter banks and re-configurable transceiver ICs as well as heterogeneous three-dimensional packaging technologies of high performance.

The world is moving toward a wireless, always-connected, communication environment. New applications such as mobile high-quality video will require continued development and improvement in microwave and radio technologies. Handsets, which will be increasingly used as entertainment platforms, will become more complex with the integration of several radios into the transceivers to handle multiple standards and frequencies while meeting demands for further miniaturization. Higher-order modulation schemes will require highly linear architectures and will increase the power consumption of the power amplifiers: efficiency and linearization are therefore key areas of continued research and development.

The goal must be to offer services/products that will enable the ultimate wireless-user experience: portable appliances universally connected to the best available broadband service, under all mobility conditions, indoors or outdoors. The achievement of this goal, however, crucially depends on the availability of the enabling wireless technology. There is a broad necessity for research in the field of advanced wireless components and systems to make the dreams of an always-connected, multi-standard, multi-service communication environment come true.

Wireless Access Technologies

Over the next 10-20 years, wireless engineering will be at the core of radical technology development, across a wide variety of areas: communications, medicine, logistics, environment, entertainment, security and energy infrastructure to name only a few. For example, wireless communications may theoreti-

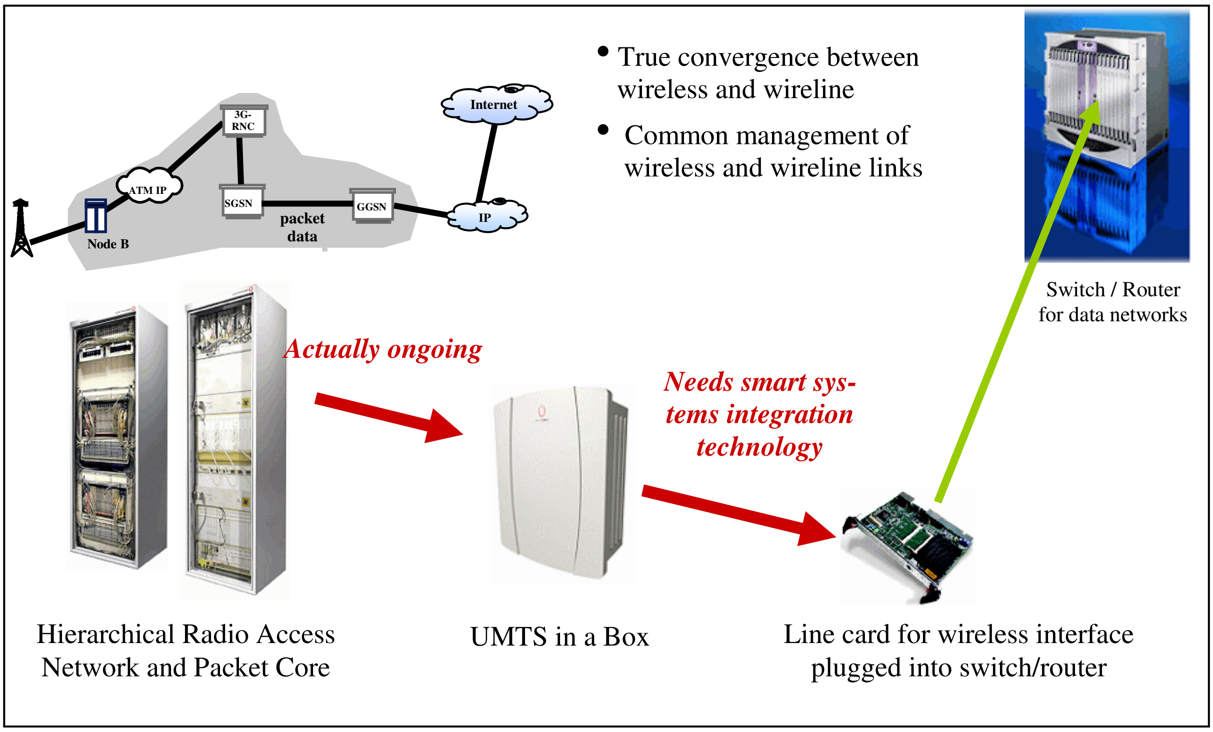

Figure 15: *Wireless infrastructure evolution: collapsing the network further and further* [12]

[12] Source: Bell Labs Europe

- Integration of actives (RFIC) and passive components (RF-MEMS)
- Concept for isolation, shielding and encapsulation required to avoid detuning
- High precision and high flexibility analog/ RF system
- Digital programming of centre frequency and bandwidth
- Analog/ RF combined with digital and logic
- Active Q factor enhancement
- Universal filter module usable with a large variety of communication systems
- Realization as LTCC module or SIP?

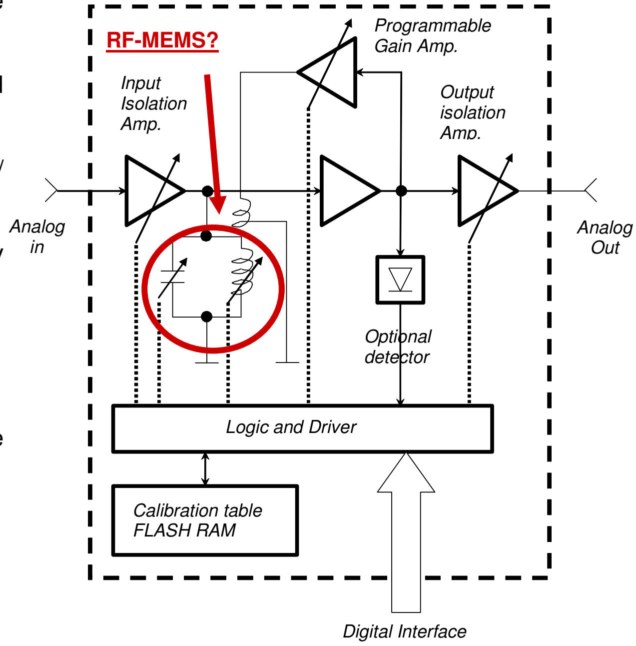

Figure 16: *Smart system: Software defined analog filter* [13]

cally provide seamless access to personalised communication devices capable of delivering Gbps of data when required, allowing a new revolution in entertainment and personal communication, and finally breaking down the artificial division between media such as voice telephony, television and data communications.

In the medical field, low-power wireless controlled therapeutic and monitoring devices will play an increasing role for applications such as defibrillators, neural stimulators and the artificial cochlea and retina. In logistics, the wireless RFID (radio-frequency identification) revolution will totally transform the way companies manage operations and logistics as they receive a complete real-time overview of their entire inventory. In environmental monitoring, the ability of dispersed networks of wireless sensors to capture and analyse real-time pollutant and climatic data — a possible future application field of a backbone based on the WiMAX standard — will play a critical role in the climate change and environmental debates.

However, these visions still remain at the edge of our capabilities, and only basic research in the core underpinning areas of wireless engineering will enable them to become reality. It is critically important that Europe invests now in tackling key research challenges in these areas in order to be a credible world force in one of the most powerful and disruptive sectors supporting the knowledge industries of the future. The portents at the moment are ominous with Europe continuing to trade complacently on the success of GSM in the 1990's, while the real innovations and breakthroughs in leading-edge areas of wireless technology, such as Ultra Wide Band (UWB), are now coming from the USA.

Wireless Market Convergence

A single word has become the most often used buzzword in the wireless space**: "convergence"**

Public cellular meets private wireless, IP data meets voice, licensed spectrum meets unlicensed bands, the phone handset meets the PDA and communications OEMs meet PC OEMs (Original Equipment Manufacturer). And they converge. The combined data communications industry is racing to bring broadband services to the users' hand palms and desktops, but for all of it to succeed it has to happen through a combination of unified, interoperable sets of standards and multi-band, frequency-agile hardware.

There is a trend towards increased data rates at increased mobility. Combining these two market requirements necessitates intense research in the field of the so called 4th generation of wireless technologies.

[13] Source: Bell Labs Europe

The Market — Status and Opportunities

Seamless roaming between indoor (WLAN and Wi-MAX) and outdoor (GSMI3G) data networks is ranking increasingly higher in the wish-list of consumers as well as corporate users, propelled by three considerations:

- experiencing an 'always connected' environment, even when individuals (and their wireless devices) move from public to private environments;
- reducing the number of wireless data devices required by an average mobile user;
- providing the best available Quality of Service according to user location and mobility.

Wireless operators (Telecom Operators and Internet Service Providers) are also latching on as seamless roaming will help push incremental data services at a time when their voice revenue growth is getting flat.

The combined end-user and operator motives are turning seamless roaming into an ingredient of the global wireless industry. A few prescient carriers, such as Telia-Sonera in Norway, dived head-first into WLAN technology early on and today lead the pack in terms of integrated services in northern Europe. Now, T-Mobile, Cingular, Vodafone and France Telecom are following suit. The 'smooth handover' between WLAN and existing GPRS and 3G networks will help reshape the nature of the workplace and business travel, boost productivity and revolutionize the mass communication and entertainment industries.

Research Challenges

Figure 17 visualizes the highly complex interdependence of radio standards, product-specific needs and technological development. This situation has various important consequences:

- Any future wireless technology or service will call for managing complexity on the system level.
- Intense research efforts will be needed to find solutions that are both technically sound and commercially successful.
- Many of the most critical challenges centre on the extremely demanding trade-offs and performance targets that must be balanced between output power, efficiency, bandwidth, linearity and cost. A key focus for these is the power amplifier system perhaps using novel wide-band-gap semiconductor material systems;
- More broadly, the challenge is to design cheap low-power reconfigurable analogue front ends capable of handling multi-Gigabit communications up to mm-wave frequencies;
- Consequently, automated electronic design (AED) tools will be needed with unprecedented capabilities. The basic challenge for the tools is that they should manage the complexity which stems from merging the digital and the RF worlds providing the accuracy and reliability that is required for the design and simulation of single chip solutions.
- The underlying (nonlinear) models of devices do not allow predicting the behaviour of a more complex circuit from the values for a transistor model. Most industrial customers, however, are interested in a successful design of systems depending on the quality of circuit or even sub-system parameters. Therefore, it will be very challenging to find the relation between the transistor model accuracy and the quality of the circuit and the system performance prediction.
- In a similar way characterisation and measurement of devices, circuits and systems face new challenges: large signal and noise characterisation of differential circuits, high input / output impedance and low input / output impedance measurement methods are by no means standard yet.
- Research is needed in advanced modulation technologies, information theory and coding techniques (e.g., what are the most practical capacity achieving codes — turbo codes or LDPC codes?)
- Modelling of electromagnetic propagation phenomena (e.g., what are the theoretical limits of both passive and active RFID systems)
- Development of efficient multiple access mechanisms and network management
- Digital signal processing for high data rate systems adaptively configuring systems in an optimal way
- High performance A-D converters and similar complex non-linear sub-systems posing a range of problems in non-linear circuits and systems

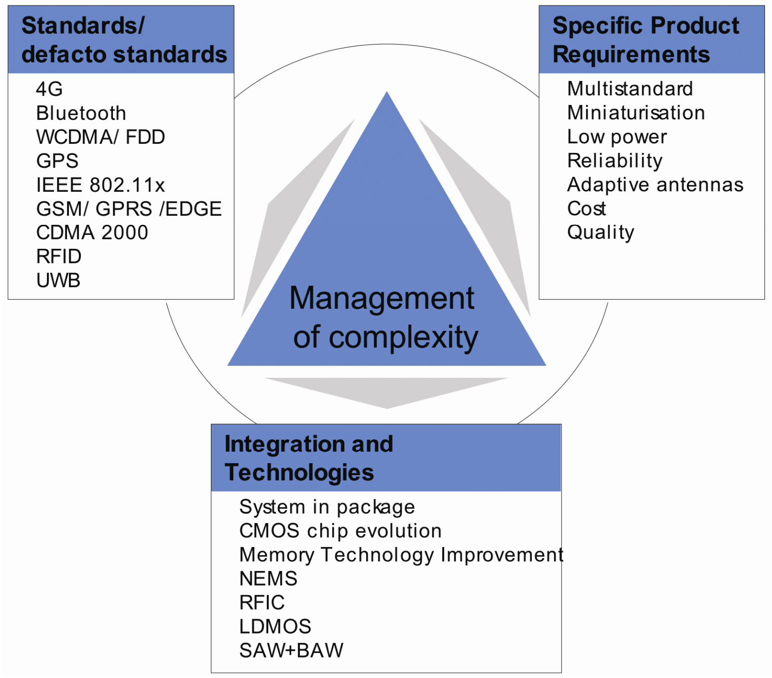

Figure 17: *Matching Standards; Product Requirements; Integration Technologies*

- What are the ultimate performance limits of wireless communications under a variety of scenarios (e.g., multiple access channels, multi-hop channels and fast-fading frequency selective channels)? While some of the theoretical limits have been determined, there is still a surprising number of potentially practical systems whose ultimate performance limits are undetermined.

In turn these basic research targets enable the answers to a range of very practical applications (e.g. design a RFID system with longer range, design a longer life wireless-powered medical implant, etc.). At this level a great deal of the work will be multidisciplinary and can encompass activities within electronic engineering, mathematical sciences, computer science, advanced materials, medicine, physics and chemistry. Therefore, it is indispensable to engage at a European scale into interdisciplinary research in all aspects —advanced devices and systems included — of wireless technologies. Broadband mobile wireless systems and services will play an increasingly important role in modern society and economy. However, the dream of being always connected can only come true if the enabling technologies exist. Therefore, it is indispensable to foresee within FP 7 appropriate working programmes and funding of research for the fields of advanced wireless technologies, components and systems. Common and concerted efforts of industry and academia at a European scale will bring back the leading role in wireless communications.

Digital Video Broadcast on Mobile Terminals

Receiving TV [Digital Video Broadcast – DVB] on a cellular phone still is a topic under research. Driven by the network operators and the service providers, high improvements of processing power, coding and decoding video streams, data transmission efficiency as well as the management of customers and applications is a challenge. Operators are in the driving seat, of course.

Wireless Sensor Networks

Wireless sensor networks will become a ubiquitous tool of the industry in some years. Their reliability and robustness will be high: sufficient to perform mission-critical functions in harsh industrial environments without interrupting production or causing downtime. Sensors and other components of wireless networks will be smart, and able to change function in response to dynamic conditions.

Wireless networks and their components will be autonomous-self-configuring, self-calibrating, self-identifying, and self reorganizing for optimal network performance and recovery. They will require no maintenance during their mission life

Moore's Law will kick in for wireless sensor systems as sensors evolve into inexpensive, disposable, "peel and stick" devices with plug-and-play compatibility.

Wireless networks will outperform wired ones in a variety of ways:

- lower installation and maintenance costs
- easier upgrading and replacement
- fewer or no connector failures
- greater flexibility in the processes they monitor and/ or control, with improved tracking of materials and equipment, reconfigurability of assembly lines, and mobility of equipment
- better exploitation of MEMS' capabilities
- rapid commissioning, thanks to self-organization, self configuration, self-calibration, and self-verification

Additionally, wireless systems will offer end users new possibilities not provided by wired systems:

- operator-independent (i.e. autonomous) control of industrial processes
- built-in redundancy, which in turn will facilitate anticipatory maintenance/ failure recovery
- ad hoc applications, with networks self-configuring to meet temporary needs

Fulfilling the potential of industrial wireless will require a cross disciplinary collaborative R&D effort. Key advances will be needed in power, reliability, integration, cost, functionality, and bandwidth efficiency.[15]

Next Generation Networks

With regard to user acceptance of future IT and communication technology, end-users will have personal access to multi-media information and services using whatever appliance, at any time and wherever they are. Nowadays the internet already offers limited but promising service profiles, as mentioned. In next generation communication networks, IP-technology will merge all the different data-transport systems into one global network access. The future architecture of the Next Generation network (NGN) will offer the user only an access point into a general media gateway. The user will receive or send just an information stream. Handling the content will just happen and will not be visible for the client.

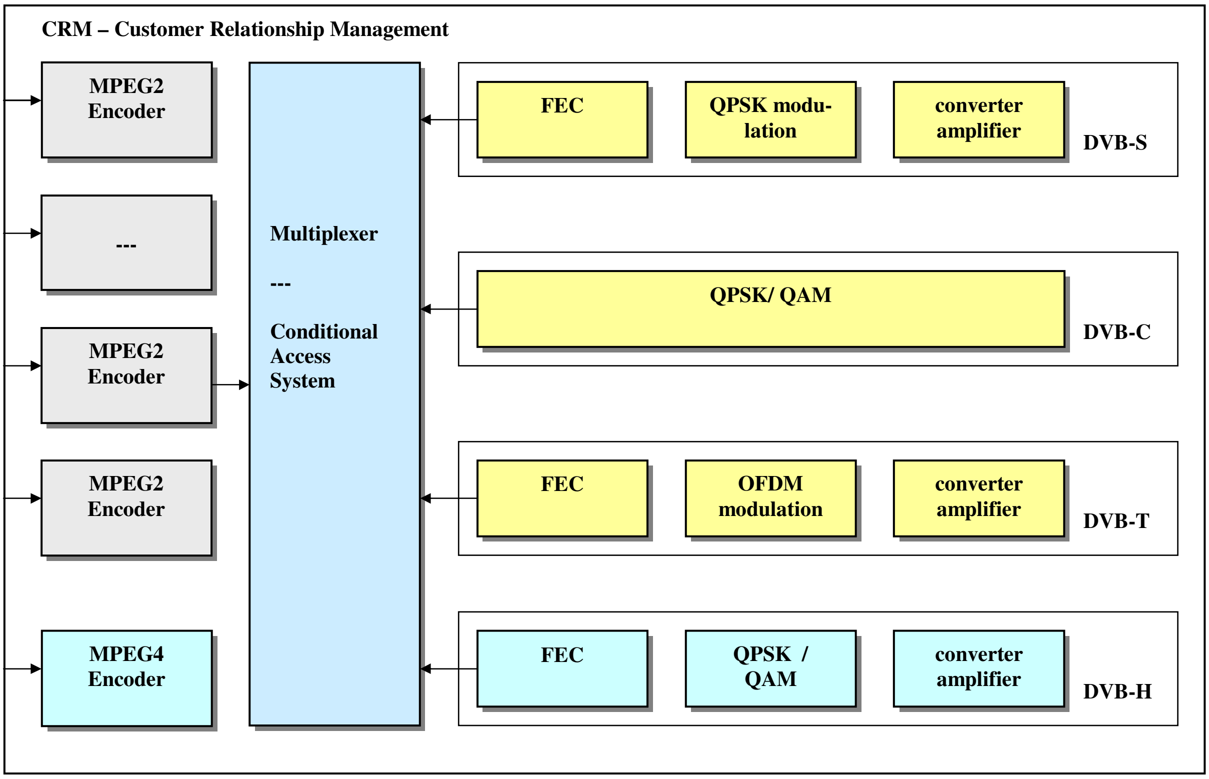

Figure 18: *Functional Block Diagram DVB-S/C/T/H*[14]

[14] Source with reference and on behalf of Vienna University of Technology – Forschungszentrum Telekommunikation Wien Betriebsgesellschaft

[15] Source: Technology Foresight

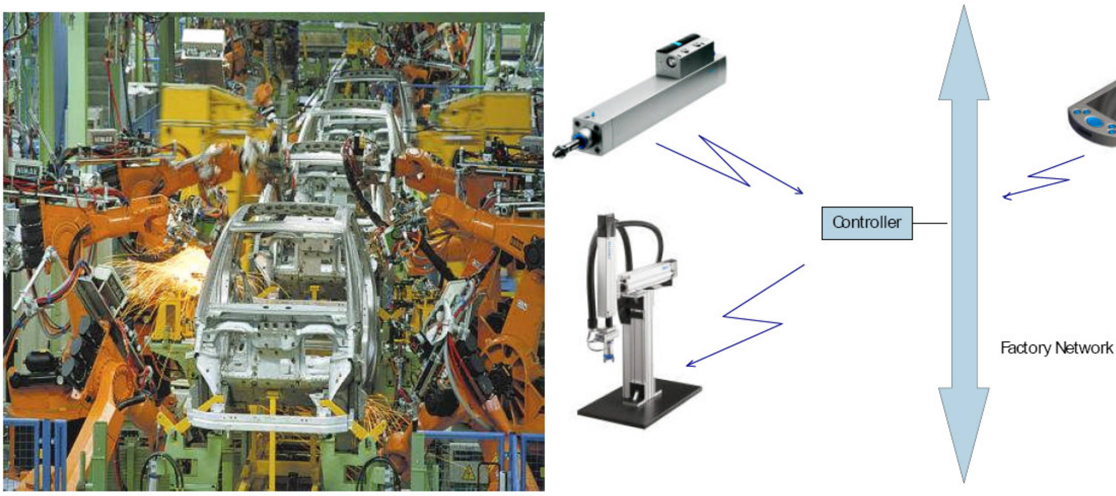

Figure 19: *Illustration of wireless network of sensors for use in industrial processes*

Inside the networks information transport will be different from now. Major characteristics of NGN will be interconnecting the media gateways, handling super-high-speed volume data, converting protocols and formats, switching and routing the information streams etc. The very next driving force for this trend will be Voice over Internet Protocol – VoIP.

The integration of optical and high end electronic components as well as modules leads to smart systems for high speed data transport. Hot plug and removing is a must for optical networks.

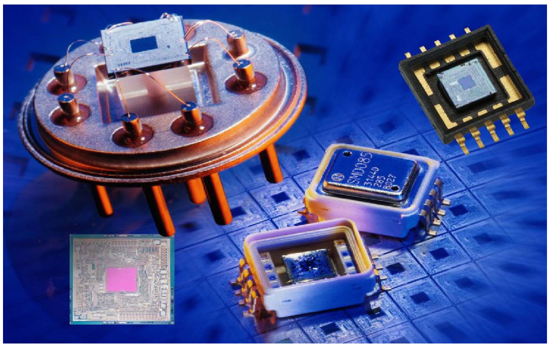

Figure 20: *MEMS pressure sensors* [16]

Optical Technologies

The NGN makes a distinction between three separated, logical functional levels:

- Transport of information
- Control of network resources
- Allocation of services and applications

The present wired or wireless communication channels will provide the customer only a transport layer accessing his personal services and applications. Different access points are routed through a redundant kernel network connected comprehensively for data transfer. The kernel network routes the traffic flow between the different access networks on the lower layers. Traffic volume and transport bandwidth will grow intensively. Only optical fiber technologies combined with wavelength technology (DWDM) can manage mass data effectively. Direct optical switching technology will make great strides and pure optical networks will be set up. Long-range data transmission (~1000km and more) without regeneration of signals will be necessary. There is a need for a new generation of pure optical routers based on DWDM. The client will make use of multimedia services and applications and so will need direct optical access to the media gateway. The volume of data and video streaming will grow rapidly. The challenges in order to realize the fully optical network are illustrated by the following examples:

- Reconfigurable, integrated function modules >= 40 Gbit/sec
- Low power dissipation direct modulated lasers
- New pure optical amplifiers for supplement wavelengths
- Photonic links into the household
- Fully optical data processing
- Optical low cost Tera bit-routers and switches
- 100 Tera bit/sec peer to peer data links
- Scalable router architectures

[16] Source: Bosch

Figure 21: *Ground communication Station in Raisting, Germany* [17]

Network Technology and Infrastructure

Traditional IT infrastructure was network centric. The paradigm has now switched to decentralization. New communication technologies are in use: XDSL, WiMAX, WiFI, WLAN, ultra-wideband, satellite communication, optical fibres. The revolution of diversification continues.

The following technologies are required in the medium term:

- Next generation networks
- Multi-services
- Multi-protocols
- Multi-access
- IP-based network
- Safety, reliability and trust
- Ad hoc networks
- Ultra wide band and multiple in / multiple out

Longer term, new innovative technologies are expected, e.g. very high speed quantum communication. Such new technologies will require advanced components, optical components, frequency-agile RF-systems, high-efficiency power transmitters etc.

Passive and Active Components for Communication

Traditional communication was founded on human-to-human information exchange. The future challenge will be connecting electronic systems directly. In particular self-sufficient smart systems will link to each other exchanging data automatically over private or public channels. They require among other things low power consumption, secure data treatment and secure data transmission, reciprocal identification and authorization, and inherent safety.

To hit the ambitious targets of next generations of mobile communication devices new RF chipsets, controllers, memories, energy storage, displays, filters, passives and other sophisticated parts like tuneable components must be developed and combined into smart systems. Increasing functionality with simultaneous miniaturisation needs smart integration technologies like three-dimensional packaging or next generation system-in-package technology.

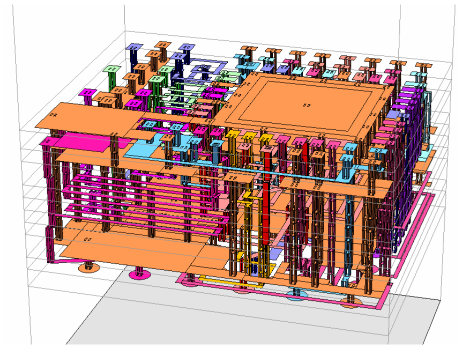

Figure 22: *LTCC (Low Temperature Cofired Ceramics) substrate with integrated passive components*[18]

NGS – Next Generation Safety Technology

In the past, wired and wireless communication was driven by technology. The industry supplied the consumer market mainly with voice communication (smaller, simpler, light-weight, long standby and talk time etc.) and internet access tools. Then, in 2003, the situation changed to application-driven market penetration. SMS is the best example. Now it appears that new gadgets are initiating business-services driven marketing and sales. Mobile personal assistants and laptop computers offer the possibility to stay permanently on-line, wherever the customer is located. On-line business needs identification, confidentiality, security and reliability, but the present situation is just the opposite. Voice communication is fully monitored worldwide, SMS is like sticking your message on an advertising column and e-mailing is like sending picture postcards for a purchase order. Market pundits therefore predict a multi billion-dollar turnover in electronic security business for the next five years.

Secure mobile terminals will merge into PDAs (Personal Digital Assistants). Wireless internet access will be standard in the very near future. As a result, private and confidential information will be transmitted over public insecure networks. The experience of

[17] Source: Siemens

[18] Source: EPCOS

internet communication with virus attacks, trojan horses and information loss may return, but more seriously than before. The new IT and communication technology must therefore put emphasis on security in order to ensure uptake by both public and private customers:

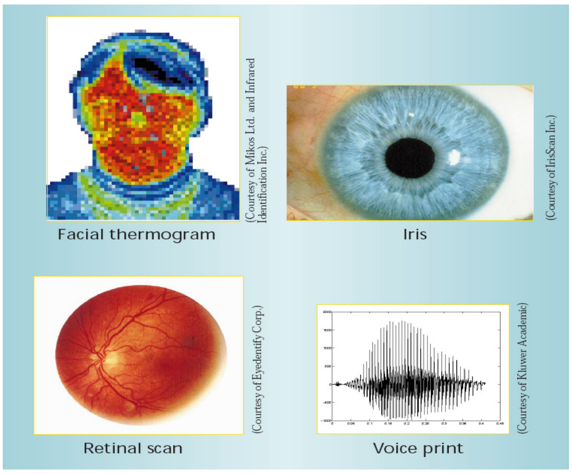

Figure 23: *Examples of different biometric characteristics* [19]

- Secure Internet Access for modern secure public services, and access to governmental services (E-Government)
- Services for computer aided teaching & learning (E-Learning)
- Secure online health care (E-Health)
- Dynamic safe environment for electronic commerce (E-Business) Electronic copyright protection (text, sound, pictures, TV, movies)
- Secure information infrastructure (including wireless service provision)
- Low cost wide band access to the internet for all citizens
- Good practice of IT

The main topics of the E-Europe action plan are safeguarding public networks with respect to fraud and computer crime, protection of private personal data, protecting the information flow for public services, and creating a general security policy for information and communication transactions. The EU has also launched research programmes and legislative initiatives with respect to these issues.

The following example illustrates how smart systems integration technology can help achieve such security objectives. Ultra-high-resolution video transmission requires broadband data transfer ensuring security performance working in concert with leading-edge security software and hardware. Smart security engines comprising super high speed cipher are of increasing importance integrating a platform approach to link computers over optical fibre lines. These features include the implementation of the quantum-based TRNG (True Random Number Generator) and an ACE (Advanced Cryptography Engine). As security algorithms become more complex in an attempt to thwart hackers, their foundation -

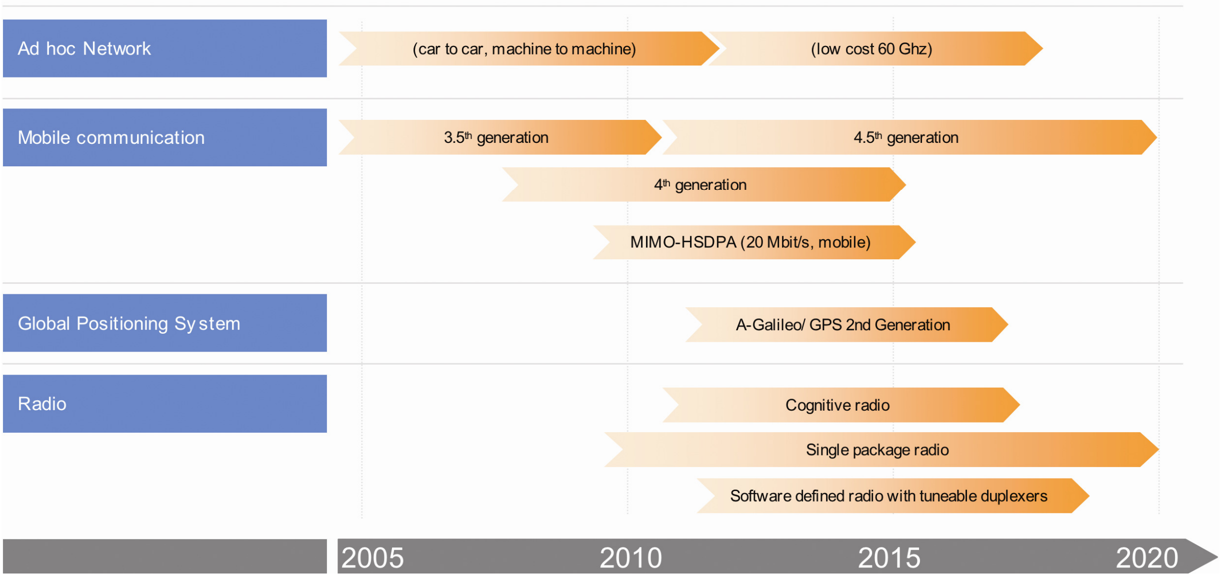

Figure 24: *Timeline for the mobility section.*

[19] Source: IBM

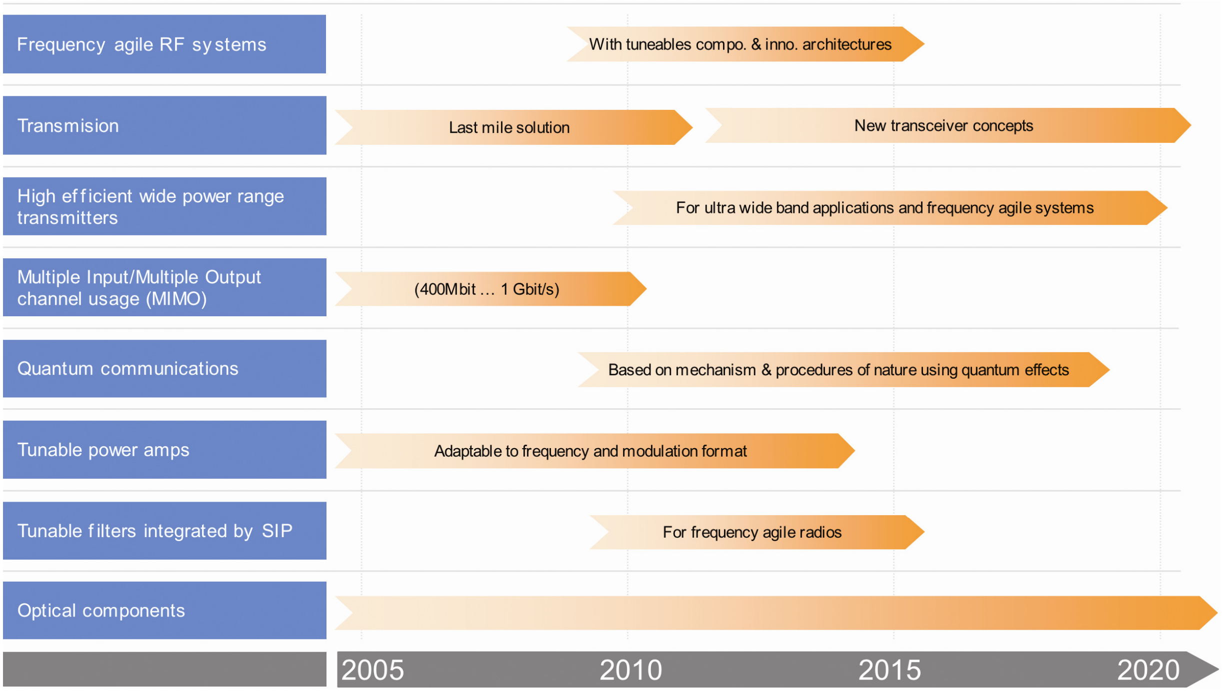

Figure 25: *Timeline for the network technology sector.*

random number generation - has become a paramount issue in delivering secure platforms.

Power Management

Wireless communication is an emerging technology of great value for a rapidly increasing number of applications. It provides convenience and flexibility for the user, but is also produces growing interferences, electromagnetic compatibility problems and electromagnetic exposure of the human body. Therefore we need to minimize the safe limit for exposure to RF emissions (SAR) from wireless terminals and the reduce the pulsation of the radio signals by optimising network structures and lowering transmission power. Solutions include smart antenna systems, MIMO (Multiple Input Multiple Output) and digital beam-forming concepts.

Further examples of innovative power management for handhelds are energy scavenging, energy storage, new power sources, reduced power dissipation, adaptive power supply, extended temperature range and life cycle improvement.

This wide range of heterogeneous technologies can only perform well by smart systems integration.

7.4 Research Strategy 2005 to 2015 and beyond

The roadmaps in **Figures 24** and **25** show estimated timelines of development activities for the visions of mobility and networking as described above.

3.5th generation of mobile communication
Evolution of current 3rd generation mobile standards (UMTS) towards higher data rates, e.g. HSDPA (high speed downlink packet access), HSUPA (high speed uplink packet access), E-DCH (Enhanced uplink).

4.5th generation of mobile communication
Evolutionary step for higher bandwidth in 4th generation radios (most likely MIMO, Multiple Input, Multiple Output).

Cognitive radio
can sense its environment and location and then alter its power, frequency, modulation and other parameters so as to efficently reuse the available spectrum.

Single Package Radio
Integration of all electrical components necessary for radio communication in a single package; eliminates external components, thus reducing costs.

Ad hoc network
Self-organizing network mostly comprised of smaller network elements, eliminating the need for central infrastructure equipment (base station).

A-Galileo/A-GPS: Global Positioning System
Integration of satellite positioning in mobile handsets, allowing auxiliary data (like satellite lists) to be transferred to the mobile in advance to the positioning attempt , thereby reducing the overall time-to-fix.

A software defined radio

An SDR is a presently realizable version of a Signal Radio: Signals are sampled through a suitable band selection filter.

MIMO-HSDPA:

Multiple Input/Multiple Output channel usage combined with High Speed Downlink Packet Access. Further bandwidth increase for mobile data communications by utilizing multiple transmit and receive antennas.

Frequency agile RF system

More and more air interfaces of different standards at multiple frequency bands lead to more and more complex devices with an increasing number of components. To avoid the parallel implementation of multiple radios new systems with tuneable components and innovative architectures are necessary.

MIMO

Multiple Input/Multiple Output channel usage

High efficiency wide power range transmitter

New transmitter generation necessary for ultra wide band applications and frequency agile systems

Quantum comunications

Newcommunication technology based on mechanism and procedures of nature using quantum effects

Tunable filters integrated by SiP

Filters tunable in bandwidth and frequency necessary for frequency agile radios

Tuneable power amplifiers

Amplifier of the transmission signal adaptable to frequency and modulation format

- Smart system, integrates actuators, sensors and high power devices
- Reconfigurable (switchable/tuneable) RF matching structures and biasing
- Operation mode software-controlled, adaptation to current frequency band, signal format, required linearity and tolerable distortions

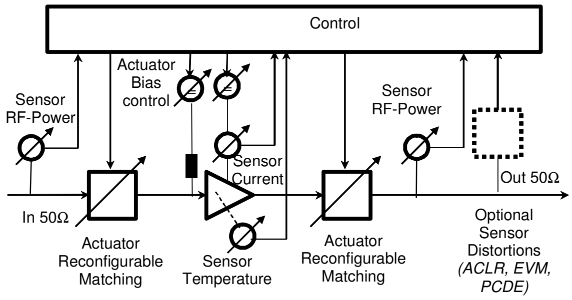

Figure 26: *Schematic drawing of a smart, tuneable power amplifier*

8. Smart MedTech Systems

This section identifies and describes core trends in the healthcare sector that will benefit the European population in relation to emerging challenges like the ageing population and personalized health care. It focuses on technology trends that will impact future medical technology business.

8.1 Vision

Smart integrated systems will provide cost-effective solutions and applications beyond what is possible today. Healthcare will shift from its present reactive, specialized, and provider-centric approach towards proactive, integrated, and patient-centric solutions. Future healthcare will benefit the patient in the following four main areas.

Assisted Health Checking. Smart integrated systems will never replace the doctor's diagnosis, but they will help medical personnel to get deeper and quicker insights into the patient's status by opening additional windows to view the internal parts of the body on a microscopic up to a molecular imaging scale. There will be personalized health monitoring of patients outside of the hospital or surgery right through to integrated delivery of care at home.

Assisted Therapy & Therapy Control. Integrated bioinformatics medical data management will help medical staff to analyze data aggregated from various sources to extract clinical significance and ensure seamless connections and data exchanges between patient, health care provider, healthcare insurance companies and pharmaceutical suppliers. Long-distance tele-transmission of patient data will enable continuous therapy control and monitoring. Therapy decisions like surgery, minimal-invasive and biocompatible methods based on smart robots will minimise discomfort for the patient

Full Functional Substitution & Rehabilitation. Smart integrated sensor/actuator systems and neuronal coupling will replace body functionalities lost due to disease, accidents or violence, enabling the patient to continue normal life. Smart robotic tools will assist the aged to maintain an autonomous life much longer than presently.

Monitoring & Control of External Influences. A network of self-organising sensory tools will continuously monitor the environment we live in to diagnose detrimental external influences to our health. This will include precautionary measures to ensure that we consume food that is beneficial to us.

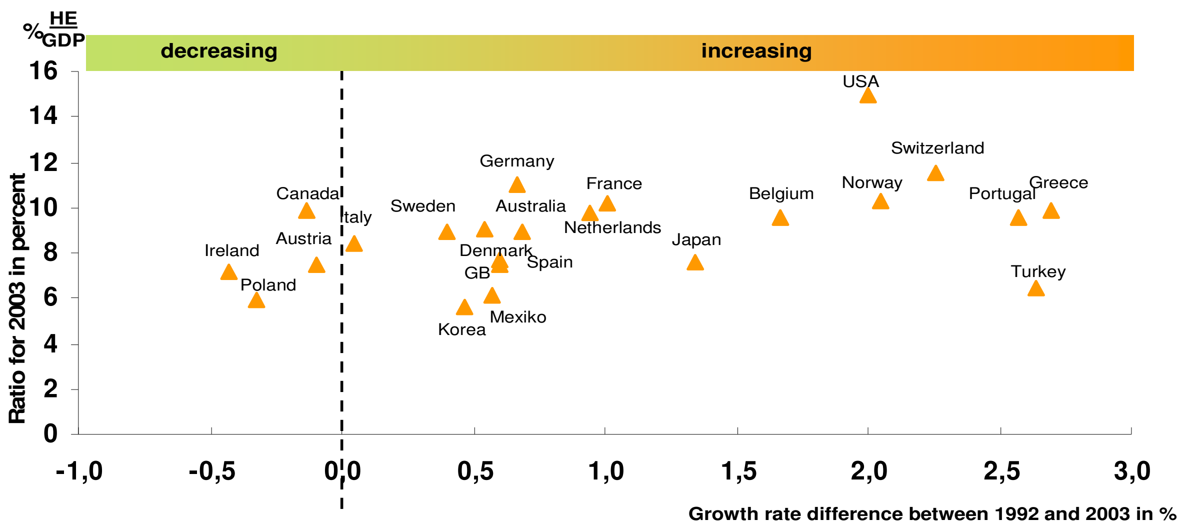

Figure 27: *Percentage of Healthcare Expenditures (HE) to Gross Domestic Product (GDP) for various industrialised countries compared to change in growth rate in the past decade. (HE and GDP at purchasing power parity exchange rates.)*[20]

[20] Source: OECD Health Data 2005

8.2 Rationale and Objectives

There is broad agreement that the European Union faces major healthcare challenges in the years ahead as a consequence of:

- an ageing population;,
- negative environmental effects on personal health, and
- demand for improved personal healthcare (in 2000 and 2001, US expenditure on personal healthcare accounted for 86% of the total).

These challenges will have significant effects on the healthcare system, as the need for medical assistance increases with age, the incidence of chronic diseases rises and demands for individualised health care grow.

It will be a major challenge for our societies to cope with the expected cost increases. Health care expenditures presently account for about 10% of gross domestic product in industrialised countries and are growing at an average rate of about 6% per annum in most countries. This trend is likely to accelerate drastically if nothing is done.

There is also a broad expectation that the quality of the health care supplied to citizens rises at least with the rate of growth of overall wealth in a society..

Increasingly, health is viewed as a matter of personal responsibility. More personalized health care is therefore likely to lead to a growing market for health products and services. The ageing society especially will have an enormous influence on this health market. Data for 2003 show that the elderly spend most for their personalized healthcare (see **Figure 28**).

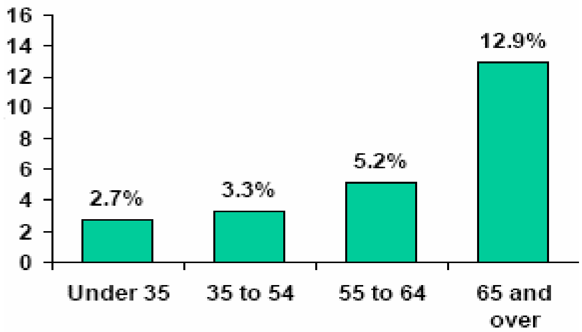

Figure 28: *Out-of-pocket payments as a percentage of total health care spending by age.*[21]

Examples:

Ageing people are expected to be the drivers for the cardiac disease market. Nowadays five million people suffer from cardiac rhythm disorder (CRD) worldwide. Due to ageing (in 2010 about 40 million people in the USA will be over 65) the world-wide market for implantable cardiac defibrillators (ICD) and cardiac resynchronisation therapy (CRT) is expected to be about 10 billion in 2009.

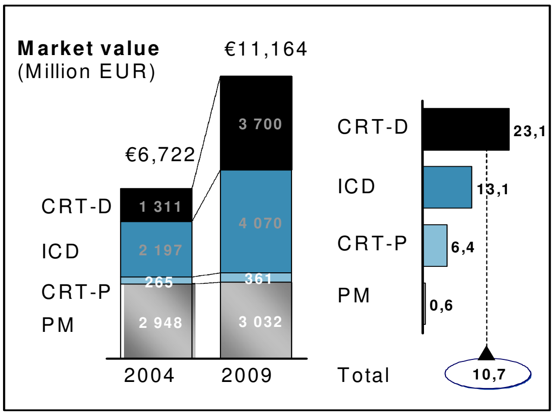

Figure 29: *Overview of the world cardiac disease market, CAGR 2004-09* [22]

The neurotechnology - neural prosthesis, neuromodulation, neuro-rehabilitation - will also have a major impact on the health market, as the prevalence of neurological disorders rises (due to ageing), the public in Western countries demands better treatment of disabilities, and new technologies like MEMS, nanotechnology and electronic miniaturization facilitate new treatment possibilities. The current market for neurotechnological treatments is estimated at €3 billion and is expected to reach close to €8 billion by 2010 with a compound annual growth rate of > 25%.

To cope with these challenges and to ensure that the European medical industrial segment maintains a competitive advantage in the global economy, Europe must mobilise its scientific and technical knowledge to develop a range of new technologies that meet the demands of the healthcare system while containing the overall cost explosion.

Objectives here are:

- smart systems integration to provide technological solutions at reasonable cost;.
- technological solutions to provide more effective health care (shorter hospital stays, increase in outpatient procedures,

[21] Source: United States Health Expenditure, Pub: 12-09-2003; Datamonitor: "Who is Looking for Health Information Online? - A Segmentation Analysis of the Online Consumer" Pub: 2002/09 http://www.the-infoshop.com/study/dc11683_health_online_toc.html

[22] Source: Morgan Stanley

preventive care to avoid severe pathologies).

- stronger companies active in the medical field (firms must not only look for new technologies/markets but also new business models to deliver complete solutions: telemedicine, e-learning, patient relationship management.
- development of a technological base to assist elderly people to live autonomously.

8.3 Research Priorities

The four identified application areas point to several research priorities. Particularly important are disruptive technologies which offer great trend-setting potential due to their powerful impact and cross-sectional technologies which can be used in various applications.

The most important areas for smart systems applications in the medical technology field are:

BioMEMS: Bio-micro-electromechanical and optical sensors

Medical applications require dedicated detection of multifarious parameters. The integration of complex sensor functionality into small, sometimes implantable smart systems will permit robust functionality and price limitation. Both are required to make the sensing solutions widely available. Functionalities include the fields of

Physical Sensing
Pressure, temperature, motion, intra-ocular parameters, heart contractility, light emission/luminescence, electrochemical parameters, motility

Chemical Sensing for the analysis of body fluids and breath:
Gas molecules like NO/acetone, Urea, Glucose, Ions/pH, total chemistry analysis of blood, urine

Bio Sensing
DNA, proteins and glyco proteins, lipids, toxins in liquid, blood, different secretion and urine.

Functional and cell biological imaging

Imaging of non-visible parts of the body for therapy-critical decisions. Smart integrated systems will yield more versatile and efficient devices that give information on the scale from the whole body down to single cells. Medical imaging will complete its transformation from a diagnostic tool to a key tool in delivering therapy and tracking progress in combating disease.

Imaging technologies
X-rays, Ultrasonic, Visible, IR, magneto-resonance, EEG, and electrical mapping

Aids for therapy and therapy monitoring

Integrated systems will deliver new functionalities to assist therapy by opening up additional possibilities of treatment and the monitoring/optimisation of treatment. These aids can be grouped into blocks concerning

Innovative & minimal invasive surgery
Ultrasound/laser, robotics, bio-robotic, endoscopes, bio-mechatronics

Heart-assisting devices
automated cardiac defibrillator, smart pacemaker

Drugs on demand
Delivery and monitoring by microsystems, first aid medication, nano-drug transport, personal integrated units for diabetes, BBB control implantable “smart” delivery.

Pain therapy & management
Pain assessment, pain monitoring, neurostimulation BION types, magnetic induced therapy

E-health, telemedicine and networking, data management

This application field centres on the acquisition, management, analysis and exchange of biotech/life sciences data, and the integration of this data with information from clinical sources. Understanding relationships in this data - a large part of which will be created by the new tools - is crucial, from determining what procedures and clinical protocols are most effective to how best to deliver health care.

Data management
Includes data fusion, multi-media, format exchange, wireless, advanced microsystems data collection/processing and storage, tele-monitoring and actuation.

Medical technology for regenerative medicine

Regenerative medicine will strongly benefit from the integration of several functionalities into new and biocompatible systems. Multi-functional integration, including the connection of devices to nerves, will open up ways to optimally help people to maintain their original style of life. Research topics include:

Prosthesis for original function
Smart prosthesis, implantable sensors, implantable skin, implantable limbs, synthetic bones and joints

Assisting devices
Safe moving, safe home management, machine-assisted physical/cognitive rehabilitation, smart limbs for disabled people

Neural interfaces
PNS (peripheral nerve system), CNS (central), VNS in particular with CMOS/neural interfacing technology

Assisted living
For the elderly: home support devices, robotic assistance, in-home care units

Environmental influences

Technologies for monitoring possibly harmful influences on human health deserve special attention since these will create a paradigm shift from a reactive to a proactive health care system, eliminating costs and improving the quality of live. Basic technologies for such applications can be derived from BioMEMS sensors and be used for monitoring:

Environmental influences
Air, water, soil, building, clothing, radiation

Food
Production, storage, safety, authenticity

Modelling cardiac hemodynamics and electrophysiology

The development of new medical systems and drugs can be shortened with simulation technologies which reduce the clinical evaluation phase on humans or animals and allow evaluation of rare clinical cases.

Hospitals require simulation technologies for the investigation of normal or abnormal electromechanical activity of the heart to help medical staff to get deeper and quicker insights into the patients' status and predict and improve the effect of a therapy

Smart systems like heart-assistance devices (heart pumps, automated cardiac implants) will improve diagnostic features, and predict and improve the effect of a therapy.

Models for the simulation of cardiac hemodynamics and electrophysiology will be much more widely used in the medical community if they require low power computation and are validated.

8.4 Research strategy 2005 to 2015 and beyond

The research strategy is broken down into four parts, according to the four identified application areas

I. Assisted Health Checking

Medical imaging technologies, as a diagnostic tool but also as a key tool in delivering therapy and tracking the progress of combating disease are of primary importance. Molecular diagnostics are important for point of care applications. These tools will be supported by biosensor/nanosensor technology including MEMS based for example on CMOS chips integrated into one simple but reliable device for multiple application scenarios. The combination with wireless data transfer, including high-level medical opinion, will shift medicine from providing reactive treatment after symptoms appear to a proactive discipline that treats and prevents disease before it occurs. Non-invasive sensors using advanced MEMS technology can simplify disease diagnosis and monitoring particularly for aged people or children and reduce expenditure compared with traditional health care. Brain examinations and diagnosis will also be supported by MEMS

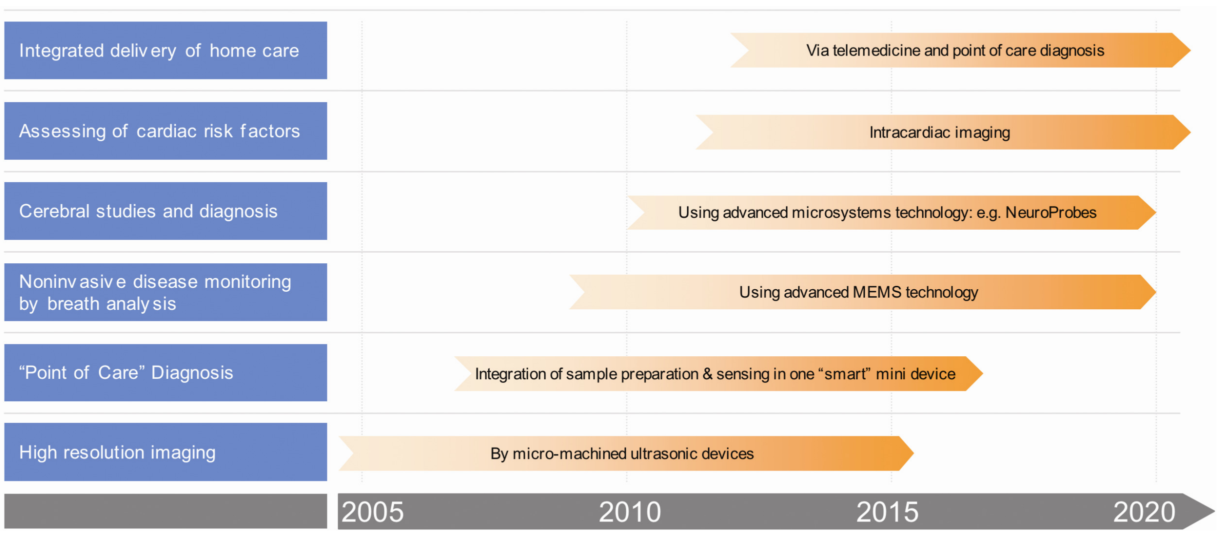

Figure 30: *Assisted Health Checking - Timeline*

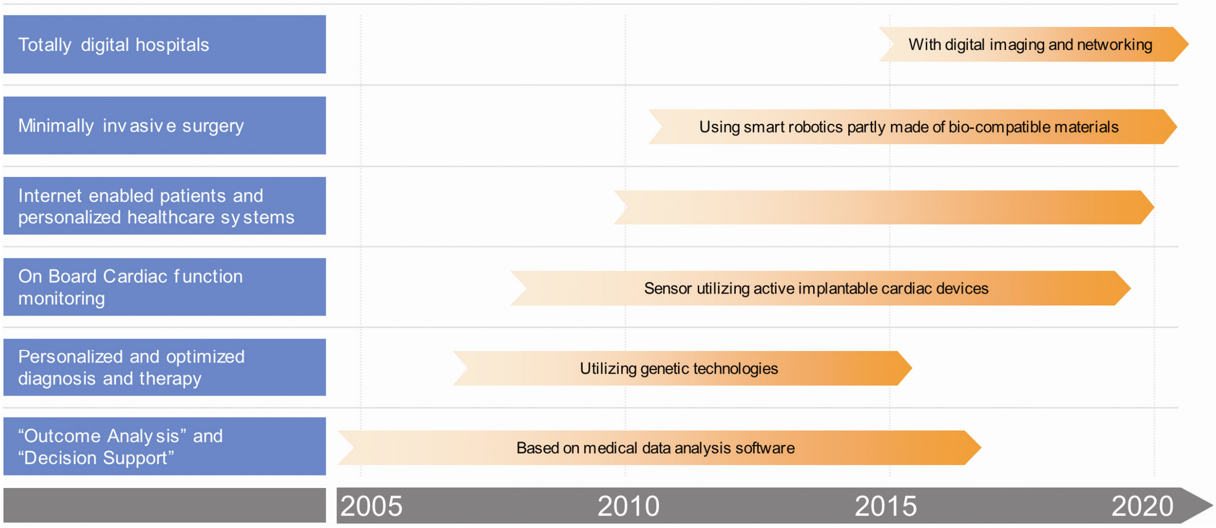

Figure 31: *Assisted Therapy & Therapy Control - Timeline*

technology. Advanced imaging technology will be the key technology, moving from today's ultrasonic devices to future intra cardiac imaging. The combination of intelligent IT technology (data management, telemedicine) with individual diagnostic systems will lead in 2015 and beyond to a totally integrated home care system.

II. Assisted Therapy & Therapy Control

A major technology for assisted therapy or therapy control will be the development of medical data analysis software which will allow direct data exchanges between patient and medical practitioner for diagnostic analysis and decision support. Intelligent and collaborative environments will then become available, allowing greatly increased efficiency in providing patient care. Personalized, web-based portals will provide ubiquitous, secure access to healthcare IT systems. Personalized and optimized diagnosis and therapy using genetic technologies (e.g. DNA chip), and drug-on-demand technologies (e.g. nano drug transportation) will lead to a more personalized medicine with greater patient empowerment. The ageing society will make the monitoring of cardiac function a major issue for the future. The development of active implantable cardiac devices (e.g. cardiac defibrillators, smart pacemaker) will extend on-board cardiac function monitoring. Smart robotics (biorobotics) or bio-mechatronic devices can assist minimal invasive surgery which reduces patient trauma and accelerates recovery. These various developments will lead to a totally digital hospital with fully automated functions like digital imaging and networking.

III. Full Functional Substitution & Rehabilitation

Smart implants are the first step towards full functional substitution. The integration of smart sensor systems is a prerequisite to improve functionality. Trends for the future (2010 and beyond) are neural prosthesis for visual, motor, deafness, respiratory and bladder control. These applications will require

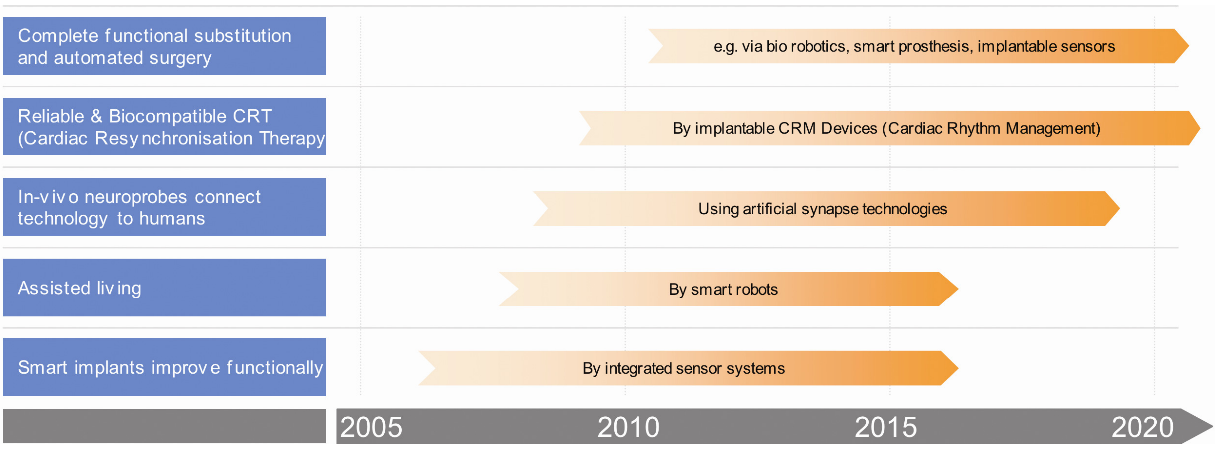

Figure 32: *Full Functional Substitution & Rehabilitation - Timeline*

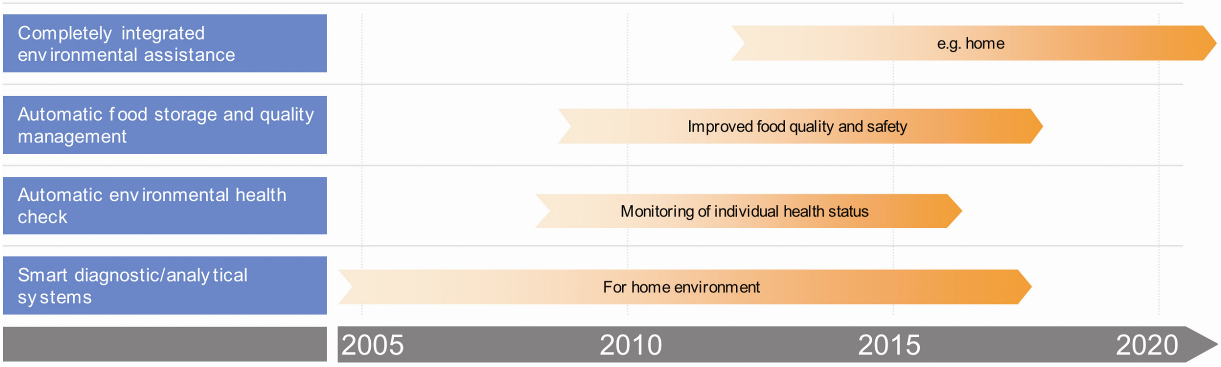

Figure 33: *Monitoring & Control of External Influences -Timeline*

the development of specific neural technologies such as artificial retinas, optical nerve stimulation, FES for walking and standing, vestibular implants or bladder stimulators. Also neuro-modulation technologies which address back pain (spinal stimulation), Parkinson's disease essential tremors, epilepsy, depression (DBS), migraine (occipital nerve stimulation) are targeted subjects

Assisted living for full rehabilitation at home or in hospital can be supported by smart robotics in home-care units or in home-support devices for the elderly e.g. machine-assisted physical rehabilitation. Obesity, diabetes and hypertension (VNS) are chronic diseases which will need assisted devices. Trends for the intra-cardiac market are preventive and predictive medicine to assess risk factors and the monitoring of the at-risk population. Reliable and biocompatible cardiac resynchronisation therapy will be supported by implantable cardiac rhythm management devices. The longer-term perspective is complete functional substitution, including automated surgery by smart sensor systems (bio robots), smart prosthesis, implantable sensors.

IV. Monitoring & Control of External Influences

Monitoring and control of external influences on human health is important for the maintenance of individual health status and will grow in importance owing to increased longevity. Small analytical systems (e. g .MEMS gas sensors based on CMOS technology) or smart diagnostic tools (lab-on-chip) will support control of the ambient environment (air, water). Automated data management systems and software-based signal evaluations in combination with intelligent sensor devices will be needed for an automatic health check. Automatic food storage technology with reliable quality management can improve storage quality, authenticity, consistency of ingredients, and product safety. Future applications of smart sensor systems will lead to a complete environment assistant for the home. These technological developments will especially benefit Europe's ageing population.

9. Smart Systems in Logistics/ RFID

9.1 Vision

Logistics and communication are considered to be the backbone of globalisation. They play an important role in the development of modern economic systems and sustainable economic growth. Radiofrequency Identification (RFID) has become a key technology in the ICT sector, because RFID tags can identify individual goods and commodities in real time and close the gap between the physical flow of things and the related information flow in IT systems. Effective smart system integration is critical – and yet RFID technology can provide added value to smart systems integration in many other industrial sectors.

RFID is one of the evolving high-tech markets in the ICT sector with an expected volume of USD 24.5 billion in 2015. There is a strong RFID industry in Europe as well as a strong potential of industrial and private RFID users. Both technology providers and users may profit from growing RFID markets and technologies. The international competition is strong, however, and Europe suffers from several drawbacks. Most importantly, there is a lack of standardisation, frequency harmonisation and research support in Europe.

Companies in logistics and retail have already launched the first RFID roll-outs. Other industrial sectors like automotive, aeronautics, and pharmaceuticals are working on the adoption of RFID for their processes. Main applications will be the tracking and tracing of goods as well as prevention of counterfeiting. The public sector, too, has already set up several RFID-based projects like the E-passport or the tickets for the 2006 FIFA World Cup in Germany. The coordination of research and development at the European Level is required urgently to improve the cross-sectorial application of RFID technology.

In the long run, RFID is a core technology for ambient intelligence. Using RFID technology, everyday commodities and goods will become “smart objects”. Elderly and disabled people will be supported by intelligent devices. The close tracking and monitoring of goods in the food chain will improve food safety. Smart industrial goods will store information about their components and their use. Waste disposal management will be switched from today’s inefficient mass-oriented approach to an individual recycling process. In sum, RFID is able to deliver more efficiency, more security and convenience.

Europe’s competitiveness depends on the development and successful use of important key technologies like RFID. By initiating the i2010 strategy, the European Commission has underlined the importance of ICT to growth and employment as set forth in the Lisbon Goals. The strategic research agenda proposed here is aimed at joining forces in Europe and fostering a successful development of RFID technology and applications

Figure 34: *RFID enabled hanging sorter/ RFID tag*[23]

9.2 Objectives

RFID research needs to span a range of different technologies in order to meet the application challenges around the key strategic objectives: low-cost high-quality **1-Cent-tags** for mass volume applications, and establishing RFID as a core technology for ambient intelligence where tagged goods and commodities become **smart objects** able to sense their environment and to communicate to other objects and IT systems.

The Seventh Framework Programme of the European Commission has the capacity to support RFID research and development coherently. Three objectives should be followed:

- strengthening the European RFID industry by supporting mid-term and long-term R&D projects
- strengthening European RFID users by supporting pilot applications and by pushing forward European participation in frequency harmonisation and standardisation activities and

[23] Source: Metro AG

- strengthening European civil societies by supporting the implementation of ambient intelligence applications with high societal benefits like health care, food safety, waste disposal and safety.

The European Platform on Smart Systems Integration is a perfect framework for gathering knowledge, bundling expertise, and developing original solutions to the major challenges.

9.3 Research Priorities

The present technological challenges to RFID need to be tackled by defining research priorities in ten technology fields from microelectronics, microsystems (in particular MEMS), software engineering, and high frequency technology (HF) where mid-term and long-term research is required. Additionally, socio-economic studies are needed (see Figure 35). These research priorities are the building blocks for realizing the vision of smart RFID systems.

Packaging

Silicon-based tag packaging (which comprises the application of the chip to a substrate, the antenna, and the connection of antenna and chip) is responsible for more than 50% of cost. It determines how a tag can be integrated into goods and packages and how it must be disposed of after use. There is a strong need to integrate mobile readers into small objects in industrial and end-user environments. Thus packaging topics with respect to RFID are: flexible and multi-layer substrates; the integration of chips and antennas into non-standard substrates like textiles and paper, and the development of substrates, conducting paths and bonding materials adequate for harsh environments and for ecologically sound disposal.

IC Design

To a great extent the design of integrated circuits (ICs) is not specific to RFID applications. However, tags for smart objects in particular require future research. In order to reduce the size of tag sensors, energy supply, and HF components must be integrated into monolithic silicon chips ("system on chip").

Energy Awareness

Energy supply is a great challenge for smart RFID tags with additional sensors and computing capabilities as well as for mobile readers. Tags and mobile reader are not connected to a constant power supply and in general cannot be recharged on time. However, tags and mobile readers should be as small as possible, which restricts the space for batteries. Research topics are: integrated foil batteries; energy saving algorithms (especially for cryptographic functions); energy harvesting (i.e. energy is gained from the environment by piezo or other effects), and an energy saving power management for all tag components.

HF Technology

Due to the usually low power level of RFID tags, high frequency or radio technology (HF) is an important issue. There is a need to further improve the antenna

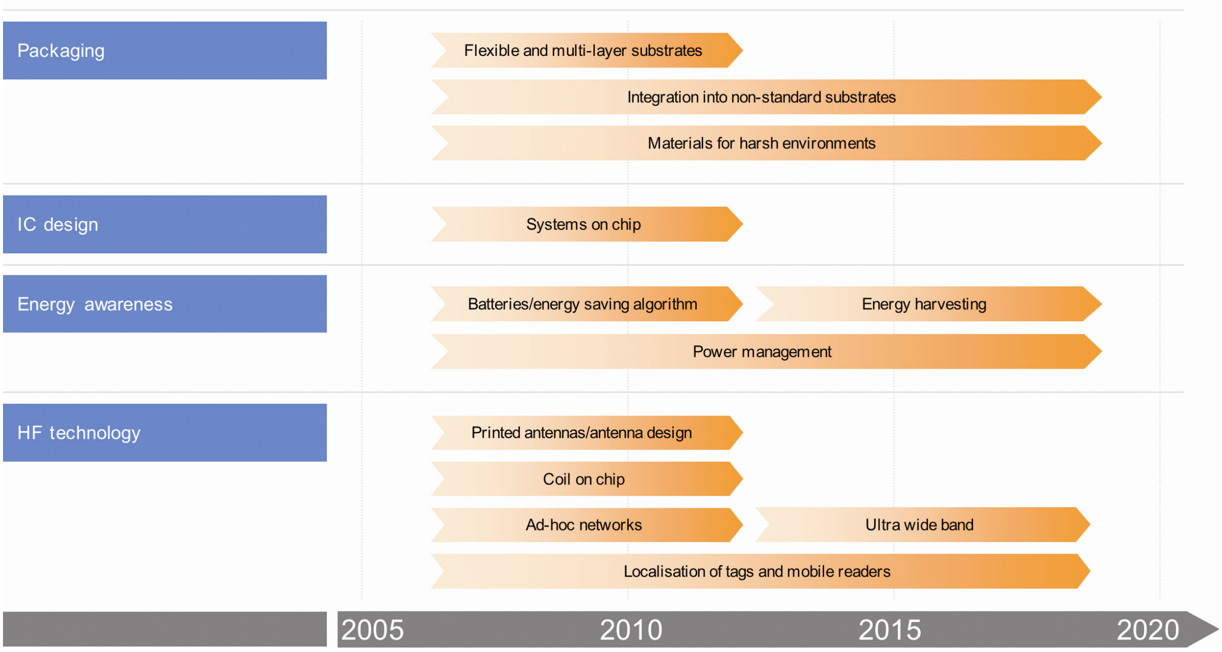

Figure 35: *Mid-term and long-term research agenda for RFID*

design of both tags and readers in order to gain larger reading ranges and predictable reading rates. Today, the metallic antenna is by far the largest component of a RFID tag. Research tasks are printed antennas which can be easily integrated into paper packages and antennas which are integrated into the chip itself ("coil-on-chip"). In the case of smart objects which interact autonomously in sensor networks, there is a great need to adapt existing ad-hoc network approaches to the restricted hardware and energy resources of RFID systems. In the long run, ultra-wide-band communication will gain more importance due to its low power requirements and to its more efficient use of given frequency ranges.

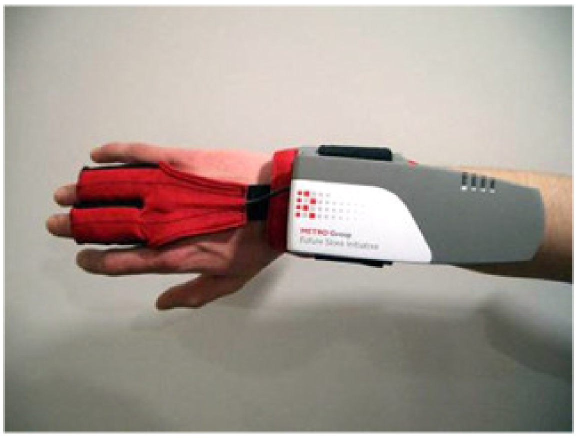

Figure 36: *RFID glove*[24]

Manufacturing

There is still great potential to enhance the manufacturing process of RFID tags. Print-like reel-to-reel manufacturing is a standard process for simple tags but still a challenge for high-quality tags. This includes the handling of thinned (and thus flexible) chips and the assembly of tags consisting of multiple chips or multiple discrete components. Even more advanced are self-assembly manufacturing processes where the explicit pick-and-place of tag components is replaced by mechanical or electromagnetic key-to-lock placement methods. Another big issue is the long-term convergence of traditional print processes and RFID manufacturing.

Polymer Electronics

The manufacturing of silicon chips is a complex and costly process. The replacement of silicon by polymer as base material for integrated circuits and electronic components promises a substantial cost cut. Polymer displays can already be manufactured. Other electronic polymer components like batteries or even ICs are still challenges as is manufacturing on an industrial scale.

Bi-stable Displays

There are a number of RFID applications which require visual display of the tag data, e.g. in retail or postal services. The energy consumption of existing LCD displays is much too high for low-power tags. Bi-stable displays (which need energy just for changing the contents of the pixels, whereas no energy is needed to maintain the current pixel state) are another challenging MST issue.

Sensors

There are many technically established sensor principles. However, even in these areas there is still need for further improvements, including their monolithic integration into the chip, the development of low-power sensors, event-triggered sensors and the down-sizing of sensors to a sub-molecular and atomic level.

Cryptography

In principle, most privacy and security tasks of RFID systems are covered by standard cryptographic methods. However, in general cryptographic algorithms are too expensive for RFID in terms of both computing time and memory usage. Therefore, standard cryptographic algorithms must be adapted to the restricted hardware and energy resources of RFID systems.

ICT Architectures

In principle, RFID tags, RFID readers and the backend IT systems are massively distributed, autonomous, and heterogeneous IT systems. However, today's IT systems like enterprise resource planning systems or production planning and control systems are not well prepared to fit into this scheme. The tags and the readers provide their information in real-time whereas the IT systems are based on batch or user-driven processing. The task is to define appropriate ICT architectures. This may lead to a shift from the current paradigm of centralised IT systems to a paradigm of decentralised, self-organising IT networks where the smart objects and the readers gain much more autonomy and responsibility.

Socio-economic Studies

RFID will have significant impacts on society and the economy: Data protection is already a major issue for certain RFID systems which process personal data. In addition, it is foreseeable that the protection of employment rights will be of equal importance in some future RFID systems. The enhanced track-and-

[24] Source: Metro AG

trace functions of RFID will reshape supply chains as well as waste disposal and recycling processes. On the other hand, RFID tags themselves must be disposed after use. Matters like these must be regarded carefully for a successful adoption of RFID technologies. There is a strong need to complement research on technology needed for RFID applications by socio-economic studies which deal with matters like new RFID applications areas besides logistics, such as health care or ambient intelligence, technology acceptance, privacy, environmental aspects, and economic effects. These studies should provide recommendations for public institutions, companies, and NGOs how to cope with the impacts of RFID.

RFID systems are complex ICT systems. A mix of advanced technologies is needed to design and to realise RFID-based systems for ambient intelligence. Moreover, it is essential that R&D projects are designed to work towards real-world applications and long-term benefits for the RFID industry as well as for both industrial and private users of RFID in Europe.

EPoSS's focus in terms of RFID research is:

- to support multi-technology R&D projects which cover all relevant aspects from microelectronics, MST, software technology as well as HF technology and which follow a systems approach;
- to support RFID projects spanning the complete value chain and including technology providers, system integrators, and users;
- to consider demonstrators and trials as essential parts of supported projects;
- to support research on socio-economic issues, e.g. on new application areas, technology acceptance, privacy, environmental aspects, and economic effects;
- to support and encourage the standardisation of project results, and
- to support and encourage easy access to patentable project results.

9.4 Research Strategies beyond 2015

The research priorities put forward here are those required to ensure the technological breakthrough of RFID. It is equally important, however, to acknowledge the future impact of RFID in gradually creating ambient intelligence and ubiquitous computing. The interplay and smart system integration that is required will not only affect logistics and retail but, to a greater or lesser degree, most technological applications in everyday life. Ambient living, smart homes, new mobile services and the "Internet of Things" all depend on the successful integration of RFID technology in industry sectors. EPoSS thus has an important place in the network or European Technology Platforms and complements them by covering new areas of innovation and key technologies in Europe.

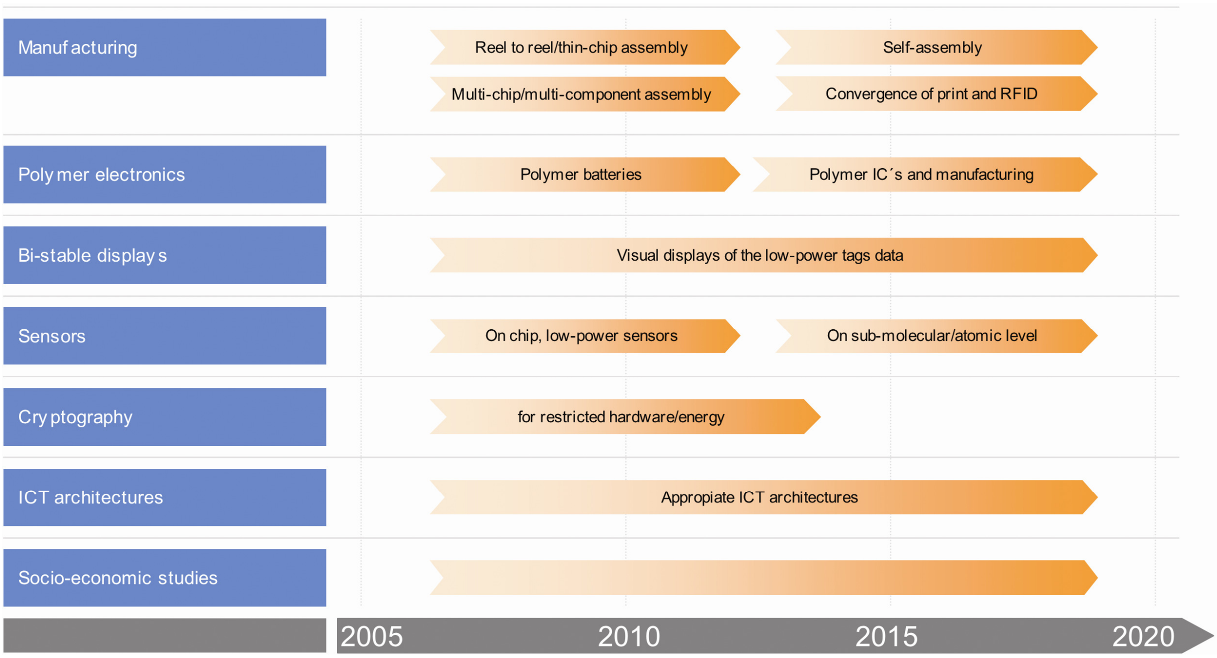

Figure 37: *Mid-term and long-term research agenda for RFID*

Figure 38: *RFID Portal*[25]

[25] Source: Metro AG

10. Cross-Cutting Issues

10.1 Introduction and background

Smart systems will be embedded in an increasing number of applications in the future. Their pervasive nature leads to specific requirements for the development and the exploitation of the components of which they are made and for the know-how required to design and manufacture them. Five drivers seem to emerge as major characteristics for research and technology trends in the smart system integration field.

Smart Systems are characterized by their high level of **heterogeneity**: They are made of very different materials which have to co-exist despite their different behaviours (thermal expansion, biochemical interactions). These building blocks will be prepared using various processes and will be exposed to a broad range of environmental constraints. Scenarios of use are also leading to heterogeneous requirements for the communication links which will build on various wireless standards. Ultimately, the radio components of smart systems themselves will have to adjust to the best air interface for a given situation (power requirements, cost, range) in real time.

Complexity is another driving characteristic for future developments in the field. Most of these systems are designed and built to embed intelligence and to enable the products in which they are used with the ability to react to their environment and to provide relevant and ergonomic information to their users. The amount of multimodal data to be processed by the system is very large. The user interfaces have to cope with complex and variable environments while taking into account the context of use and rapidly changing user behaviours.

Most of the applications require the development of **autonomous** solutions and thus face major energy management challenges. Most of the basic functions embedded in the systems have to be designed according to strong power requirements exploiting the most relevant energy sources. In many applications, energy resources are the main bottleneck preventing larger market penetration of autonomous devices in both industrial and consumer products. The development of generic solutions will have to follow two tracks: low power functions and improvement of energy resources.

Figure 40 illustrates the fourth characteristic of smart systems: their various constituting elements cover a very large scale of geometric features. Basic blocks are made of layers and structures on the nanometer scale which are embedded into micro devices. Together they are assembled on the macro scale in order to meet environmental and user interfaces requirements. The **multi scale** nature of smart systems will have a very strong impact on the design tools and manufacturing techniques required in the industry.

Heterogeneity	Complexity	Multiscale requirements	Autonomy	Multidisciplinarity
▪ Processes ▪ Substrates ▪ Materials ▪ Multisensing ▪ Wireless standards ▪ Environments ▪ …	▪ User interfaces ▪ Large data ▪ Data fusion ▪ User behaviour ▪ System integration ▪ …	▪ Nanomaterials ▪ Nanostructures ▪ Functionalization ▪ Microtechniques ▪ IC technologies ▪ Mechanical behaviour ▪ Macrostructures for user interfaces ▪ Large area electronics	▪ Low power sensors ▪ Low power communications ▪ Low power actuators ▪ Distributed intelligence ▪ Energy scavenging ▪ Energy storage ▪ Energy management…	▪ Physics ▪ Mechanics ▪ Electronics ▪ Software science ▪ Chemistry ▪ Biochemistry…

Figure 39: *Crosscutting issues – Main drivers*

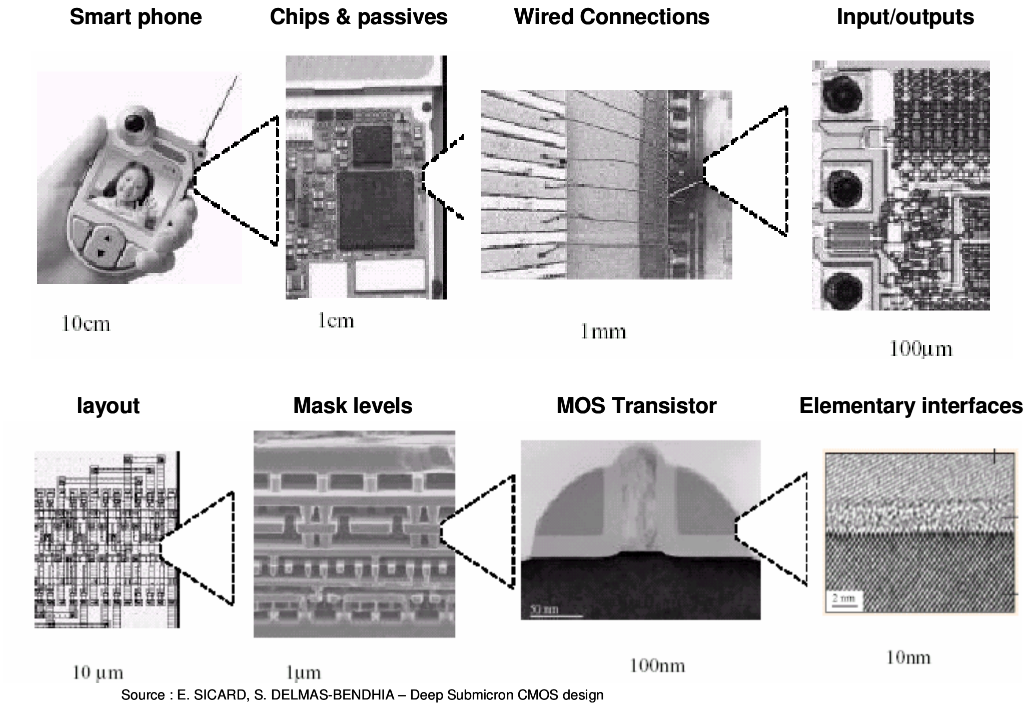

Figure 40: *The multi scale nature of smart systems*[26]

Finally the four above-mentioned characteristics are reinforcing a trend already observed in the scientific community of teams involved in smart systems developments: **multidisciplinarity**. Process and product innovation require a large body of know-how, ranging from chemistry to electronics, from mechanical engineering to biology, from sociology to software engineering. The ability to manage this “melting pot” and to set up effective and efficient project management methodologies will be a new paradigm for R&D institutes and companies, and thus pose a strong cultural challenge.

These five characteristics will shape the technological environment in the next two decades and will have a strong impact on the scientific community by initiating new research fields, and by providing new opportunities for product innovation.

10.2 Rationale and objectives

The European Technology Platform on Smart Systems Integration (EPoSS) is driven by a set of application fields which require system-oriented solutions and devices. The generic research activities proposed in the EPoSS framework will therefore be focused on integration issues. Whenever relevant, system developers will use basic technologies, processes and IP blocks carried out under other initiatives (ENIAC, ARTEMIS). But new research will be required on basic materials and to develop processes and new functionalities, especially in order to meet environmental and specifications-driven constraints identified at the beginning of the design process.

The main challenge the EPoSS community will face is its ability to identify generic research issues and technology blocks that may be used and exploited in a large range of applications and systems. These issues will be positioned at two levels (see **Figure 41**) and will feed application platforms with solutions to be integrated by system designers.

At the technology and component level: basic technologies such as materials science, new processes, micro and nanoscale devices, nanostructuring and surface engineering, packaging. In this area, many European SMEs hold leading positions and will bring advanced knowledge and market momentum to the EPoSS initiative: equipment manufacturers, materials providers, advanced packaging specialists, MEMS foundries.

At the subsystem level, emphasis will be put on the development of generic solutions providing the main functionalities for smart systems; this includes wireless communications, energy management functions (energy scavenging from mechanical, electromagnetic, solar or thermal sources; energy storage through batteries, super capacitors or fuel cells, and power management electronics), sensors and actuators, security.

[26] E. SICARD, S. DELMAS-BENDHIA – Deep Submicron CMOS design

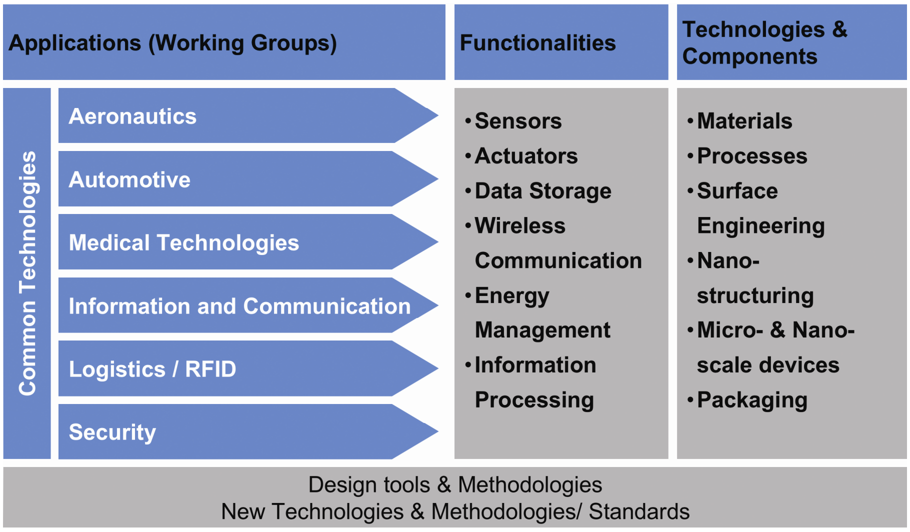

Figure 41: *Schematic drawing of the structure of Research priorities in EPoSS*

The scientific and technology community within EPoSS will aim at:

- identifying new concepts and issues that may strongly impact the various application fields
- providing long term visions and roadmaps to help decision makers set research priorities
- involving a large network of research entities and industrial partners to enlarge the basis of partners and industries that may benefit from EPoSS technologies.

EPoSS will particularly involve universities, research institutes and upper stream industries likely to provide state of the art information on all the core competencies required by smart systems.

10.3 Research priority - Technologies and Components

Figure 41 summarizes the main issues that have been identified as future contributors of breakthrough and added value to smart systems applications.

Materials

In the field of materials science and associated processes, the main challenges for EPoSS are new solutions that meet the low-cost/high-complexity specifications of smart system applications.

Alternatives to semiconductors for planar substrates and processes must be explored to enable the emergence of low-cost large-area intelligent subsystems. **Polymer** substrates, for example, are needed for so-called "polytronics" or "flextronics", which will be applied in man-machine interfaces (displays, haptic and tactile interfaces etc), smart surfaces and labels, and more generally in components that exhibit extended areas. **Ceramic** substrates, capable of withstanding high temperatures and inert to chemical attack, are necessary for harsh-environment operation. Also micro-reactors, micro-combustion-chambers, micro-thrusters and -turbines require ceramic structures. Ceramics tend to be hard, brittle and abrasion-resistant and cannot be shaped by precision machining or micromachining. These 3D-structures must be manufactured using near-net-shape techniques such as casting and injection moulding. The technologies for **active materials** based on polymers, ceramics or metals and their composites require further development: their generation and the optimisation of their properties, the adaptation of low-cost processes (printing techniques) for the fabrication and integration of electrically active materials (printronics), and their characterisation and the control of effects such as ageing (of the active phase, the host material and their interfaces). **Fibre** substrates with active surfaces are being developed to combine the resilience and tenacity of the fibre material (e.g. carbon or SiC) with sensing/actuation functions (see Figure 42), or to bring distributed sensing/actuation functions to optical data communication.

Low-cost, robust techniques for **surface functionalisation** on the nano- and micrometer scales must be developed in order to permit embedding of smart devices and intelligent functions into or onto a variety of structured surface. This includes the preparation of glass or polymer arrays for biochip applications as well as the functionalisation of textile fibres to embed functions such as energy storage and generation, connectivity, bactericidal and anti-microbial activity etc. Smart surfaces possess sensing/actuation functions and exhibit engineered catalytic, electrical, thermal, mechanical, magnetic etc. properties. The use of nano-scale structures, scaffolds, nano-particles etc. is going to increase in many devices. Functionalisation of such structures will enable new applications in the life sciences and sensing fields.

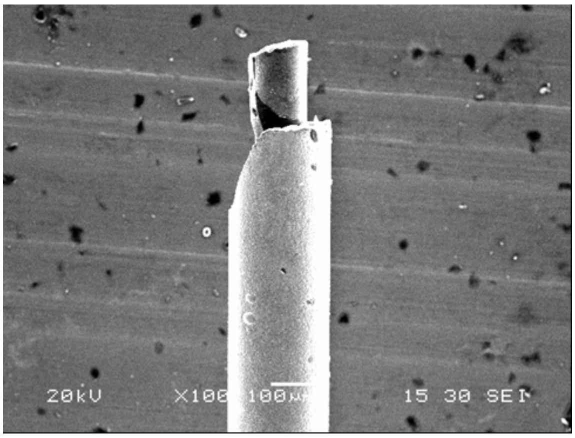

Figure 42: *Piezoelectric AlN coating applied to a carbon fibre with high mechanical resilience*

Thin-film deposition technology must be improved for active materials exhibiting piezoelectric, magnetoresistive, magnetostrictive or shape memory effects. The incorporation of such materials in MEMS-like devices can impart new functionality. Shape-memory alloys (SMAs), which in addition show super-elastic behaviour, could be used in imaginative new ways like for instance overload protection and self-repair in shock-sensitive structures.

Dedicated slurries, feedstock, inks and pastes must be designed and developed to allow printing, casting, injecting, dispensing, spraying etc of the materials to be deposited on the substrates described above. Many of these deposition and replication technologies presently exist, but the rheology and composition of the materials must be adapted to the critical dimensions of the new micro-devices targeted. Also, the foreseen incorporation of nano-particles radically changes the behaviour of these materials during deposition and curing. This may further inspire fabrication methods of (semiconductor) functional material by non-conventional, potentially low cost, processing methods.

With GaN and other compound semiconductors maturing in integration technology, they will become important materials for integration of various functionalities. EPoSS will push further the integration of microsystems that fully exploit the potential of these materials, in combination with Si or other devices.

The addressing of biological applications and the incorporation of biological structures into systems will call not only for the exploration of new materials in micro- and nanofabrication but also for new fabrication and integration methodologies. Important issues such as sterilisation, biocompatibility, biostability and the interfacing between fabrication methods and biological protocols will need special attention.

Special packaging materials will need to be developed to answer the new demands posed by the widened application fields. Their function will go beyond traditional encapsulation for protection against the environment. Heat dissipation is only a first step.

Materials & processes

- Polytronics
- Polymer Substrates
- Ceramic substrates
- Fibre substrates
- Active materials
- Low cost processes
- Surface engineering…
- Printed Wiring Boards

Micro & Nano scale devices

- Biochemical sensors
- NEMS
- NEMS Arrays
- Non linear sensors
- Multisensor systems
- …

Packaging

- System in package
- Wafer Level packaging
- Silicon on Wafer
- Silicon on Silicon
- Silicon on Nothing
- High temperature packages
- Low noise packages

Smart systems integration design tools & methodologies

- Monte Carlo simulation
- Finite elements
- System level design
- Architecture exploration

Figure 43: *Crosscutting issues - Research priorities*

Smart systems interact with their environment, and the package will be the first point of contact. Rather than sealing the device, the package will filter and concentrate the relevant interactions with the system's environment. The boundary between active device and package will disappear as the package takes on more and more active functionality. In the end, there will be no more system-in-a-package or system-on-a-package: *the system will be the package*.

Printed Wiring Boards

Considering that the Printed Wiring Board (PWB) has been the main platform for integrating components to a module or system level in all of the fields of application for the past decades, the further development of this technology is seen as critical to the success of Smart integrated Systems of the future. The ongoing developments target further miniaturization of systems, using approaches like 3D integration, including heterointegration, integration of active and passive components. The path towards integrating the different functions of a complete system, like logic, storage, sensing and actuating are key elements of smart systems using a PWB based integration platform.

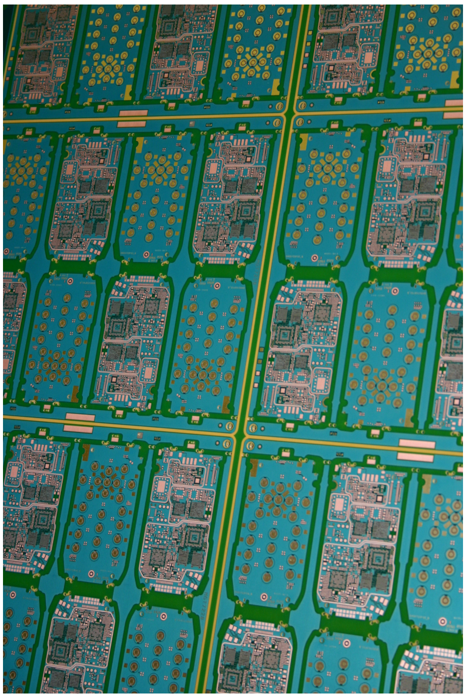

Figure 44: *Printed Wiring Board*

Key topics in PWB related RTD will be closing the gap between IC pitch and pitches achievable with PWB manufacturing technologies today, developing the PWB towards an IC substrate type of precision with the cost structure of a standard PWB, yielding Systems-in/on-Package. This requires developments in manufacturing technologies, but more prominently in the field of polymeric and composite materials, with a possibility of leveraging polymer nanotechnology, metallurgy, powder technologies as well as printing technologies.

The existing PWB technologies are highly developed for the telecom sector, in particular for mobile applications. Transferring this advanced technology into other industries is seen as a major contribution towards implementing a smart integrated system platform based on PWB technology.

Micro and nano scale devices

The second challenge comes from the trends and opportunities offered by miniaturization techniques. The trend towards reducing current microstructures in order to reach nanostructures has appeared over the last three years. **Figure 45** presents a nano accelerometer (on the left) that has been developed under the European project Mimosa. It is compared to a state-of-the-art structure (on the right). Beam thicknesses are in the 150 nm scale and inter-beam distances are down to a few tens of nanometers.

Such structures are unveiling completely new scientific problems including nano characterization, new manifestations of basic forces such as Van der Waals force and Casimir effects. Together with the trends towards the development of nano devices based on new transistor structures or new concepts such as carbon nanotubes, these new devices are also opening the door to new electronic interfaces (MOS detection, coupling effects, non linear effects) and signal processing and metrology techniques. The main rationale for developing these structures is the opportunity to drastically reduce the cost and surface of elementary devices, allowing the fabrication of distributed arrays (by a factor of 100 in our example). These arrays may help system designers build smart functions exploiting the principle of redundancy to improve instrumentation performance. Applications span from physical sensors to high frequency resonators, and from biochemical sensor arrays to new image sensing cells. This roadmap is illustrated on the graph in **Figure 45** where the rupture in intrinsic performance due to the scale factor will be compensated through the use of new detection schemes, arrays of resonant structures and other concepts.

The reduced size of these devices will have strong implications for system and subsystem designers calling for new techniques for read-out circuits (MOS detection for instance) and breakthroughs in interconnection and packaging technologies. New concepts such as nano imprinting and printing systems will have to be developed as well in order to keep costs down.

Packaging

Packaging is one of EPoSS's most important issues. The proposed System in Package (SiP) solutions enable a high degree of miniaturization by applying 3D techniques on the wafer, substrate, component and package levels e.g. integration of sensor devices, stacking of several functional layers with integrated components etc.

The functionality of new systems in the different application areas can be considerably enlarged by the implementation of mechanical, optical and/or biological functions. The realization of such systems is based on new architectures, components and heterogeneous system integration technologies of various devices, including electrical and non-electrical devices (MEMS), and has to be carried out more cost efficiently, with a high degree of miniaturization and flexibility in adaptation to different applications.

The focus on heterogeneous integration allows designers to integrate devices for sensing, electrical signal- and data-processing, wireless communication, power conversion and storage. The heterogeneous integration concept offers the possibility to integrate System-on-Chip solutions (SoC) for subsystems and results in a higher overall functionality of the systems, a shorter time-to-market cycle and a high degree of flexibility with respect to application requirements.

Each application requires special solutions: biocompatibility in medical applications, mechanical resistance to shocks and vibrations in automotive and transport, EMC resistance in industrial applications. In addition, applications in daily life items involve use of diverse materials like polymers, glass, metals, and operation in different conditions and on different substrates: textiles, paper etc.. Smart system devices have generally a tight relationship with the electrical and non-electronic world by sensing, actuating, interacting in a hostile environment. Heterogeneous integration is hence an absolute necessity, together with a multidisciplinary approach involving microelectronics, optics, mechanics, fluidics, chemistry, biology.

Different processes, materials, and characteristics (e.g. sensitivity to magnetic and electric environments (EMI), thermal and thermal-mechanical requirements, environmental aspects, harsh environment) have to be addressed together. Designers in the field of RFID are already facing these issues which will expand to other industries (textile, infrastructure monitoring) soon.

The key attributes of packaging and system Integration can be summarized as:

- system partitioning / modularization / 3D integration
- chip-package co-design
- integration of electrical and non-electrical components
- increased complexity and functionality
- integration of different functions in one package
- integrated power conversion and storage
- integrated wireless communication
- high reliability at low cost

More generally, all the common constraints of packaging & system integration tasks such as design and modelling, choice of materials and integration techniques, thermal management, environmental friendly and low-cost fabrication will have to be handled in the future.

Research priorities include:

- integrated and embedded component technologies for sensors, actuators, integrated circuits (IC´s) and other components;
- passive device integration and integration of MEMS devices;
- lower cost large-area manufacturing technologies for assembly and component embedding;
- 3D stacking of sub-system layers by soldered or glued interconnects or lamination and 3D stacking of multiple functional layers on wafer and substrate level as well as integrated optical interconnects for devices with photonic functions;
- integrated fluidic and gas access to sensors and actuators;
- flexible large area component integration (reel to reel), and
- low-cost assembly and integrated power supply

Smart system integration design tools and methodologies

Application developers willing to integrate complex microsystems or smart sub-systems are facing several challenges due to current limitations of product design tools. Current CAD software suites are in general specialized on specific functions: finite element simulation for mechanical, chemical or EM phenomena (Ansys, Coventor, Intellissuite,

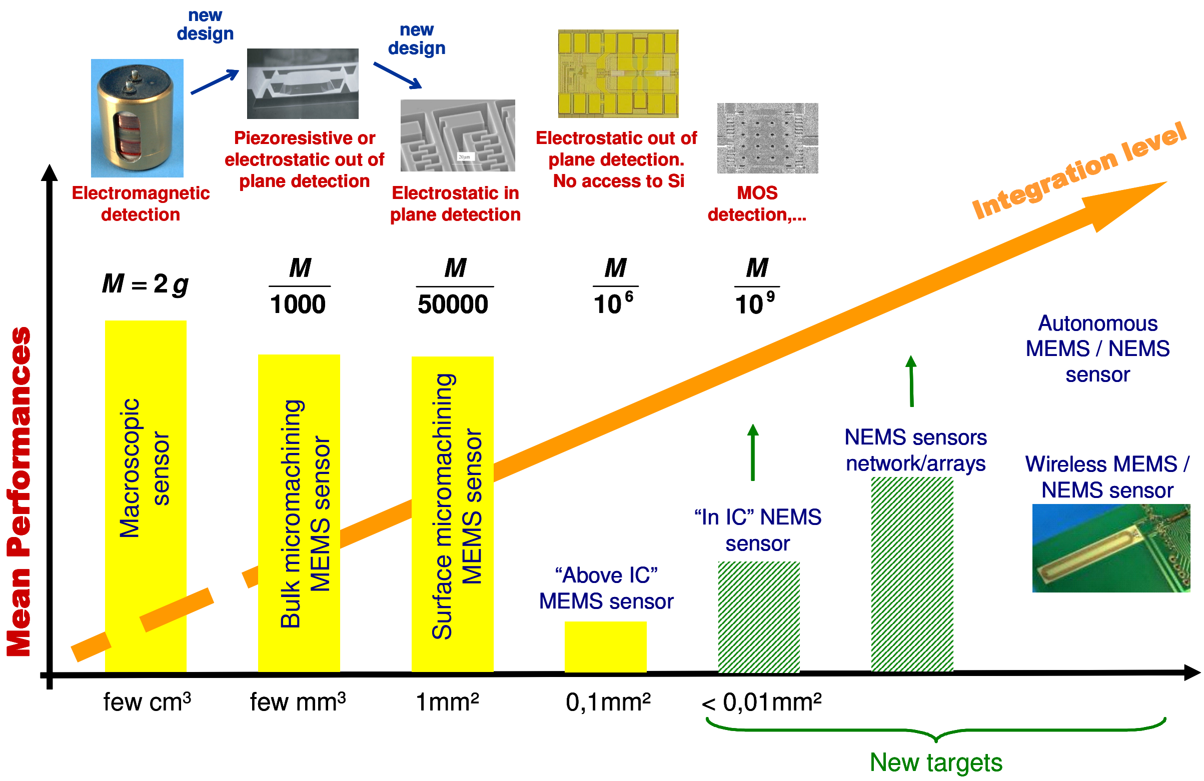

Figure 45: *MEMS/NEMS – Evolution & Trends*

HFSS,…); analytical or functional models for high level system simulation (UML, Matlab/Simulink, System-C); electrical behaviour of the devices for integrated circuit design and simulation (Cadance, Matlab/Simulink, VHDL-AMS, Verilog-AMS, System-C). In general computing power limitations lead engineers to use an increasing level of complexity as long as the scale of the devices to model and simulate are decreasing. For complex and heterogeneous systems, that means that specific tools and tasks deal with the adaptation and the transfer of simulation data from one level of model to the next. This is time-consuming and one challenge in the future will be to develop methodologies and tools that enhance the productivity of system designers.

The diagram in **Figure 46** shows that a big challenge for system designers in the next ten years will be to specify and contribute to the development of methodologies and tools leading to a better unification of software tools for the design of macro-scale systems composed of micro- and nanoscale devices. This will also have to include knowledge management issues to enable industrial actors to build on former projects and benefit from learning curves.

Export of component models to different system design languages: Controller, circuit and system design are utilized by different tools and languages. Export features of component models have to be investigated.

Methods and tools for model parameter adaptation based on experimental results: Currently, not all parameters can be predicted as precisely as necessary. Model parameter adaptation and identification based on experimental results are required. Particularly, the coupling of atomistic and nano-scale effects in component and system models has to be considered.

10.4 Research Priority - Enabling Functionalities

The graph shown in **Figure 47** highlights the main issues that have been identified as the most common functionalities to be integrated in a wide variety of smart systems.

Sensors and actuators:

Today the design process of a MEMS device is usually performed independently from the electronic circuits to which it is connected. A great improvement in performance and power consumption can be reached when a design methodology is employed with a complete system (mechanical and electrical) model approach allowing the exploration of new architectures where mechanical and electrical constraints are jointly optimized.

In the field of physical sensors, solutions of the future will offer multi-parameter characteristics on the same chip together with integrated low level signal-processing to optimize power consumption and data storage features of the system on which they are embedded.

Biochemical sensors will have to be developed through the integration of highly heterogeneous techniques and materials (biocompatibility, fluidics, optics) and sensor arrays will also integrate sample conditioning to optimize robustness, sensitivity and to fulfil cost requirements.

In the field of actuating technologies, electromagnetic motors have dominated miniature actuation since the very birth of portable consumer devices, but more recent actuators, in particular piezoelectric motors, are expected to achieve a substantial market share. However, these are not realistically expected to challenge all of the electro-magnetic actuators, since there are major applications where the traditional technique has cost or performance advantages.

Electrostatic actuators were among the first to be considered in microsystems. This was mainly because it was the actuator type that could be integrated in silicon micromechanical structures, but also because it was believed that this type of actuator would become advantageous at smaller size. The size effect of the electrostatic actuators has been investigated by several research groups and the conclusion is that the available forces are too low for most of the applications in present and planned products. Electrostatic actuators are therefore mostly utilised in optical deflection systems, e.g. the Digital Micromirror Device developed by Texas Instruments. Another actuator material group of great interest is shape memory materials. Shape memory metals have the highest work density of all the actuator materials and are ideal when large forces are needed. Typically these materials have moderate strain and rather poor efficiency which limits the field of applications. Another challenge with these materials is the possibility of integration since there are no suitable mass-manufacturing processes that can handle components made of these materials.

The race to find "the actuators of the future" has begun, however. The development of artificial muscles, based on polymer actuators, has become the focus of much interest in the USA and Japan. The interesting point from a European perspective is that it has so far been a highly diversified market. If the basis of future actuator technology can be made available to the relevant European R&D groups, there will be good opportunities for European SMEs to grow and to be able to compete with the present multinational (read Asian) companies. It is believed that the most important development will be within

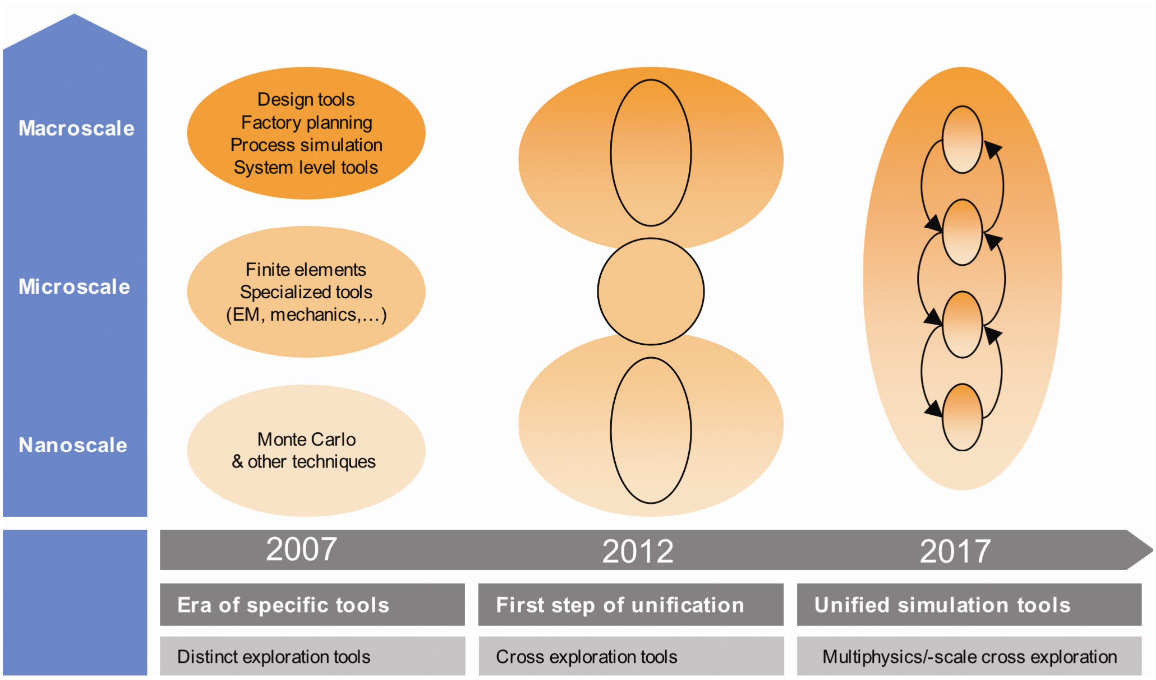

Figure 46: *"Scales" of design*

materials science and a key competitive factor will then become know-how regarding materials processing. An offensive and focussed research effort can therefore provide the necessary lead in this important area. Priorities for research include long term stability of material, multilayer structures and material optimization for low voltage operations.

Energy management

Energy efficiency is a major issue for all economies, and particularly european ones. In this area, smart systems integration opens extraordinary opportunities. The automotive industry has experienced a 1% gain in energy efficiency each year over the last 20 years because of micro electronics technologies which allowed an active control of fuel injection. The same should be done in a number of areas, from white to brown goods, or industrial goods.

Illustrative of this, more and more devices have a sleep mode that is consuming a significant amount of energy over their lifetime. Developing the energy management modules to be used by product developers will have a huge energy saving impact. Such a solution will help implement the EUP directive more efficiently. Technologies to achieve this range from low power wireless, adapted actuators and possibly energy scavenging technologies. For cost reasons, all these functions will have to be highly integrated with mechatronics technologies.

In addition to the product level, energy efficiency will require new capabilities for products to be smart for energy management systems ; for instance, alternative energy sources (such as solar) will require a sophisticated load management able to switch a device to a low power mode ; smart systems in devices will manage this capability by providing power consumption information, by managing device operating modes, by communicating with the load management system of the building, by using information coming from sensors.

The efficiency of smart systems themselves is another critical technology for the future.

Energy management issues are strongly dependent on the use case scenario. The battery characteristics of a medical implant permanently monitoring physiological parameters is very different from the energy source of a wireless sensor which spends 99% of its time in idle mode and which is woken up once or twice a day to make a temperature or acceleration measurement.

However, the progress of silicon technologies over the last ten years is leading to a whole family of autonomous devices displaying average power consumption in the 10µW to the 1 mW range. These figures seem to be compatible with small form factor energy scavenging devices such as vibration micro structures, PZT systems, thermoelectric and photovoltaic cells.

Specifically in this area of devices, we must try to learn from efficient bio-processes and search for new ways of generating energy for extremely low power devices.

New materials and new architectures will have to be developed to increase drastically the yield, the quality factor or the figures of merit of such solutions. Nanotechniques such as NEMS and surface functionalization will be of the essence.

Energy storage solutions will have to be improved and optimized to meet new requirements such as low cost electrolytes and electrode materials, higher

Sensors & actuators

- Gas sensors
- Bio sensors
- Temperature
- Pressure
- Acceleration
- Gyros
- Force
- Humidity
- Vision
- Acoustic
- …

Wireless communications

- Biochemical sensors
- NEMS
- NEMS Arrays
- Non linear sensors
- Multisensors
- Vision sensors
- Smart retinas

Safety & Security management

- Cryptography
- Privacy management
- Redundant architectures
- …

Energy management

- Energy scavenging
- Vibrations
- µPhotovoltaic
- Thermoelectricity
- Energy storage
- µFuel cells
- Ink batteries
- microbatteries
- Energy management
- System monitoring

Data storage, info processing & HMI

- Signal processing
- Data fusion
- Data Management
- Knowledge management
- Decision making tools
- Data structures
- Data storage

Figure 47: *Crosscutting issues – Enabling functionalities*

energy or power capacities, smaller volumes and better load characteristics (cyclability, required time for recharge)

The quest for environmentally friendly solutions will be of high importance since most of these devices will be spread in very large quantities and will be supposed to work on their own for years or decades.

Finally, the variety of energy sources and the variety of the functions to feed will require new concepts of energy management architectures such as dc-dc converters, battery monitoring blocks. This will lead to new concepts for Quality of Service for the wireless sensor node systems.

Wireless communications

The developments of new standards and the progress of silicon devices operating at radio frequencies will increase the need for new architectures dealing with multimode systems. This calls for new studies on antenna, substrates and packaging materials as well as the development of new RF MEMS components based on new materials and new processes. The high industrial and economic risk induced by the above IC approaches for passives and filters requires that alternative approaches based on heterogeneous integration have to be explored.

As the number of complex signals to be transmitted increases, there is an increasing demand for more powerful signal processing to be integrated in the system itself. Currently available DSP systems already fall short of the demands of many types of integrated sensors. The situation clearly calls for innovative solutions that meet the needs of integrated systems such as ultra low power implementation.

The large scale dissemination of wireless devices will also depend on the ability of the scientific and industrial community to develop very low-cost low-power modems based on innovative concepts. Such devices will enable the development of wireless sensor networks for applications such as air-conditioning monitoring of cars, structure-monitoring of planes, and body-area networks of sensors for fitness or medical applications. This area covers as well remote powered links using RFID-like techniques: new concepts and new interfaces compatible with miniaturized devices or harsh environments (cars, human body) will have to be proposed, explored and demonstrated.

Data storage, information processing and man machine interfaces

As far as data storage issues are concerned, two classes have emerged. Solid state memories which are integrated in the ITRS roadmap and mass storage functions that are addressed through magnetic and optical technologies. The development of mobile or highly distributed devices and systems will require the development of new concepts that go beyond the current roadmaps. Data storage may become a commodity that can be distributed, organized freely in the subsystems, and requirements for smart memories with optimized structures will appear in the future. The need for an ultra-low power, all-purpose memory that can be integrated on non-Si substrates will become apparent. It is now evident for memory technologies that the era of development driven predominantly by simple data rate/data density parameters will not be innovative enough in the near future. Not that these parameters will not be crucial for future products, rather that only the combination of efficient memories with data archival, retrieval, processing, communication and networking capabilities is likely to be successful in increasingly demanding future technology applications and markets. Thus, creating complex memory networks and devices, with enhanced flexibility and robustness, combining mass and dispersed memories, able to fulfil some of the most challenging dreams of the ICT society will be at the core of the coming challenges.

In the field of information processing, the opportunities offered by smart systems to deploy sensors on large areas or to offer new systems with multisensing functions will call for the development of new mathematical tools and algorithms which will be adapted from current data fusion and signal processing techniques in order to meet the low power requirements of the platforms on which they will be embedded.

Safety and security management

Security issues have to be addressed in the future for most of the EPoSS applications. The large dissemination of information favoured by smart systems adoption increases the vulnerability of most systems. The development of low power cryptography techniques for protecting personal data and guaranteeing reliable authentication processes will be mandatory. The security of smart systems will also depend on the ability to identify potential threats and to develop countermeasures that build on various technologies: multi-sensing techniques for NRBC threats, other sensing technologies such as terahertz imaging and biometry. Physical protection of devices through smart and functional packaging techniques will enable the European industry to fight efficiently against forgery and counterfeiting.

11. EPoSS Interactions with other Technology Platforms

EPoSS will deliver indispensable functions for improving the competitiveness of entire sectors such as aeronautics, automotives, safety and security, logistics, medical equipment and process engineering. It will make a significant contribution to addressing major socio-economic problems in the health or environmental sectors e.g. by providing solutions towards assisted living for the handicapped and elderly, towards more predictive preventive medicine, by assuring quality of food and by addressing major environmental problems and risks, and by making road traffic and aeroplanes safer.

EPoSS will promote the development of smart integrated systems taking into account the requirements defined in other technology platforms, particularly those addressing issues at application level. In particular, EPoSS will help to fulfil the objectives defined by the European Technology Platforms **ACARE** (Aeronautics), **ERTRAC** (Road Transports) and **eMOBILITY** (Mobile Communication).

EPoSS is structured to give voice to users;. Working groups have been set up to identify technological priorities in the key application areas: automotive, aeronautics, telecommunication, medical technologies and logistics/RFID. Thus R&D can be steered early towards product development and market needs.

The core objective of EPoSS is to accelerate R&D of future hardware components and their combination in

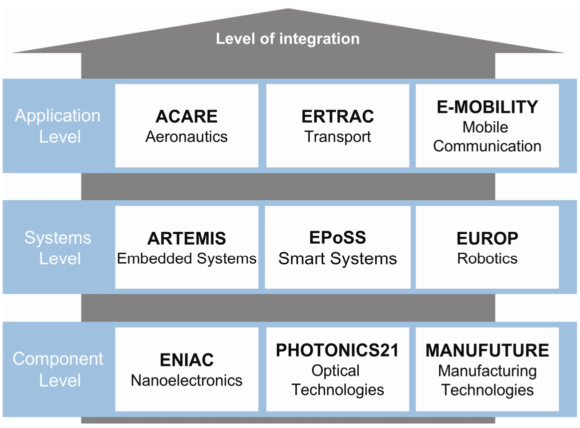

Figure 48: *EPoSS and other European Technology Platforms*

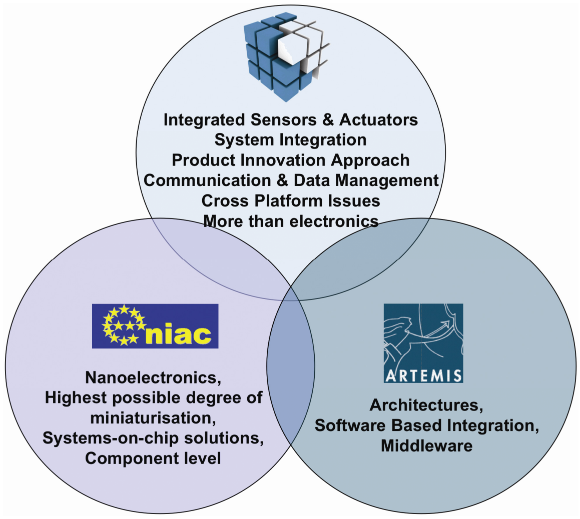

Figure 49: ***Technology Platforms in the MNT Environment***

order to realise systems which are able to fulfil complex functions (e.g. object recognition systems combining ultrasonic, infrared, radar and video components).

By focusing on the physical basis of systems, EPoSS clearly distinguishes its mission from **ARTEMIS**, the Embedded Systems Platform, which is contributing to systems integration essentially by focussing on “system design, distributed architectures, computing platforms, security, middleware and tools”. In a division of labour between the two Technology Platforms, ARTEMIS in particular will focus on:[27]

- “reference designs for embedded platforms and software in a broad variety of application domains,
- middleware layers for open seamless environments that support fast application development,
- the basic computing and communication technologies that underpin future embedded systems,
- software tools that support rapid design and prototyping.”

[27] Building Artemis, Report by the High-level Group on Embedded Systems, p. 18

Thus there is complementarity between both platforms which will also be followed at project level.

EPoSS is essentially "driven by functions". The technological solutions promoted by EPoSS are systems solutions and therefore in many cases will deliver decisive features of the end product. As outlined above, these functionalities will often need to integrate different components and to rely on solutions realised by other players in the value chain. Therefore interaction and cooperation with other technology platforms at component level are essential – in particular with **Photonics21** and **ENIAC**.

Being a system-level-oriented platform EPoSS will be predestined to cover the micro-to-macro-level. Using and involving the component-level outcomes of micro-, sub-micro- or nanotechnology and biotechnology Smart Systems Integration Technologies will leverage it onto a system, a product level. Smart System integration will release the full product potential of "enabling technologies" like nanotechnology and biotechnology.

Both Photonics 21 and ENIAC are focussing on enabling technologies for Smart Systems even if the majority of smart systems related aspects can't be covered. Photonics21 is exclusively concentrating on optical components, ENIAC is focussing on semiconductor development aiming at achieving the smallest possible dimension and thus on increase of performance. In this sense an ideal basis for cooperation is provided since these issues are not part of the EPoSS spectrum of activities as shown in Figure 50.

Particular attention has to be attributed to the cooperation with ENIAC's "More than Moore" Working Group. "Moore's Law will continue to address the intelligence issue by doubling the computing power that can be put on silicon chips every two years, but what will be needed to implement interactivity will be something considerably 'More than Moore' – technologies that ...will provide silicon chips with the equivalent of the eyes, ears, arms and legs that allow humans to demonstrate their intelligence in such highly interactive ways. It will be the combination of nanoelectronics with other nanotechnologies such as nano-bio-technology and nanomechanics that will allow these intelligent interactive systems to be made small enough, cheap enough and sufficiently low power consuming to embed into everyday consumer products... ".[28] By using the „More than Moore"-chips as key components, e.g. SoC solutions and following an extended SiP approach - and combining them with smart systems technologies - smart, cognitive and producible devices will be realised.

The **ARTEMIS** approach to evolve Embedded Systems, special-purpose sophisticated fixed-function multi-processor systems of the present day associated with increasing communication capacities[29] leads to another field of possible strong cooperation. The results of this platform will be appreciated as an input by EPoSS.

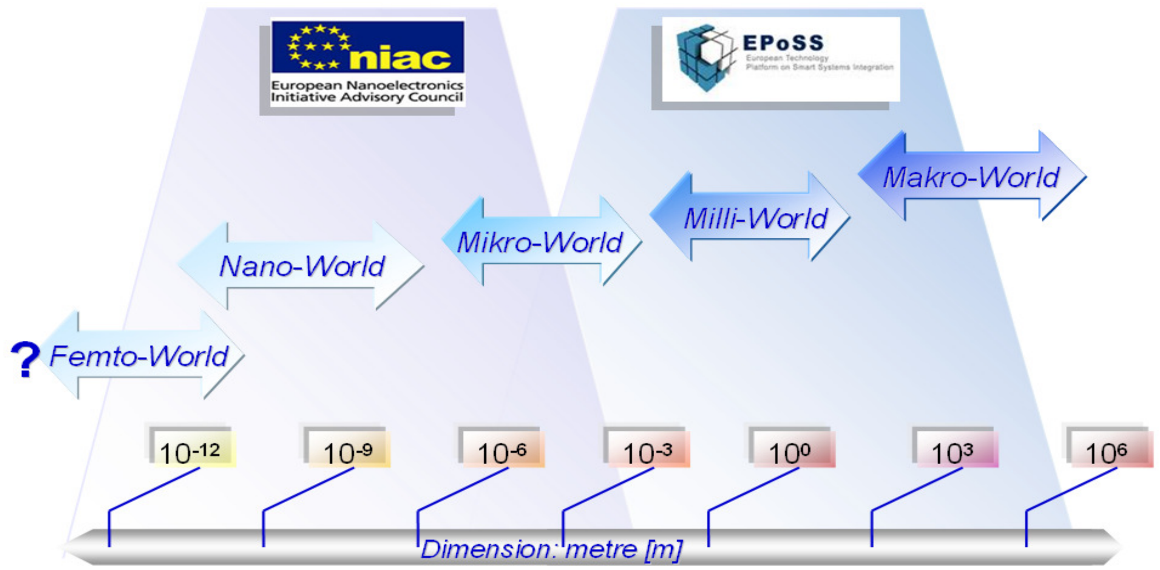

Figure 50: *Scales of the EPoSS world*

[28] (ENIAC Strategic Research Agenda 2005, p. 7f)

[29] Artemis Strategic Research Agenda Short Version - June 2005

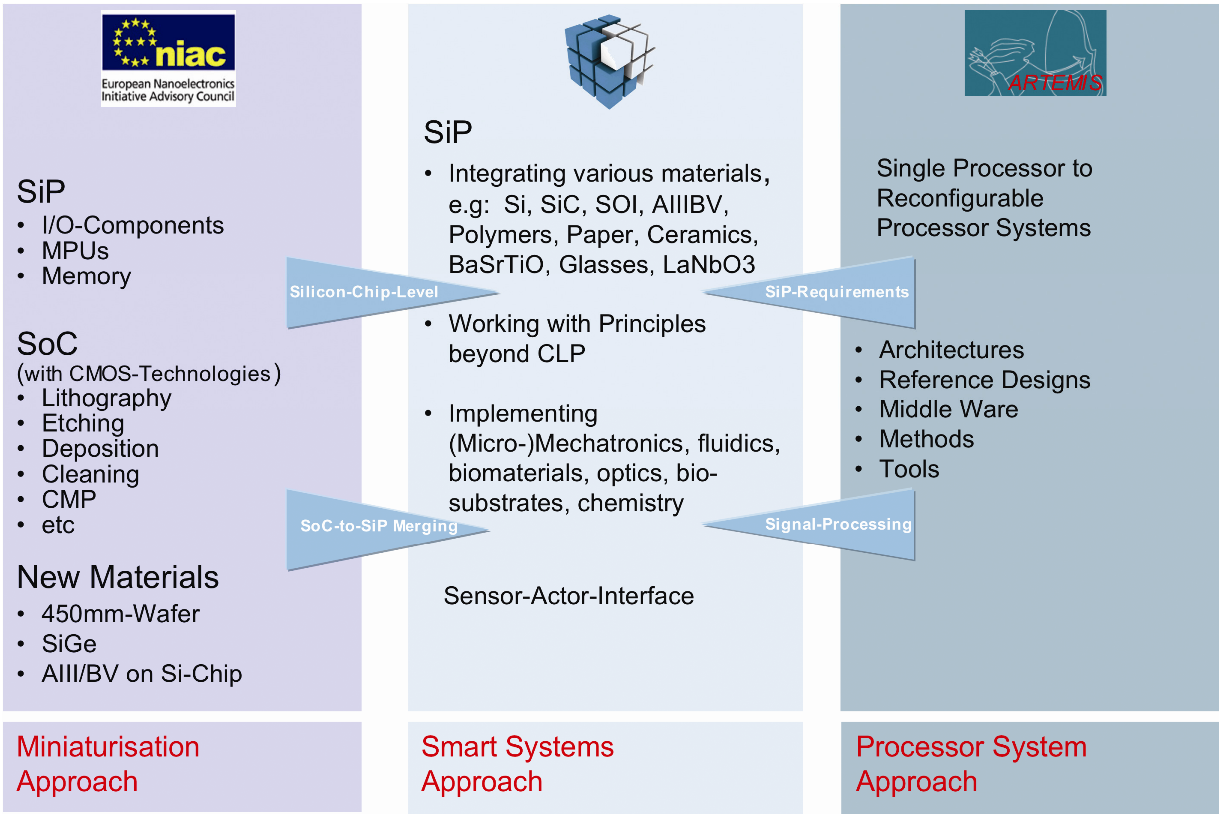

Figure 51: *EPoSS' Interactions with other ETPs*

Modus of implementation

At practical level the EPoSS High Level Group, particularly those members whose companies are also represented in other technology platforms, will establish an appropriate dialogue and regular exchange on priorities with ENIAC, ARTEMIS and Photonics21. Wherever technological details will have to be discussed these issues may be delegated to the Steering Group. The EPoSS Steering Group (SG) will establish a regular exchange on technological issues and activities with these platforms. Therefore they invite representatives of other platforms to their meetings, take part at the meetings of other platforms, and inform on up-coming projects. The SG - together with the secretariat - will set-up a concept for a regular annual consultation meeting involving the mentioned IST technology platforms

12. Acknowledgements

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13. Figures