Sensors to Support the IoT for Infrastructure Monitoring: Technology and Applications for Smart Transport / Smart Buildings

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OUTLINE

- Presentation Objective
- Definition
- Functional Requirements
- Situational Analysis
- Drivers for Adoption
- Trillion Sensor Iniatiative
- Smart Transport
- Smart Buildings
- Sensor Overview
- Case Studies
- Critical Success Factors / Challenges
- Summary and Conclusions
- References
- Schedule of Upcoming Events of Interest

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ROGER GRACE BACKGROUND

- Education: BSEE, MSEE (Raytheon Graduate Fellow) Northeastern University, Boston, MA; MBA Program, University of California Berkeley
- Design Engineer with specialty in microwave and RF, 13 years…Raytheon, Avco
- Applications Engineer, RF semiconductors, 3 years, Avantek/HP
- Marketing Manager, MEMS, 3 years, Foxboro ICT
- Marketing Consultant, MEMS, Sensors and Semiconductors, 30 years
- Guest Lecturer, University of California Berkeley, 1990-2003
- Alumni Engineer of the Year, 2004, Northeastern University
- Co-Founder and Past President of Micro and Nanotechnology Commercialization Education Foundation (MANCEF)
- Published over 70 papers and articles on MEMS/Sensors
- Organized and Chaired over 30 technical sessions worldwide on MEMS/Sensors
- Board membership…Florida MEP, University of Michigan WIMSS, Northeastern University High Rate Nanomanufacturing Center
- Organizing committee includes Transducers 2009,COMS, Smart Systems Integration (EU), Advanced Microsystems for Automotive Applications (EU), IRISS(EU)
- Citizenship…US / Portugal

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MARKETING COUNSEL

ROGER GRACE ASSOCIATES OVERVIEW

- Founded in 1982,a pioneer in the MEMS strategic marketing and analysis sector
- Clients include the “who’s who” of industrial and government organizations worldwide
- Headquartered in Naples, Florida/ San Francisco, California
- Focus on MEMS/Semiconductors and Capital Equipment
- Capabilities include
  - Custom market research
  - Market strategy development
  - Merger and Acquisition (M&A) due diligence
  - Integrated marketing communications
    - Promotion
    - Positioning and Branding
    - New product launches

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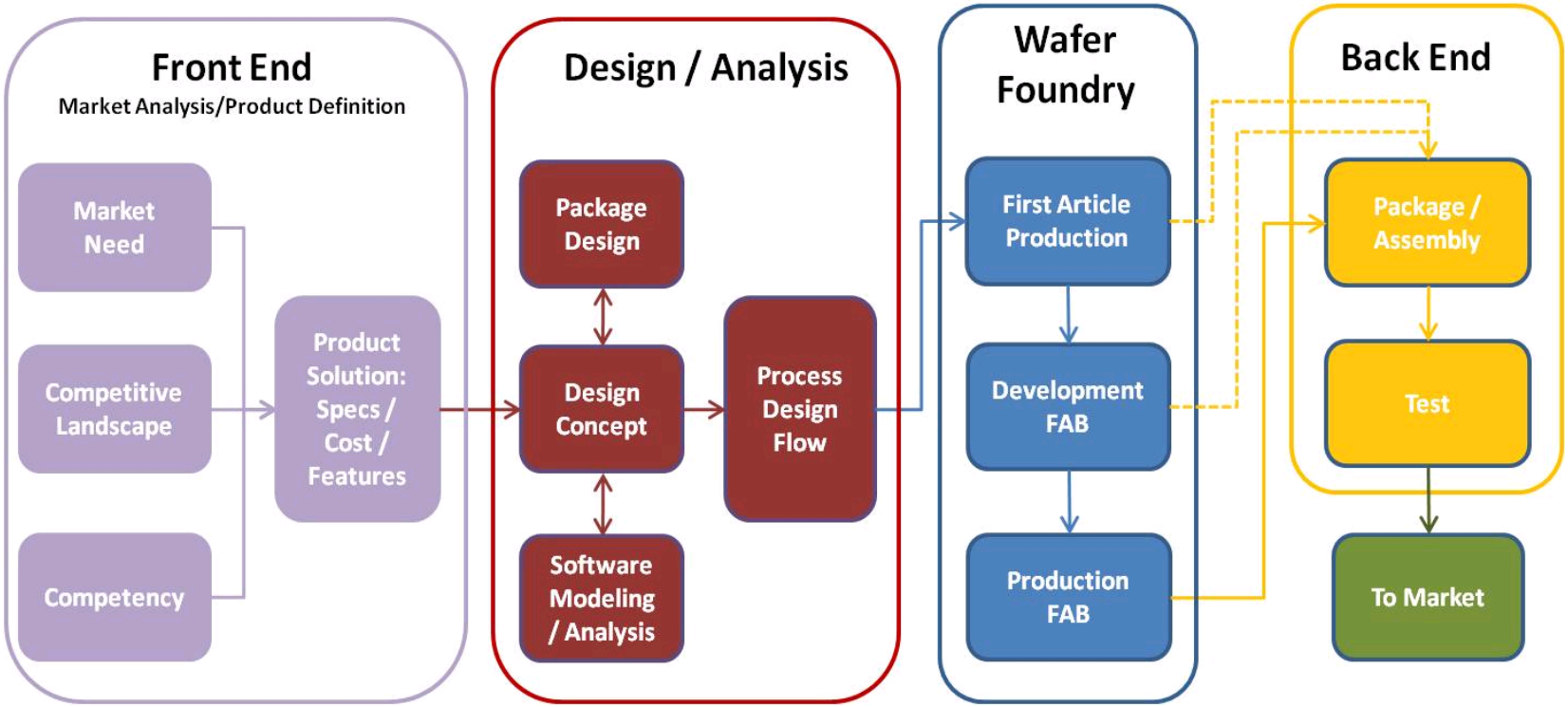
COMMERCIALIZATION PROCESS



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PRESENTATION OBJECTIVE

- Demonstrate the unique benefits of MEMS-based systems solutions (MBSS) and its applicability to create cost effective solutions for the Internet of Things for the built infrastructure of “smart” transport and “smart” buildings and its role in empowering the Trillion Sensors Universe

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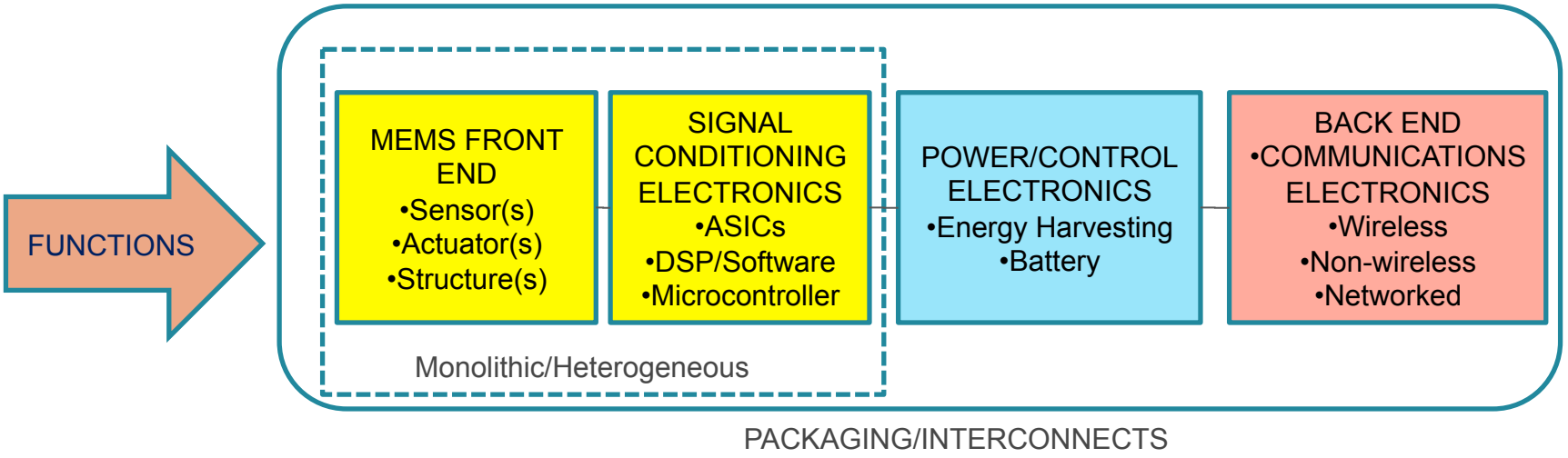
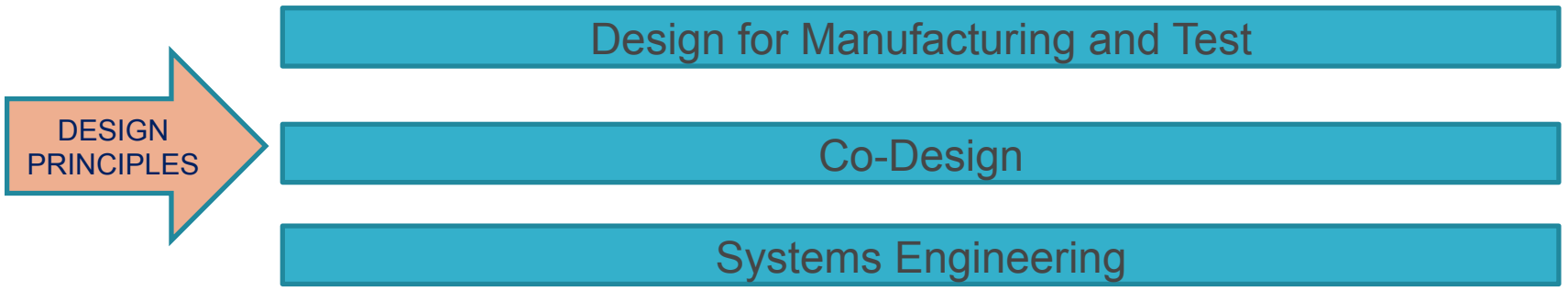
DEFINITION

- Traditional “MEMS” and “MST” are not typically systems…they are in fact devices
- “MEMS-Based System Solutions” (MBSS) a.k.a. “smart systems” are an integration of MEMS-based sensors/actuators/structures with other functionalities e.g. signal processing, networking delivered in a package and optimized for a customer application/solution “(R. Grace)

MEMS-BASED SYSTEMS SOLUTIONS / WASNs





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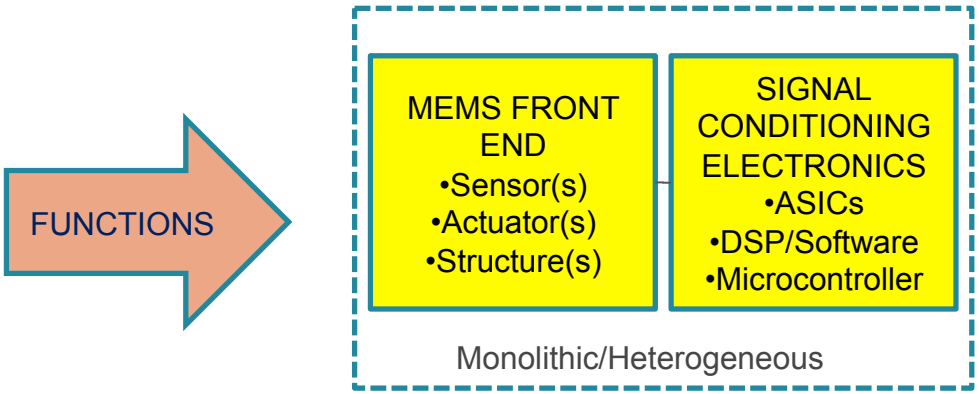
MEMS-BASED SYSTEM SOLUTIONS / WASNs



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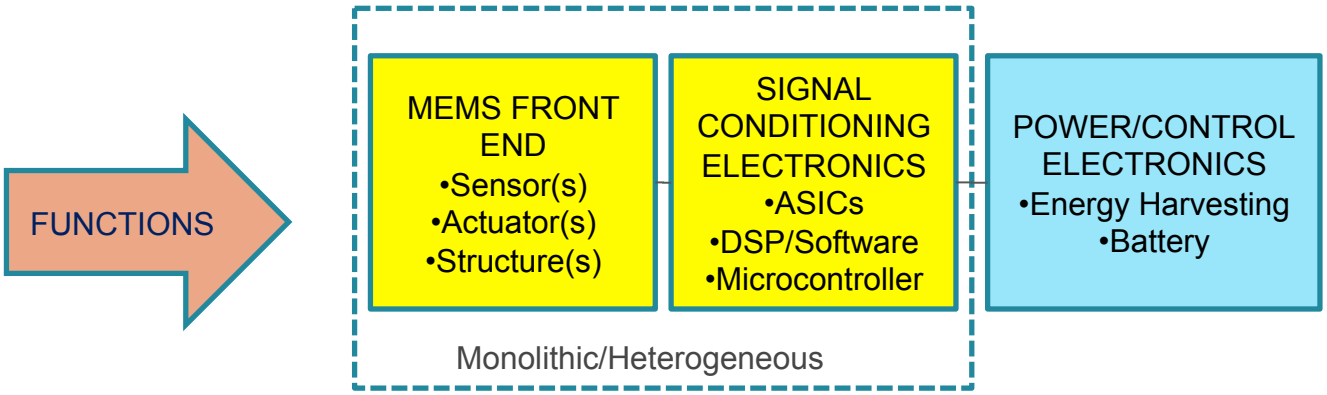

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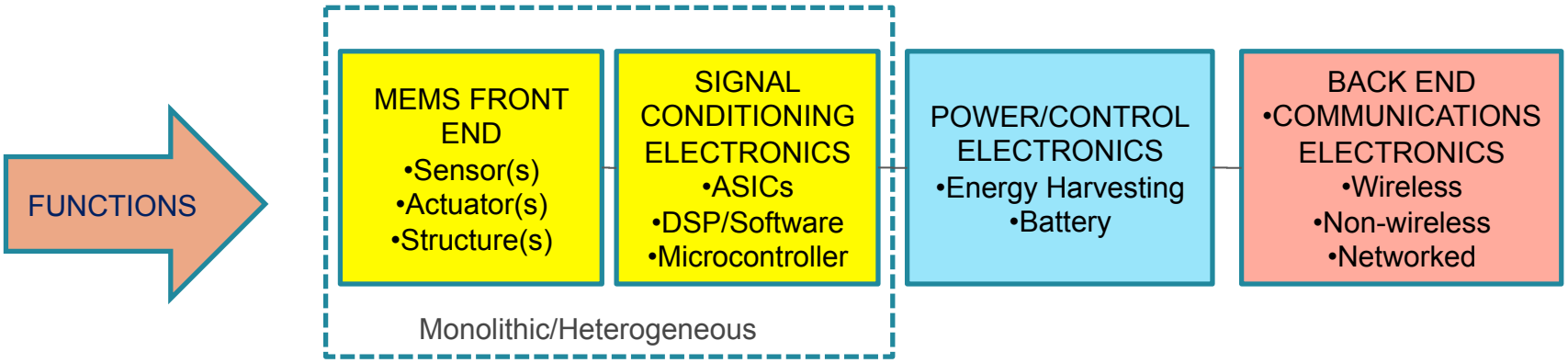

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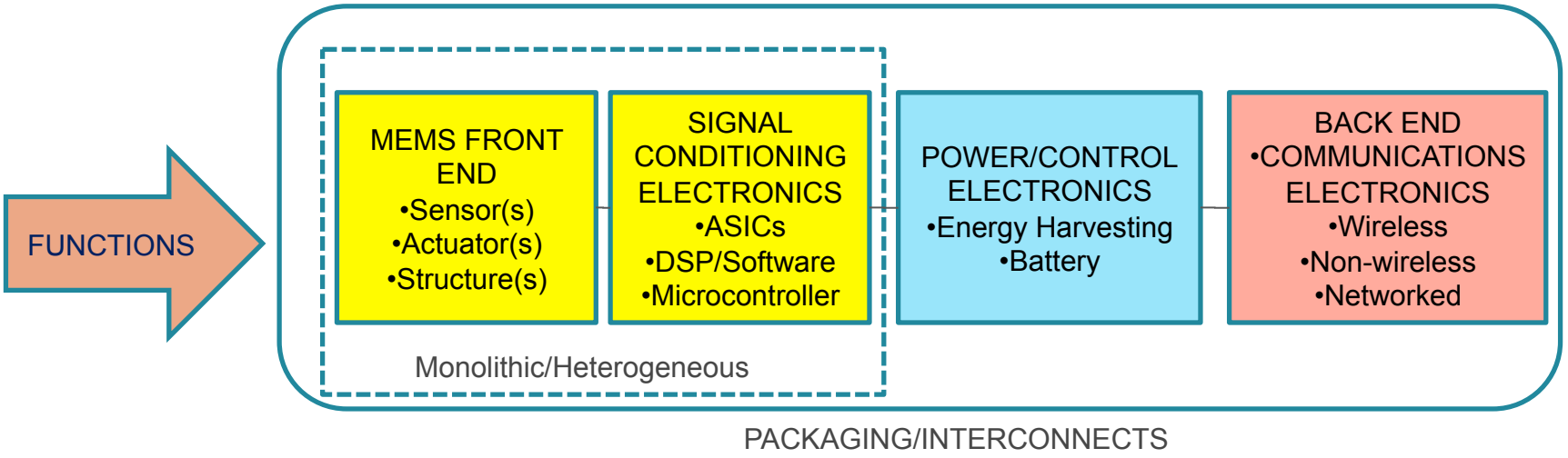

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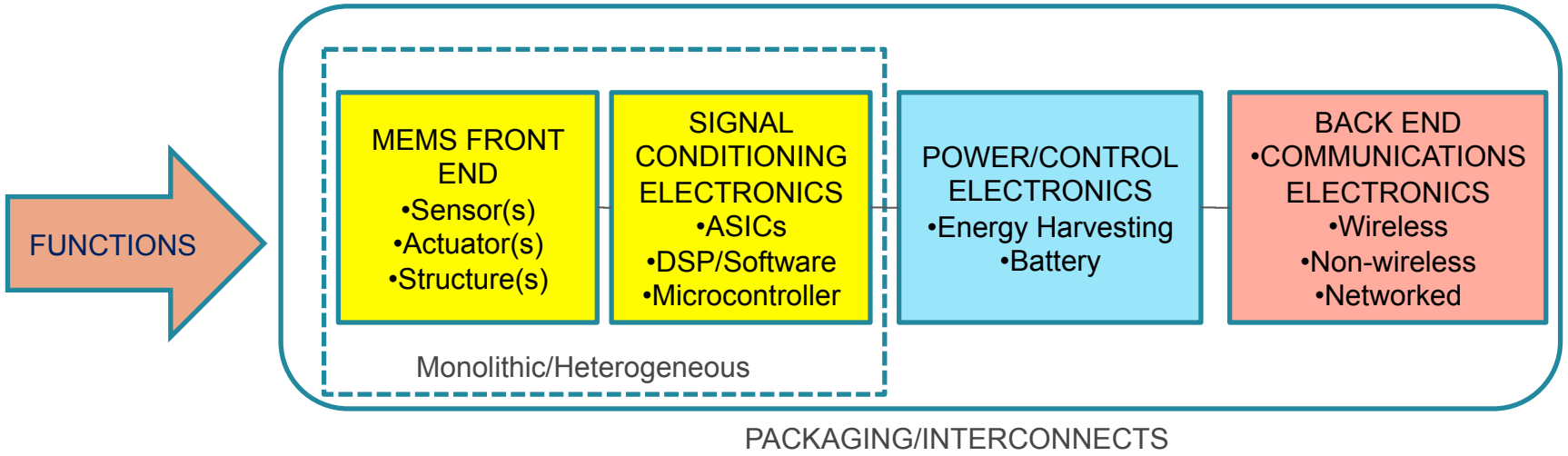

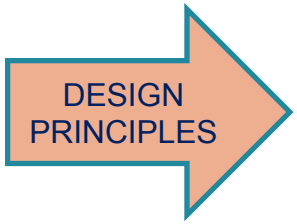

Systems Engineering

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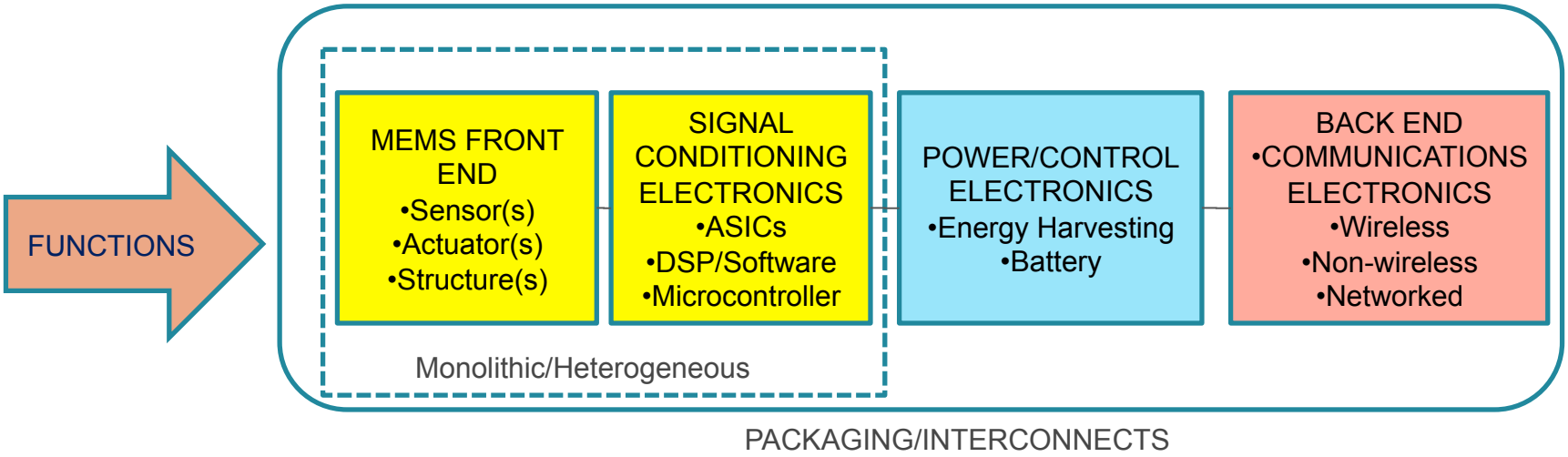
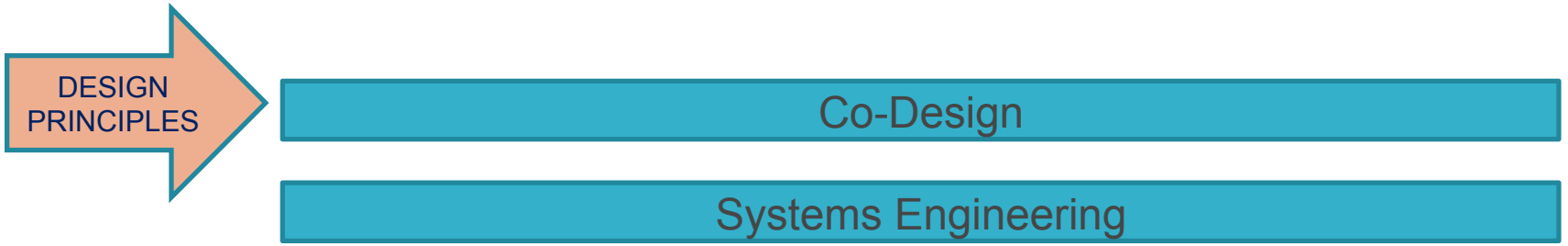
MEMS-BASED SYSTEM SOLUTIONS / WASNs





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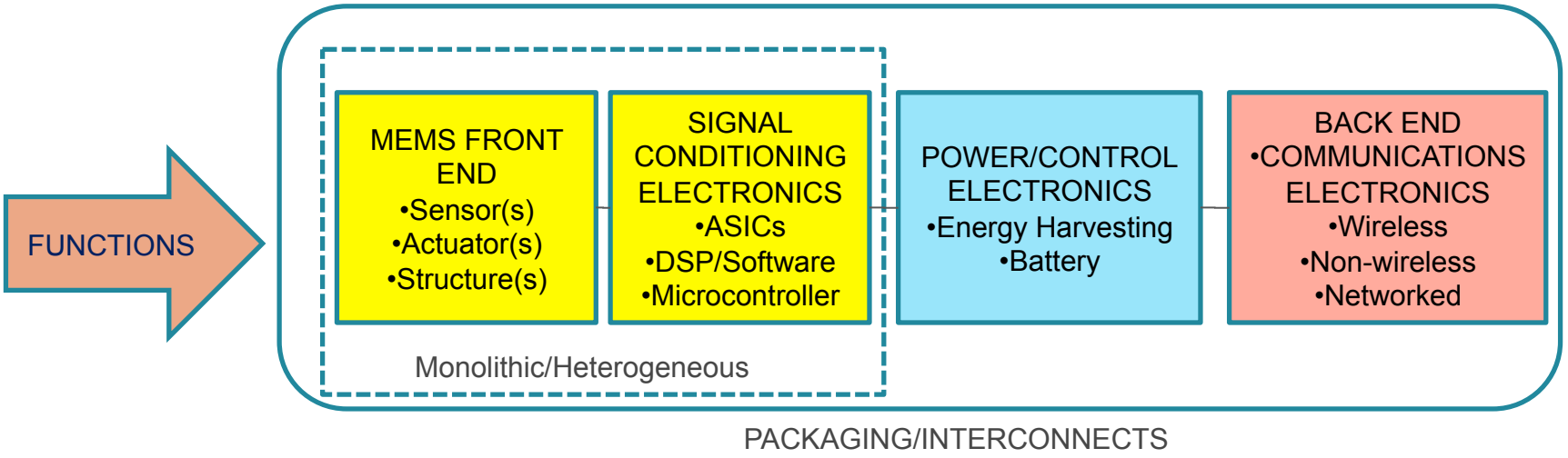

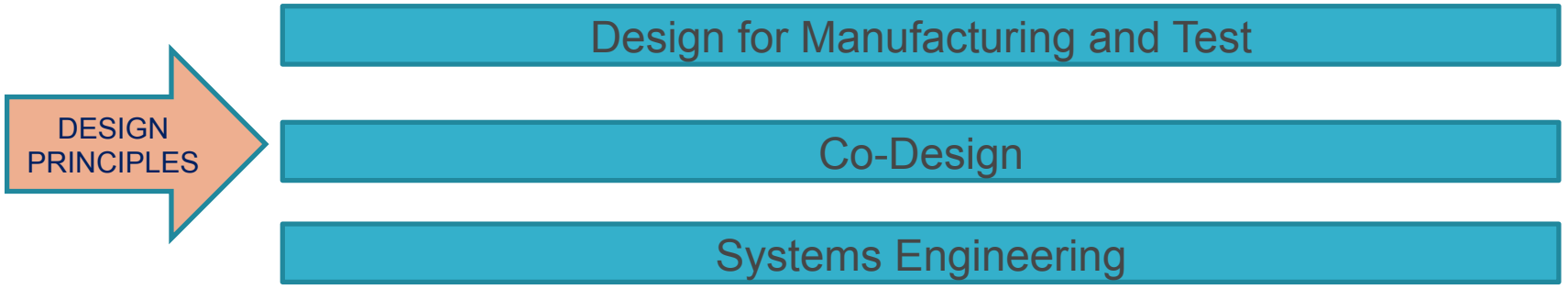

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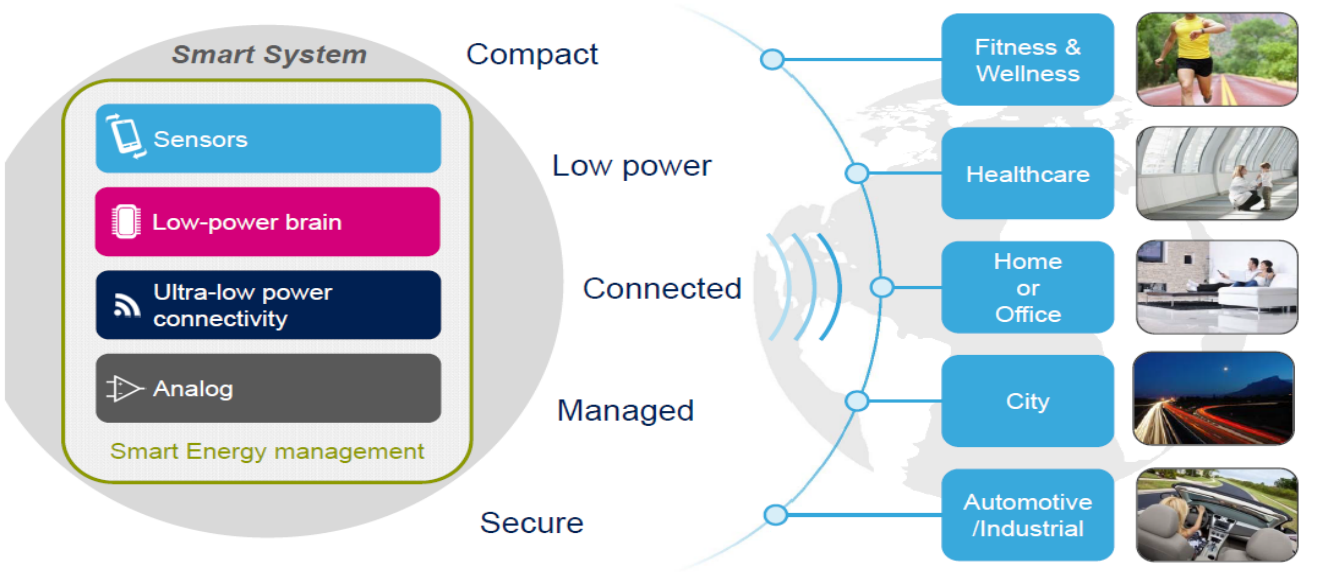
SMART SYSTEMS ENABLE IoT

Smart Systems to enable IoT



DRIVERS FOR ADOPTION OF MBSS / TECHNICAL

- Broad availability of commoditized devices
- Novel implementations of unique sensors / actuators / structures
- Need for product differentiation
- Off-the-shelf availability low-cost signal conditioning & processing devices,memory…ASICs ,DSPs, Flash, E2PROM
- Large availability of software developers
- Evolution of wafer level packaging / TSV / films
- Desire to maximize value added and maximize profit margin
- Continuous price reduction of MBSS components
- Relatively low barrier to entry for prospective suppliers

STATUS OF MBSS SYSTEM ELEMENTS

• Sensors	with the exception of chemical sensors… mature and available from many suppliers / in-house
• Low Power ICs	mature and available from multiple suppliers / in-house
• Embedded Software	developing quickly and available from several suppliers / in-house
• Energy Sources	batteries mature…energy harvesting currently under development by several organizations
• Communications ICs	mature and available from many suppliers / in-house
• Packages	mature…however new “breakthrough” low cost / robust packaging needed to help reduce solution cost…and can account for 30-50% of BOM
• Testing	several companies providing integrated test systems to device developers / many suppliers developing systems in-house

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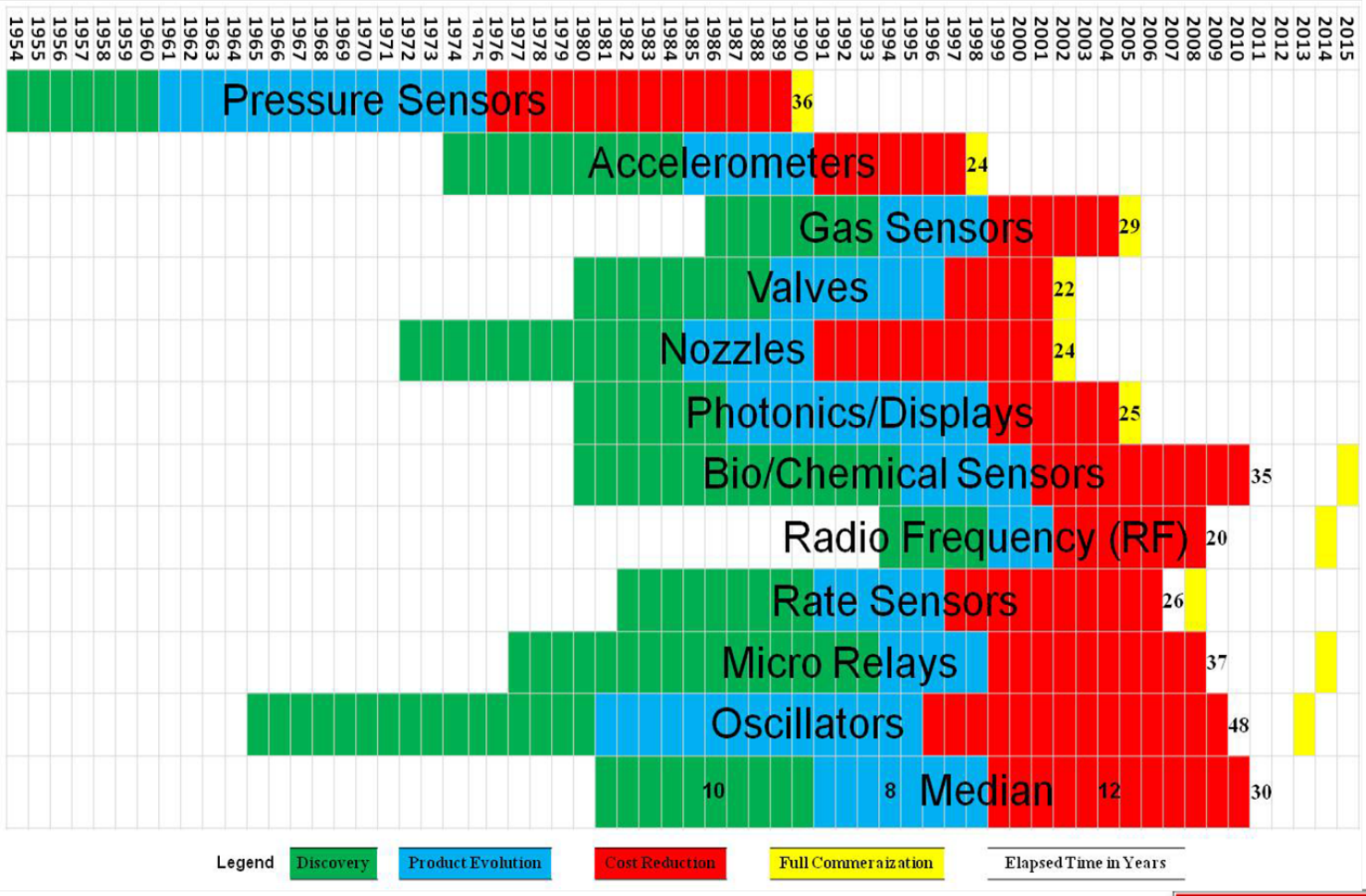
MEMS COMMERCIALIZATION TIMETABLE



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MBSS SUPPLIER / USER BENEFITS

- User
  - Faster time -to- market solutions
  - System engineering left to the “experts”…ability to focus on core competencies
  - Lower cost approach (more than likely)

- Supplier
  - Ability to achieve enhanced product differentiation
  - Greatly enhanced profit margin over providing just commodity devices
  - Mature technologies / commodities / readily available from multiple suppliers provide low risk selection and implementation of solution

TRILLION SENSORS INITIATIVE

- Created by MEMS guru and pioneer Dr. Janusz Bryzek in 2013
- Objective is to create ROADMAP to facilitate the commercialization of technologies and applications that will propel the sensors market to one trillion units by 2020
- Focus is on sensor-enabled applications that address the issues of quality of life: food, water, environment, healthcare, energy, safety
- Driven by the recent bestseller book by Peter Diamantis…
- Trillion Sensors Summit conferences
  - Stanford October 2013
  - Tokyo March 2013
  - Munich Sept 2014
  - San Diego November 2014
  - Orlando December 7-11,2015
  - PRESENTLY SOLICITING INDIVIDUALS TO PARTICIPATE IN THE ROADMAP DEVELOPMENT
- The “built environment” is a critical element and chapter in the roadmap

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DRIVERS FOR ADOPTION OF MBSS / BUILT INFRASTRUCTURE

- The Built Infrastructure is a key constituent of the Internet of Things (IoT) movement
- Smart Transport
  - Reduction in street and highway road congestion
  - Facilitate parking space selection
  - Reduce vehicle emissions and fuel consumption
  - Reduce accidents for motorists / pedestrians /bicyclists
  - Supports future use of autonomous vehicles
  - Highway system road and bridges aging…safety issues
- Smart Buildings
  - Reduction in carbon footprint / Increase in energy efficiency
  - Enhanced quality of building environment for occupants
  - Enhanced safety to cope with natural disasters…flood, fire, earthquake

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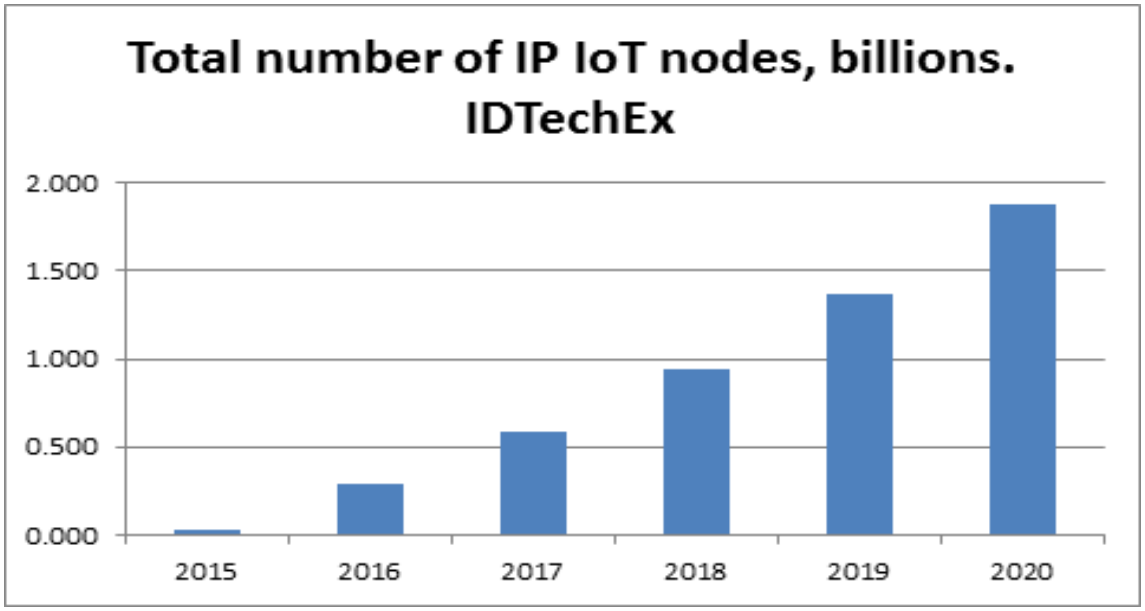
MARKET FOR IOT NODES



- Source: ID TechEx

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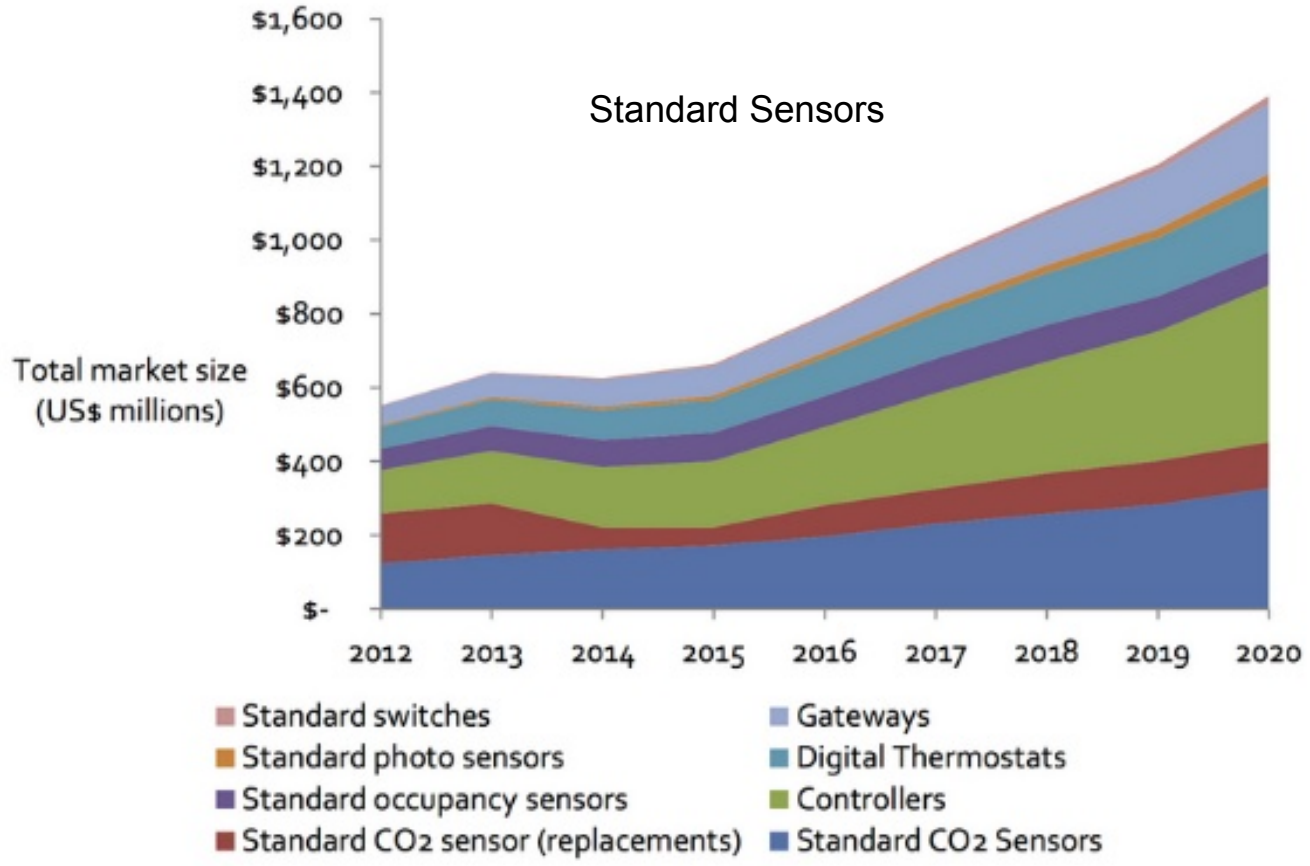

Source: Lux Research 2012

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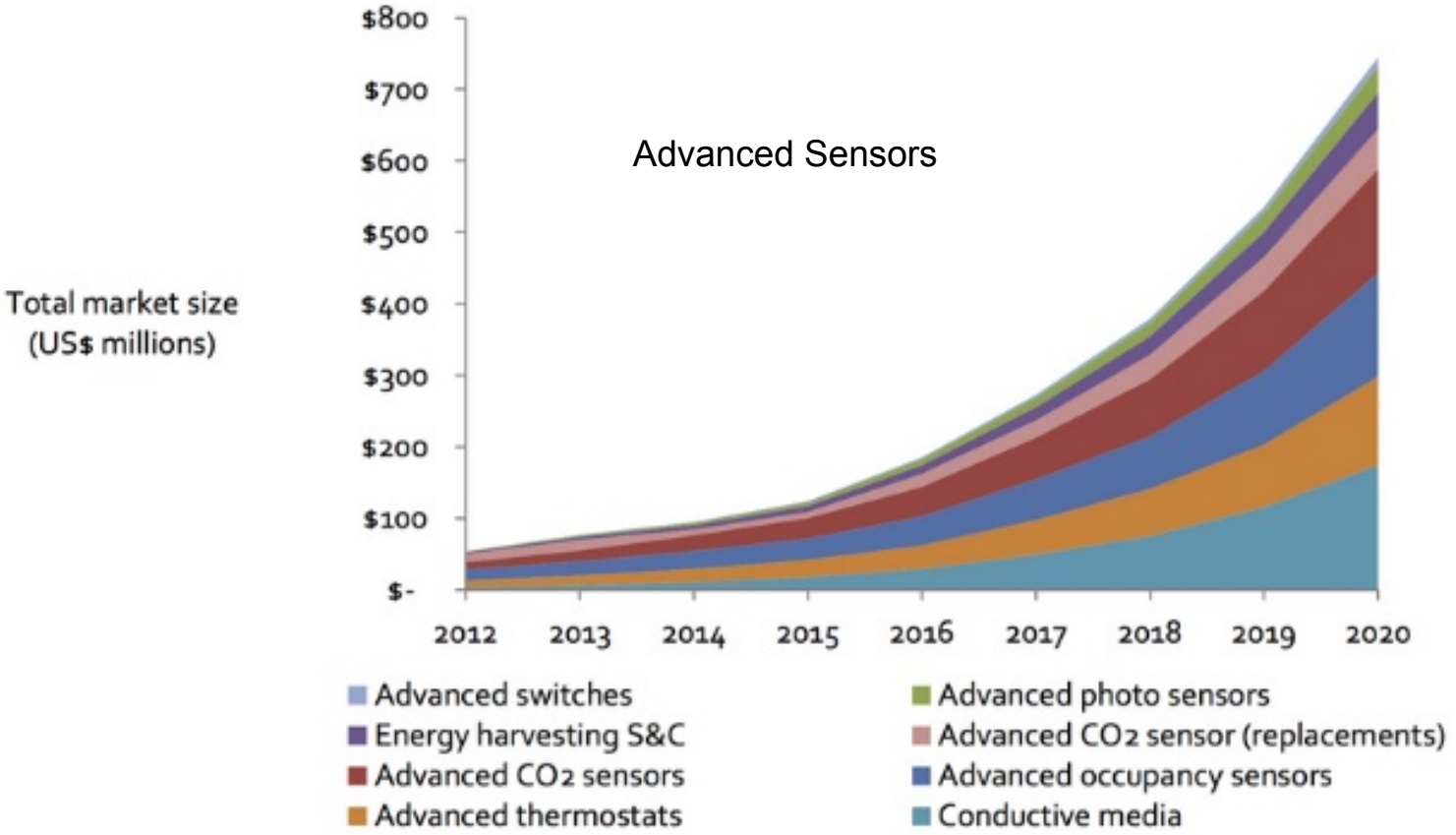
MARKET FOR SMART BUILDINGS SENSORS



Source: Lux Research 2012

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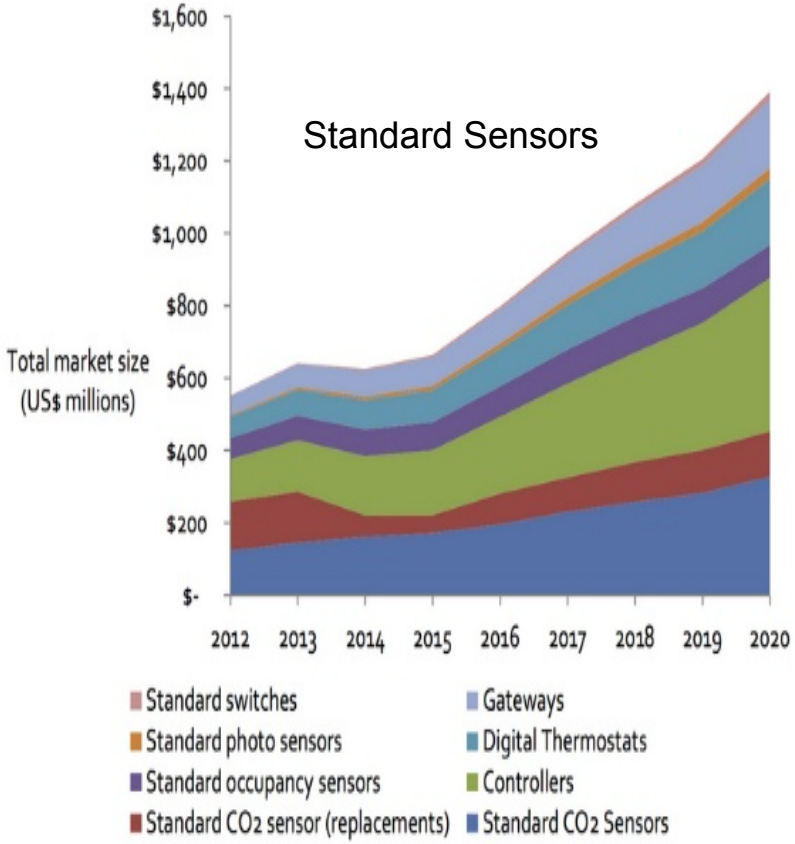
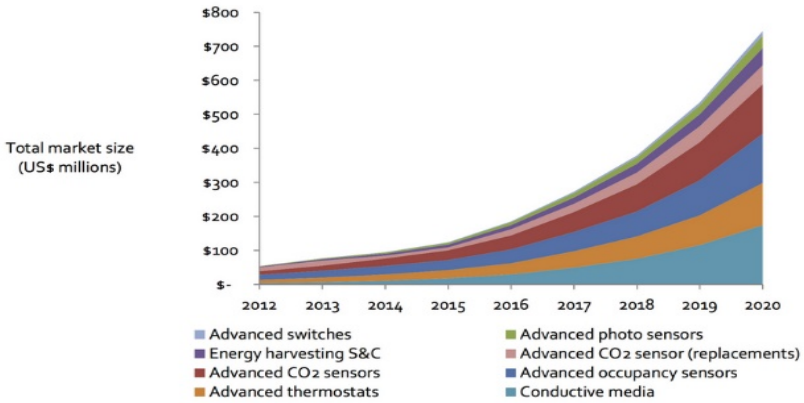
MARKET FOR SMART BUILDINGS SENSORS

Standard Sensors



Advanced Sensors



Source: Lux Research 2012

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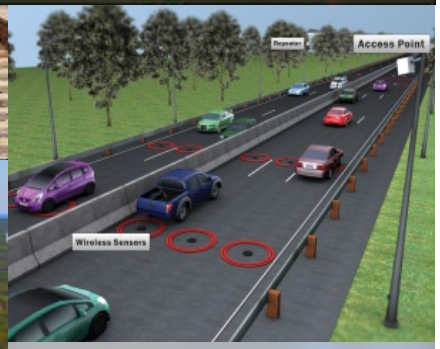
SMART TRANSPORT

- Defined as:
  - Roads
  - Bridges
  - Tunnels
  - Train tracks
  - Canals / locks
  - Levees



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US HIGHWAY SYSTEM / SITUATIONAL ANALYSIS

- Major construction of highway roads and bridges constructed during the 1950's to 1970's as part of the interstate highway system
- Many have exceeded their design life expectancy and are still in use
- Local, state and federal agency funding have been limited to support adequate maintenance and repair
- Recent study…Federal National Bridge Inventory…showed that out of 607,380 bridges:
  - 65,605 were classified as "structurally deficient" (note 1)
  - 20,808 were classified as "fracture critical" (note 2)
  - 7,795 were classified as both

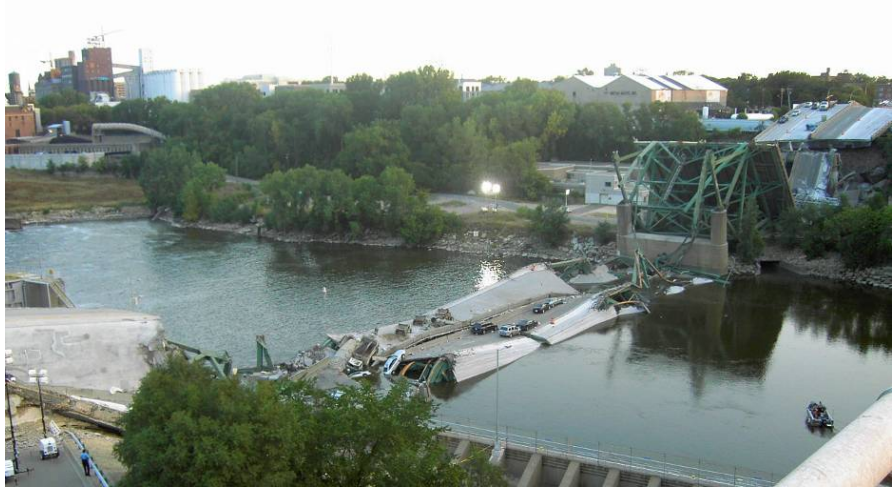
Note 1:a bridge is defined as "structurally deficient" when it is in need of rehabilitation or replacement because at least one of its major components of the span has advanced deterioration or other problems that lead inspectors to deem its condition poor or worse

Note 2: a bridge is considered "fracture critical" when it does not have redundant protections and is at risk of collapse if a single, vital component fails

SENSORS FOR SMART TRANSPORT

- Roads
  - Vibration…accelerometers
  - Presence…optical, magnetic, microwave
  - Light level…optical
- Bridges / Tunnels
  - Vibration…accelerometers
  - Force…strain
  - Wind velocity / direction…anemometer
  - Metal corrosion…chemical sensor
  - Light level…optical

AGEING US BRIDGE INFRASTRUCTURE



Collapsed I-35W Mississippi River bridge

Fracture in a gusset plate

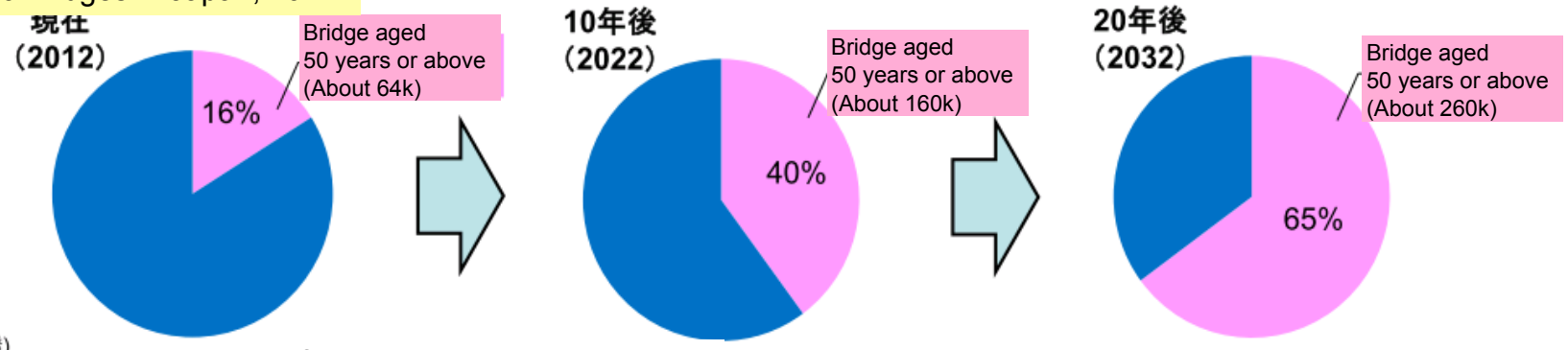
(http://en.wikipedia.org/wiki/I-35W_bridge_collapse)

Courtesy: S. Kamanaga

AGEING BRIDGE INFRASTRUCTURE IN JAPAN

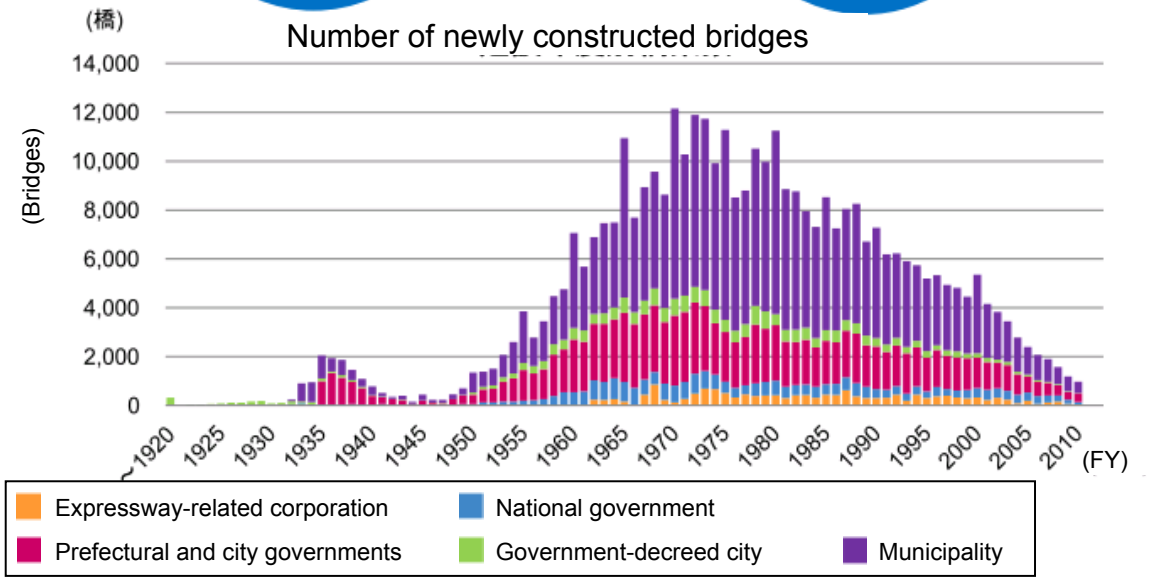
Present

700,000 Bridges in Japan, 2012



10 years later

20 years later



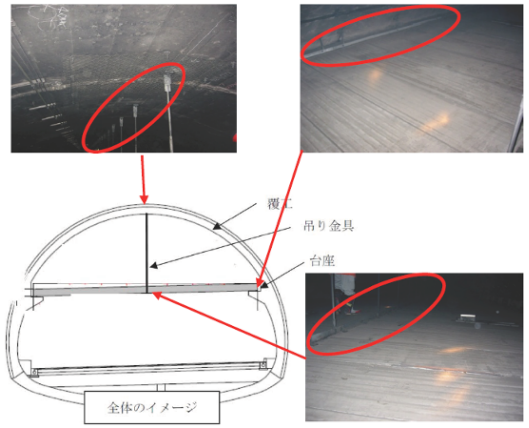
(Translated Source: http://www.mlit.go.jp/road/sisaku/yobohozen/yobo1_1.pdf)

Courtesy: S. Kaminaga

AGING INFRASTRUCTURE IN JAPAN

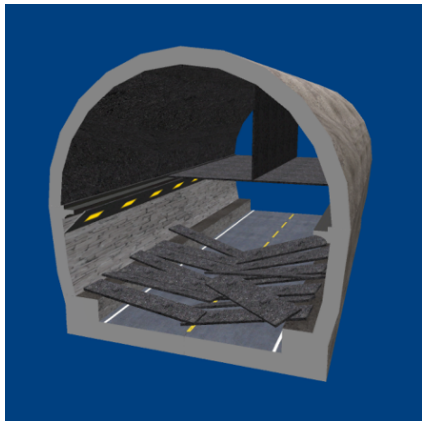
Collapsed Ceiling Panels at Sasago Tunnel, 2012

Ceiling panels of tunnel



Weak points of ceiling panel

After collapsed ceiling panels



Model showing collapsed ceiling panels

(Source: Report of MLIT; http://www.mlit.go.jp/road/road_tk1_000033.html)

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AGING BRIDGE INFRASTRUCTURE IN JAPAN

Stopped Ambulance car short of
Collapsed Narutaki Bridge in Kyoto by Typhoon in 2013

Courtesy: S. Kaminaga

(http://www.kyoto-np.co.jp/top/article/20130918000073/)

SMART BUILDINGS / SITUATIONAL ANALYSIS

- Definition: buildings empowered by information and communication technologies in the context of the merging Ubiquitous Computing and the Internet of Things: the generalization in incrementing buildings with sensors, actuators, micro-chips, micro and nano-embedded systems will allow to collect, filter, and produce more and more information locally, to be further consolidated and managed globally according to business functions and services. (Source: European Commission)
- US Census has reported over 160 million households
- Globally 1.7 billion households
- In additional, there are tens of millions of commercial buildings
- Most of these buildings need to provide heating and cooling to its occupants

SENSORS FOR SMART BUILDINGS

- Energy management parameters
  - Temperature
  - Air flow
  - Presence / motion
- Building occupant comfort parameters
  - Temperature
  - Presence / motion
  - Humidity
  - Light level
  - Air quality
  - Air flow
- Security / Safety parameters
  - Presence / motion /vibration
  - Temperature
  - Smoke

BUSINESS CASE

- Many MEMS/MST devices have become commoditized over the past couple of years…accelerometers, microphones, pressure sensors
- Smart Systems Solutions offers a “way out” of this fighting for market share and continuously declining prices and gross margin
- Value added to the basic front end vis-à-vis intelligence/ communication/packaging is a solution

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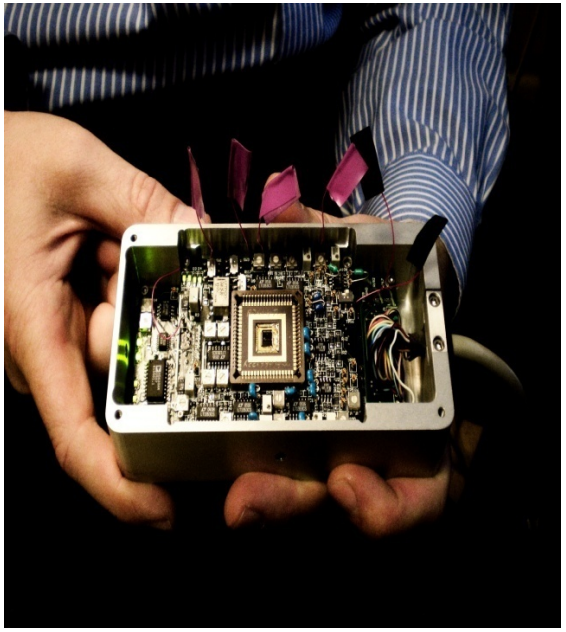
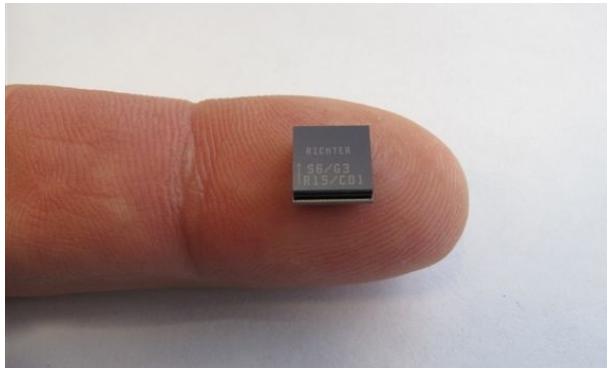
MEMS-BASED SEISMIC PLATFORM

- Supplier: HP, California / Oregon ,US
- In-house design of high performance two-axis accelerometer, battery, power management chip, microcontroller, memory, wireless chip, housing/package…"measurement engine"
- Key specs:
  - < 50 mw./axis power
  - < 100 ng /square root hertz
  - >130 dB dynamic range
  - 0-250 Hz BW
  - 7 mm. x 7 mm. die/package
- Current application massive distributed sensing array for land-based oil and gas exploration (Shell),future applications include structural and machine health condition monitoring





- Courtesy: Hewlett Packard Research

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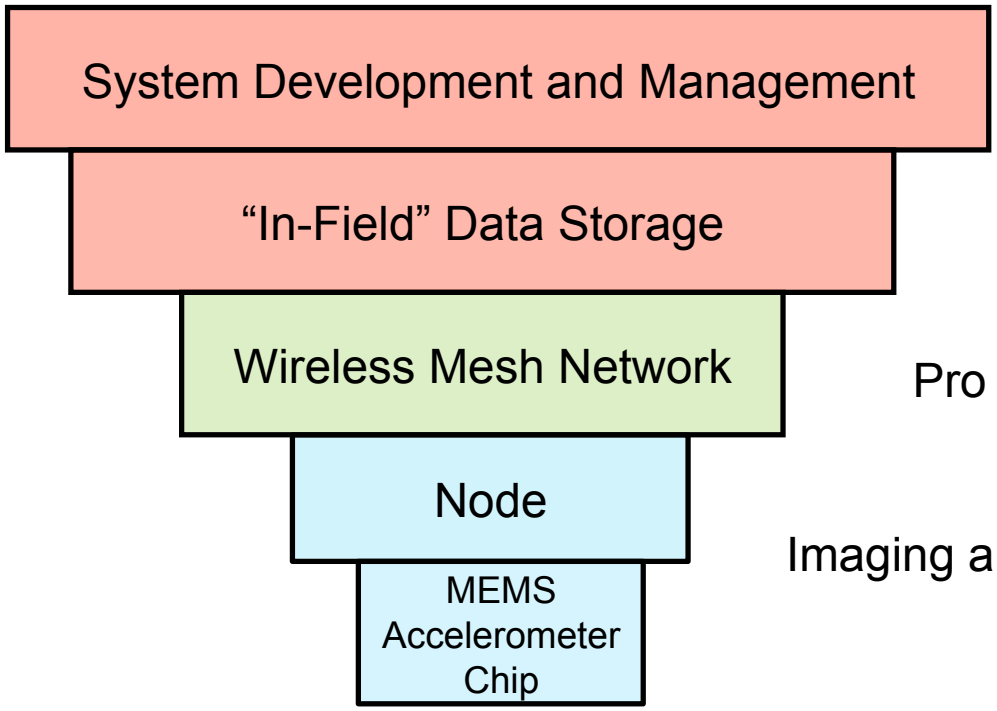
H.P. – SHELL OIL/GAS EXPLORATION



Enterprise Business

Pro curve

Imaging and Printing Group

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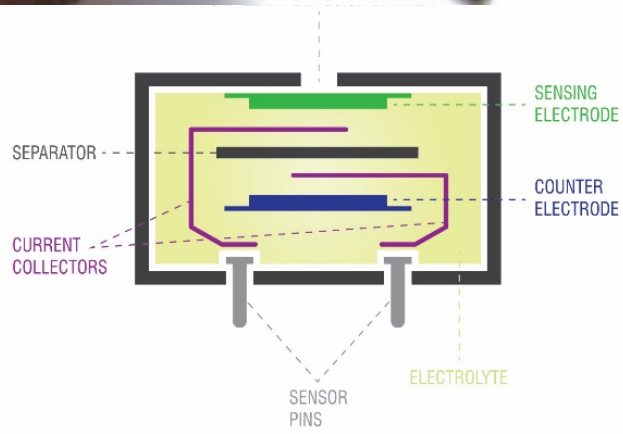
SPEC SENSORS

- Location: Hayward ,CA
- Parameter sensed: Gases-Alcohol, CO,Ozone,H2S,NO2,SO2,NO (one at a time)
- Technology: Electrochemical
- Construction: Screen printed/gas sensitive conductive ink, laminated plastic package top and bottom; connection vis-à-vis leads/ feedthroughs
- Size:15 x 15 x 3.5 mm (current)
  10 x 10 x 2.5 by end of 2015
- Introduction date: Late 2014
- Production status: Early production
- Applications: Environmental monitoring (inside/outside), breathalyzers
- Note: Printed/not flexible
- Outgrowth of NSF SBIR Phase One in 2009



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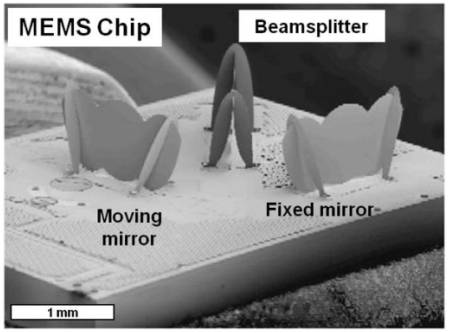
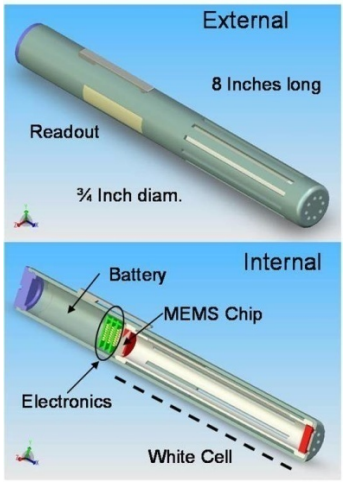
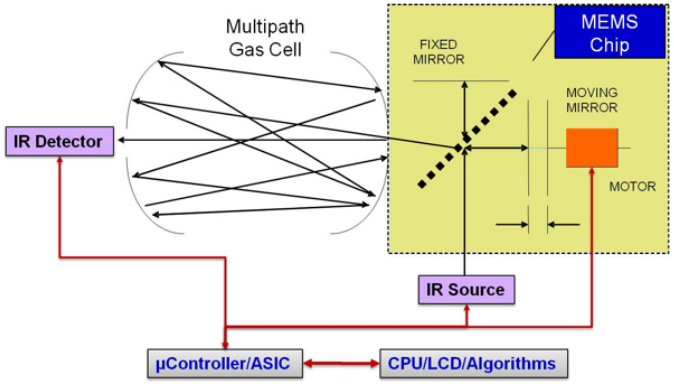
MEMS FTIR SPECTROMETER

- Supplier: Block Engineering / Marlborough, MA
- Miniature Fourier-Transform Infra Red Spectrometer..”Chem Pen”
- Uses Sandia National Labs SUMMiT V process for the MEMS
- Currently funded through DOD R $D…$6 M US
- Smart building application includes environmental monitoring: air quality smoke detection. Other applications include chemical warfare agent detection monitoring, hazardous materials analysis, food and water quality
- Courtesy: Block Engineering







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CASE STUDIES

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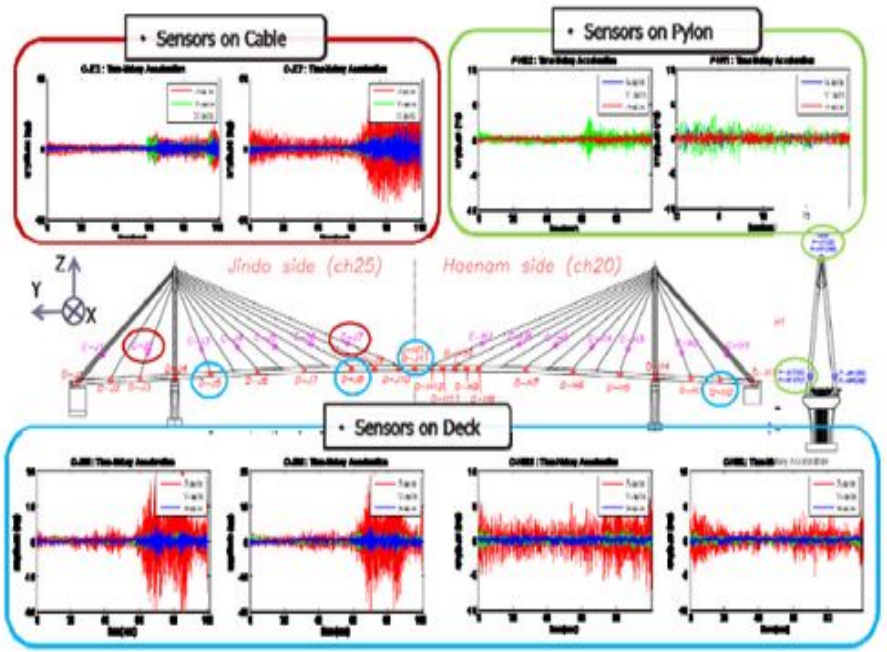
STRUCTURAL HEALTH MONITORING BRIDGE / JINDO ISLAND KOREA

- Investigator: University of Illinois, Urbana -Champagne (Prof. Bill Spencer), Seoul National Univ. and MEMSIC
- System operating 2009-2012
- World's largest application with 113 wireless nodes / 659 data channels
- Off –the-shelf sensors include: 3-axis accels., temperature, humidity, light, wind, speed/direction.
- MEMSIC Imote 3- wireless module for data intensive monitoring, high sample rates, high synchronization between nodes
- Objective: successfully validate models



- Courtesy: Univ. of Illinois Urbana Champagne

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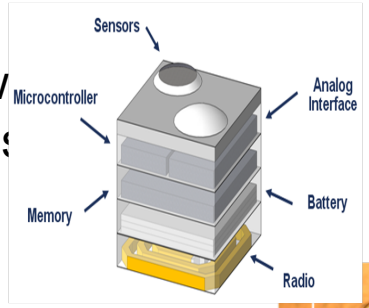
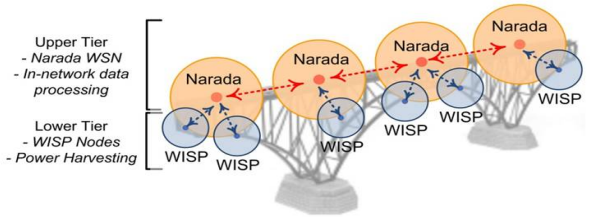
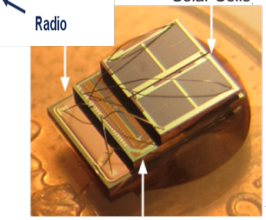
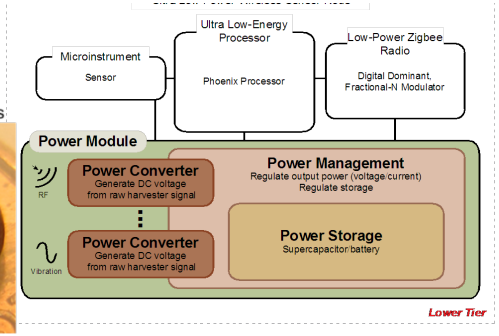
STRUCTURAL HEALTH MONITORING BRIDGE / MONROE MICHIGAN

- Investigator: Univ. of Michigan WIMSS (Prof. Gerry Lynch)
- Supported by US NIST for bridges and DOD for structural ship hull monitoring
- Current implementation uses off the shelf accelerometers and strain gages
- Research areas include chip stacking, energy harvester, low loss CMOS circuitry and wireless transmitters
- Courtesy: University of Michigan WIMSS









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STRUCTURAL HEALTH MONITORING BRIDGE / CARQUINEZ CALIFORNIA

- Investigator: University of Michigan / WIMSS-Prof. Jerry Lynch
- Customer: California Dept. of Transportation
- Installed in 2011
- 31 “Narata” wireless nodes with remote sensors including accelerometers, strain gages, temp., anemometer
- Solar panels/battery backup/storage

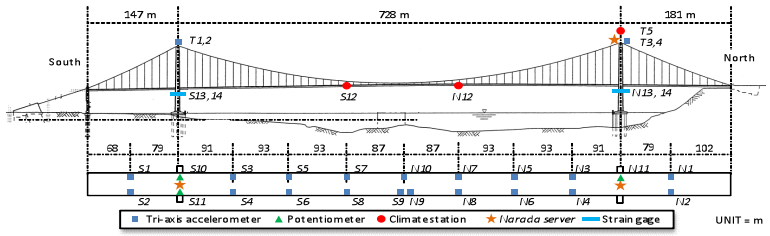
Project objective:

determine scalability of data management techniques

how to “harden” system elements for long term use

How to deploy cost-effective solutions

- Courtesy: University of Michigan WIMSS



Strain Gage Node

Accelerometer Node

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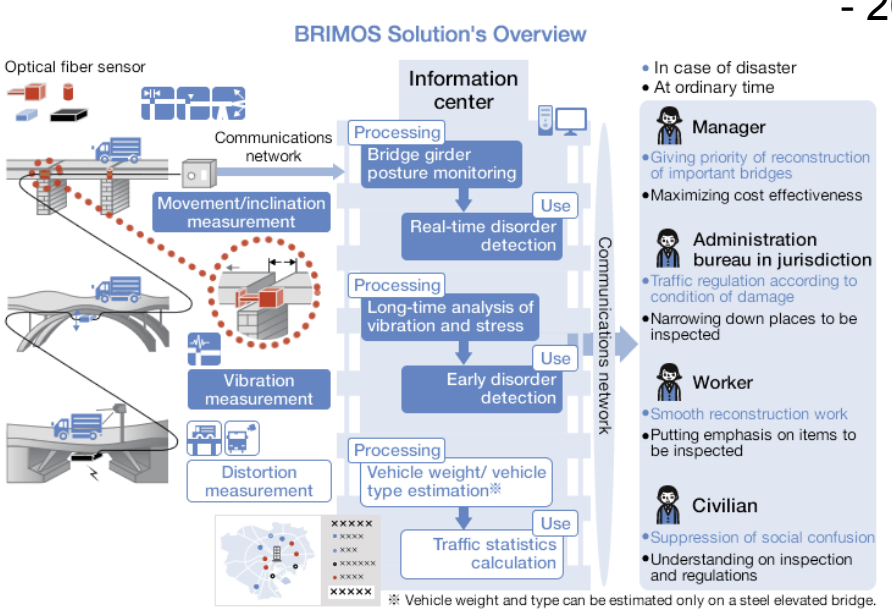
STRUCTURAL HEALTH MONITORING / BRIDGES

Key Project Experiences

- 2010: Chiangsu Interchange Bridge (China) (Pilot project)
- 2012: Tokyo Gate Bridge (Japan)
- 2012: Can Tho Bridge (Vietnam)



Tokyo Gate Bridge

NTT DATA

(http://www.nttdata.com/global/en/services/bds/case/casestudy-01.html)

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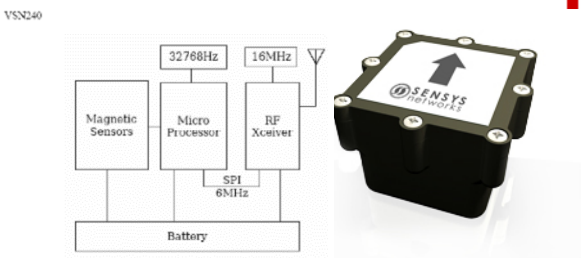
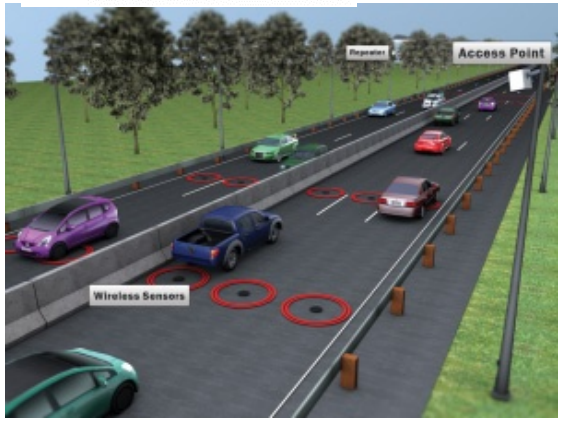
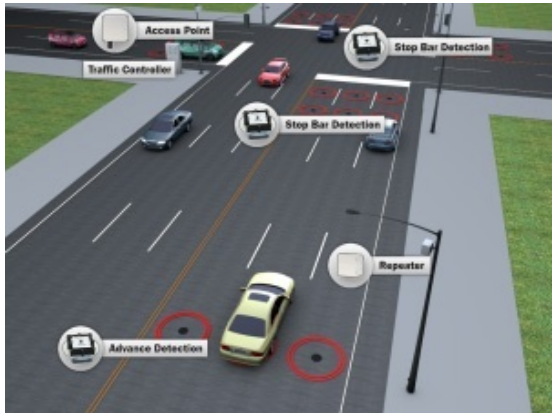
SMART ROADS

- Supplier: Sensys Networks, Berkeley CA
- 200,000 sensors installed to date (Washington DC, Modoc CA, St. Louis MO)
- “Hockey Puck” package (4 x 4 x 3 in.) embedded in the roadbed able to detect presence of vehicles…many benefits over conventional loop systems…especially cost
- Uses “off the shelf” magnetic sensors, high level of proprietary algorithms
- Currently developing module with high sensitivity accelerometers to measure vibration for vehicle determination
- Application for highway vehicle density, vehicle intersection monitoring and control
- In development of radar-based pedestrian / bicycle crosswalk monitor and control system (and parking status system







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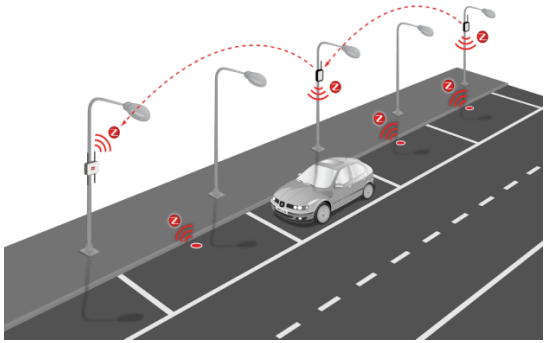
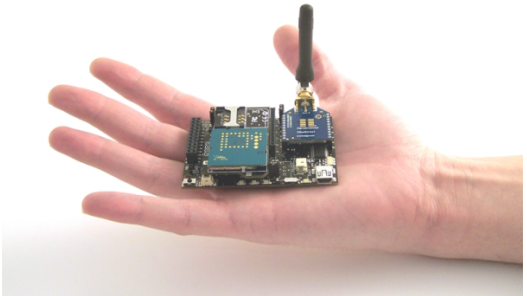
- Courtesy: Sensys Networks

SMART PARKING

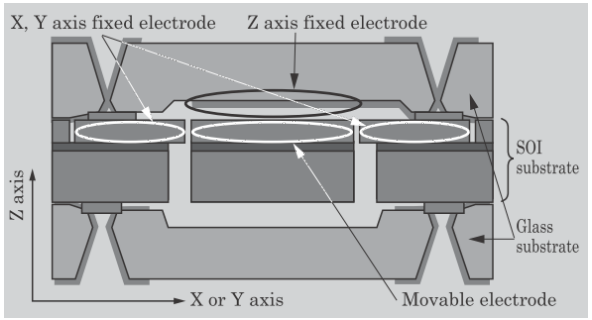
- Supplier: Libellium (Spain)
- Customer: EU / ST-7th. Framework Program
- "Smart Sandantar" installed in 2012 in Sandanter,Spain; results currently being evaluated for use in other European cities
- 1,000 nodes (Waspmote platform)- open source
  - 400 nodes for Smart Parking and traffic flow
  - 600 nodes for environmental monitoring of CO2 and NO2 levels
  - Luminosity sensors for street light control
  - Off- the- shelf qty. 3- one axis magnetometers, temp. sensor (for compensation), radio
  - Size = 12 cm., installed (road sensor)
  - Non-rechargeable battery…7-10 year life





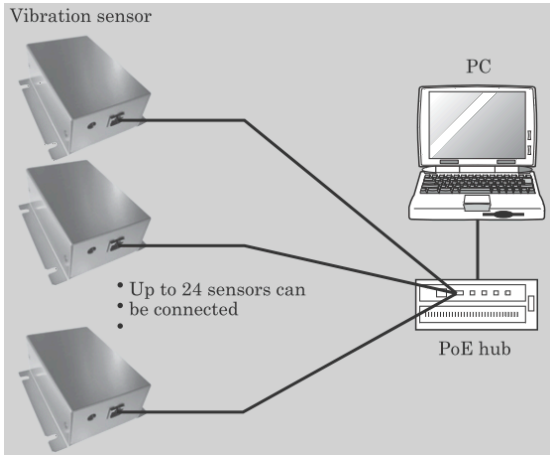
- Courtesy: Libellium

BUILDING EARTHQUAKE MONITORING / JAPAN



Cross-sectional schematic drawing of sensor device

Building with installed vibration sensors



Connection example of vibration sensor

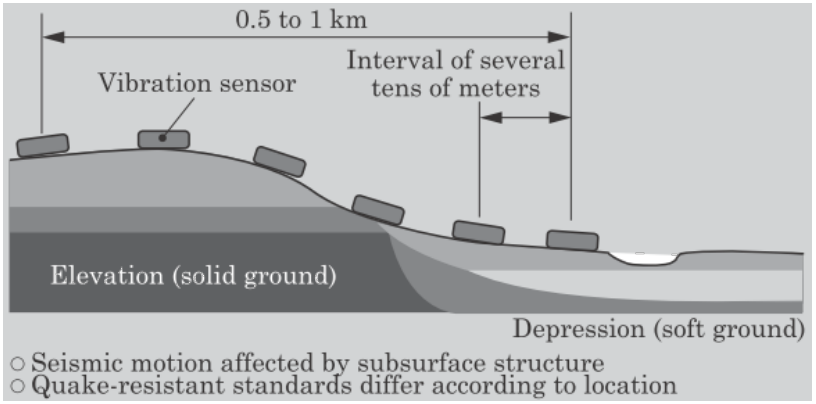


Illustration of ground measurement

(Source: S.Sakaue, al et., FUJI ELECTRIC REVIEW, Vol.58, No. 1, pp.32, 2012)

SMART BUILDINGS / SMART THERMOSTAT

- Supplier: Nest Laboratories / Palo Alto CA (acquired by Google for $3.2 Billion in 2013)
- Smart thermostat for residential application
- Multiple parameters sensed:
  - Near and far motion
  - Ambient light
  - Temperature
  - Humidity
- Wi-Fi enabled
- Self-programs to the usage of the home by its residents behavior vis-à-vis algorithms
- Reduces the cost of heating / cooling
- MSRP: $249.00
- Courtesy: Nest Laboratories

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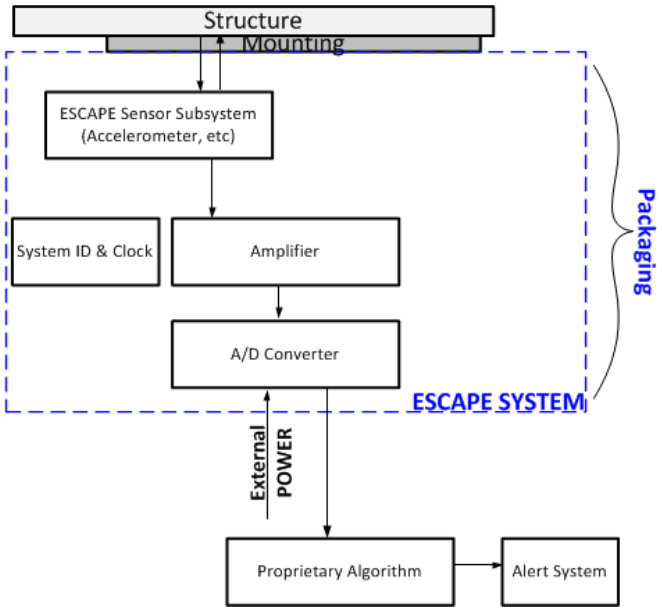
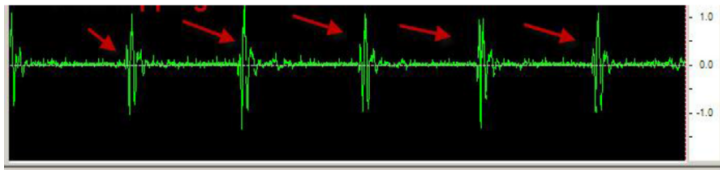
“ESCAPE” SYSTEM FOR FIRST RESPONDERS

- Supplier: Innoveering-headquarters at the Morrelly Center (Applied Science Foundation for Homeland Security) in Long Island, New York
- “ESCAPE”: Enhanced Structural Collapse Awareness and Prediction Equipment- integrates CSOTA vibrational sensing technology, coupled with miniature electronics and team’s robust algorithm.
- Building/structural collapses are the fourth leading cause of firefighter fatalities. What is urgently needed is an alert system that reliably informs the battalion chief of building health & imminent building structurally collapse.
- Teamed with leading experts in structural health monitoring and algorithm development.
- Access to first responders (former NYFD), ATF, FBI, NY MTA, TSA & training facilities for eventual field testing.
- Status: currently conducting bench-top tests of it’s GEN1 system with partial integration of an advanced signal processing algorithm.
- Courtesy: Innoveering



Acceleration Signal Input to ESCAPE Algorithm



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CRITICAL SUCCESS FACTORS / CHALLENGES

- Smart Transport
  - Ability to determine which bridges and roads need repair and when
  - Determination of optimum deployment scenarios…placement / number deployed
  - Who will fund the efforts?
  - When will the funds be made available?
  - Ability to justify the cost of installation of smart roads vs. user benefits to government agencies
  - Availability of low cost / durable packaging
  - Availability of extended usage power sources (energy harvesters?)
  - Data sampling and data acquisition strategies for optimum performance

- Smart Buildings
  - Determination of optimum deployment scenarios…placement / number deployed
  - Ability to justify the cost of installation versus payback vis-à-vis breakeven analysis
  - Ability to demonstrate solution benefits to the lessees and owners
  - Availability of low cost / durable packaging
  - Availability of extended uage power sources (energy harvesters?)

SUMMARY AND CONCLUSIONS

- The built infrastructure of “smart transport” and “smart buildings” offer a wide spectrum of application opportunities for Trillion Sensors realization
- There are many compelling financial and quality of life reasons for the adoption of “smart transport” and “smart buildings”
- Trillion Sensors realization will be driven by a proliferation of the “systems solutions” approach (including multiple front end sensor designs) in the immediate future since they bring numerous benefits to their users and suppliers including:
  - faster time to market
  - providing the suppliers with extended leverage of their technology, higher product differentiation and maximum price / performance
  - Smaller, more robust solutions
- We have provided vis-à-vis case studies of some early examples of successful implementations of “smart” transport and “smart” buildings
- The commoditization of MEMS e.g. inertial and pressure sensors has enabled system solutions in a variety of high volume consumer products paving the way for creation of solutions for “smart” transport and “smart” building applications
- Smart Infrastructure is an important and integral part of the Internet of Things (IoT) movement

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- Sensys Networks
- Nest
- Libellium
- Block Engineering
- S. Kamanaga
- Innoveering
- J. Bryzek

UPCOMMING EVENTS OF INTEREST

• Sensors Expo**	June 9-11, 2015	Long Beach, CA
• IWLPC**	October 13-15, 2015	San Jose, CA
• MIG Exec. Congress*	November 4-6, 2015	Napa Valley, CA
• Global Sensors Summit**	November 10-11, 2015	La Jolla, CA
• Printed Electronics**	November 18-19, 2015	Santa Clara, CA
• T Sensors Summit*	December 7-11	Orlando, FL
• FLEX 2016**	February, 2016	Phoenix, AZ

*Roger Grace in attendance

**Roger Grace to present

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