HETEROGENEOUS INTEGRATION ROADMAP

2019 Edition

Chapter 11: MEMS and Sensor Integration

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Chapter 11: MEMS and Sensor Integration

This chapter is in preparation, and will be integrated into the Roadmap at Version 1.1, planned for the end of 2019. In its place is the following summary and a series of slides giving the current status of MEMS and sensors integration and some information that is relevant to the progress needed over the next 10 to 15 years.

Executive Summary

Traditionally, the challenges in the semiconductor packaging industry have been driven by the quest for continued miniaturization which enables faster, smaller, and more cost-effective devices. This has been fueled by continued shrinking of physical geometry of silicon processes primarily in the digital domain, and secondarily in the mixed-signal domain. Unlike electronics signal processing, sensors are unique in their manufacturing processes. Sensors are discrete devices that primarily perform one function of sensing and/or conversion to analog electronic signal. The analog world around us consists of varied types of phenomena and elements such as motion, sound, magnetic fields, light, liquid, gas, materials, and more. Accordingly, there are multiple different types of sensing devices that industry continues to develop depending upon what phenomena is being sensed.

The major challenge in developing a MEMS and Sensors Integration roadmap is that it can include any future electronics device that can sense and convert to an electronic signal. The potential for developing discrete sensors is infinitely varied and diverse. It is a challenge to predict sensor packaging approaches that can be designed, or how these devices operate as discrete devices and can be integrated with other electronics functions in the signal chain. Packaging of sensor devices brings unique challenges in that sensing elements are required to interact with the outside real world. This task is further compounded by the fact that each application may have difference operational environments and performance requirements. For example, when it comes to the operational environment, inertial MEMS sensors must be mounted on the moving element of the system, which is quite different than a gas sensor where packaging must have a physical opening for gas to interact with the sensing element. Furthermore, if we only consider inertial MEMS-based sensors, using them in an automotive application requires high reliability, repeatability, and long life; using them in a consumer hand-held application requires lower power and higher mechanical reliability challenges and relatively lower thermal challenges at a lower cost, with a short life-cycle.

The working group is focusing the discussion on MEMS-based inertial sensors. The following presentation slides show how this TWG is defining the issues for heterogeneously integrating MEMS-based sensors to other parts of the signal processing value chain as applied to Automotive, Avionics, Handheld/Mobile/Consumer, and Medical Healthcare applications. It discusses current-state-of-art in integrating discrete MEMS sensors. It establishes background to continue expanding the scope of the roadmap efforts by adding other sensor types, and continue the visioning process for potential solutions.

Heterogeneous Integration Roadmap

HETEROGENEOUS INTEGRATION ROADMAP

MEMS and Sensor Integration

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MEMS and Sensors Integration

- Objective : Document what needs to happen in sensor packaging to enable Heterogeneous Integration
- Specific goals of this TWG
  - Defined the scope, focusing on inertial sensors in this iteration
  - Identify challenges for the path to heterogeneous integration (application driven/commonality)
  - Identify potential paths in the next 5, 10, and 15 year horizons

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Commonality of Signal Chain

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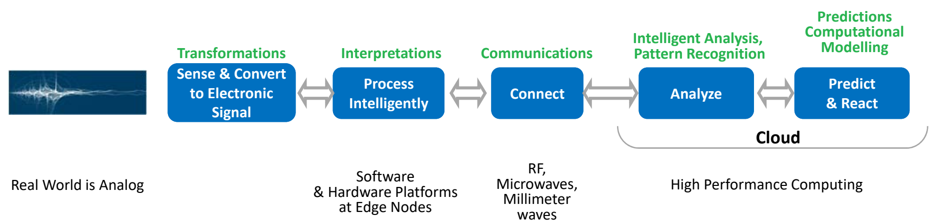
- Across any application domain, the basic signal chain from real world-to-cloud remains (more or less) common
- Sensors interact with the real (analog) world



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Defining Scope for TWG

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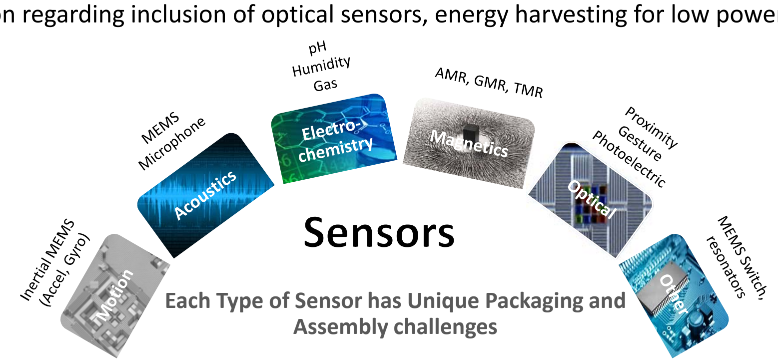
- Real (analog) world requires different sensing modes. Each sensing mode has a different set of requirements and approaches
- TWG focus was initially narrowed to Inertial MEMS (to be expand in later editions). Ongoing discussion regarding inclusion of optical sensors, energy harvesting for low power, and types sensors.



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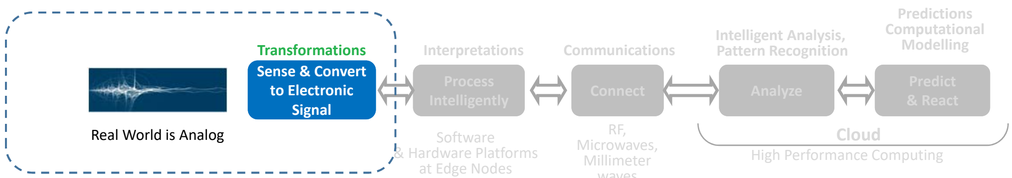
Current State of the Art – Signal Chain Viewpoint



All Inertial MEMS have sensors and an ASIC (for digitization of signals) combined into a single package.

Packaging approach is to use mature plastic package based on organic substrates + putting multiple chips together

General trend for sensors hubs is to achieve increased level of functional integration for system-level performance improvement and cost.
E.g., inertial sensor combos (6 to 9 DoF); IoT sensors nodes

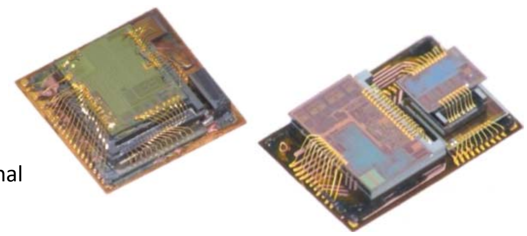


Image Sources for deconstructed packages: SYSTEMPlus Consulting

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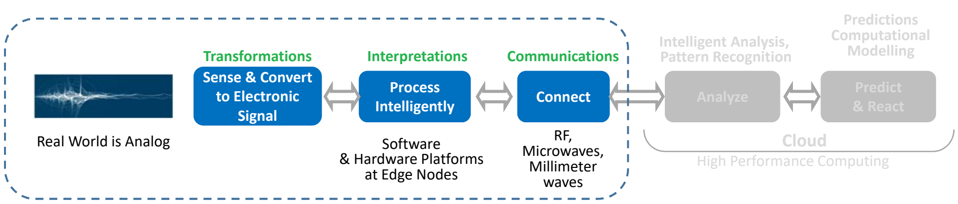
Integration Upward on Signal Chain



- Go beyond standalone component-level integration (e.g. combo sensors)
- Integration of components that are not from the same silicon processes
  - Inertial MEMS sensors have their own micro-fabrication technology (including capping process)
  - Micro-processors use digital silicon processes
  - Most of the RF roadmap is towards GaAs/GaN/SiC processes
  - Needs for integration of passives, antenna, power sources, etc, in the same advanced integrated packages
- Challenge: How to integrate these up the signal chain?

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Relative Performance Specifications

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- Industrial and Avionics applications require order of magnitude increase in performance
  - Individual 6 DOF may not be good enough
- Heterogeneous integration provides this solution
  - Near-term: multiple 6 DOF implementation combined with µ-processor and algorithms.
  - 5+ years: Combos with up to 10 DOF (accelerometer, magnetometer, gyroscope, and pressure)

Metric	Typical Consumer	Typical Industrial	Typical Navigation /Avionics
Gyroscopes			
Noise Density (°/sec/√Hz)	0.02	0.004	< 0.004
Ang. Random Walk (°/√Hz)	TBD	0.2	TBD
In-run stability (°/hr)	>15	< 6	< 1
Bias repeatability (°/sec)	> 6	0.2	< 0.2
Accelerometers			
Dynamic Range (g)	< 4	> 40	> 12
Noise Density (µg/√Hz)	250	25	TBD
Vel. random walk (m/s/√Hz)	> 3	0.03	TBD
In-run stability (µg)	100	10	< 10
Bias repeatability (mg)	> 1000 X	25	
Power	Battery Operated, Ultra-Low power is must	Low power	Nice to have low power

Reference: multiple sources, to be referenced in manuscript

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End Applications Drive Different Integration Paths

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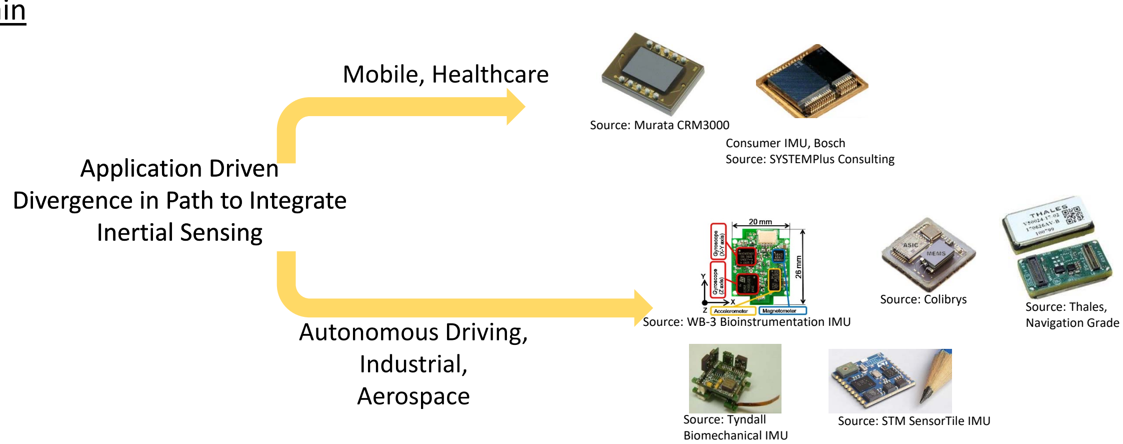
- Diverging paths to integrate Inertial MEMS sensors with <u>other components of the signal chain</u>



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To Enable Heterogeneous Integration

- **Challenge # 1:** Performance roadmaps for sensors diverge based on end applications
  - Sensor specifications: Full scale range, Sensitivity, Offsets, Noise, Power consumption
  - How much intelligence to build in (µProcessor) and what/how to transmit (RF)?
  - Signal Integrity: RF and Sensor coupling effects, shielding
  - Materials: tradeoffs for sensor stress sensitivity vs. RF
  - MEMS sensor testing: test costs for inertial sensors are quite high (e.g. up to 50% at packaged level)
  - Standardization: components are closer to standardization, how can this be applied to integrated solution?
- **Challenges # 2:** MEMS/Digital/RF silicon processes can be combined heterogeneously
  - Design tools to enable heterogeneous design process
  - What are potential design architectures for integrating complex functions (e.g. sensors fusion)?
- **Challenge # 3:** Can platform commonality be designed across signal chain?

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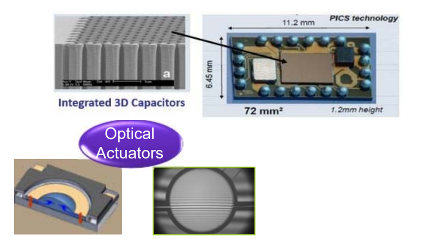
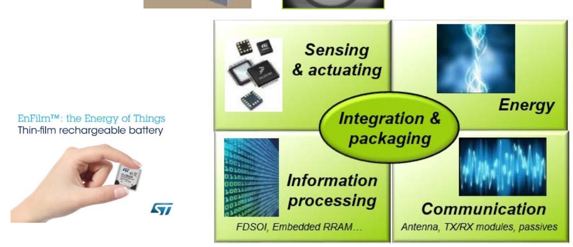
Increasing integration

- RF functions within miniaturized components footprint
  - Integrating TX/RX function, digital to analog conversion, PA and antenna.
  - Integrating high quality passive devices in close proximity to active sensors and ASICs.
- Integrating advanced materials
  - piezo electric materials for actuating (PZT, AlN, electroactive polymers)
  - Getter materials
- Integrating energy functions in package:
  - Storage: solid thin film µbatteries
  - Energy harvesting sensors/systems





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Automotive/UAVs

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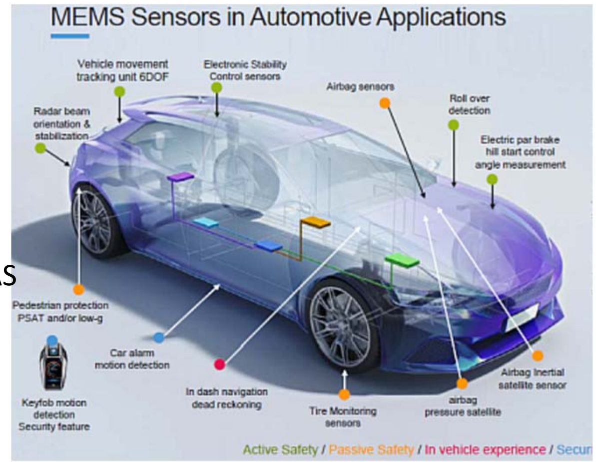
- Maturing standalone MEMS sensors
  - Airbag
  - Rollover detection
  - Stability control
- These mature solution are within vehicle, do not communicate outside
- Emerging uses for autonomous driving & ADAS
  - Vehicle tracking 6-DOF IMUs
  - Dead reckoning for navigation
  - Audio noise cancellation



Source: Steve Taranovich, EDN. Image referenced to NXP

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MEMS Sensors in Healthcare *(see chapter 4)*

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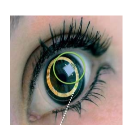
Proliferation of MEMS sensors is a tremendous opportunity for implantable medical devices

- Invasive devices
  - Implantable in the heart, the eye, the ear, an artery, a muscle, a bone, a nerve
  - Diagnostic; Improve therapy
  - Sensor, stimulate, ablation, drug delivery
- Health & Well-Being
  - Skin patch
  - Monitoring: ECG (Cardiac), pulse-oximetry, glucose, dehydratation, activity
  - Sweat sensing and analysis
- Key Drivers:
  - Regulations
  - Miniaturization, lower cost, reliability, ultra-low power
  - µ-Processor and RF integration
- Challenges ahead
  - Hermeticity, sterilization, biocompatibility
  - Time to market

X2 Patch Concussion Monitoring



MEMS Strain Gauge Intraocular Press Sensor

https://news.illinois.edu/view/6367/233722

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Navigation: Avionics/Aircraft/UAVs *(see chapter 6)*

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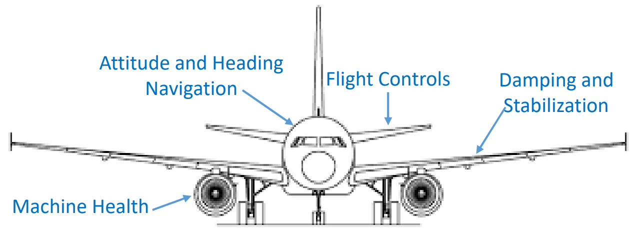
- Key Drivers:
  - Size and Weight Reduction
  - Reduced complexity
- What needs to happen?
  - MEMS-based system performance targets



- Heterogeneous integration enables reduction in complexity, size, and weight
  - Need for design architecture on how to optimally combine sensor + µ-Processor + transmission

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Applications & Packaging (1/2)

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	Current State-of-Art		5 to 10 years	
	Application Areas	**Packaging**	**Application Areas**	**Packaging**
Mobile / Consumer	• Tilt • Navigation • Gaming	• Traditional low density LGA • Thick sensors	• Tilt • Navigation • Gaming	• Size reduction, WLCSP • Thin sensors • Integration with µProcessor • EMI shielding
Automotive	• Air bag crash sensors • Rollover • Stability control	• Traditional large body SOIC / LFCSPs	• Navigation grade IMUs • ADAS • Audio noise cancellation	• SiP based modules • Substrate technology • Integration of µProcessor for intelligent processing • Integration of RF for communication

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Applications & Packaging (2/2)

	Current State-of-Art		5 to 10 years	
	Application Areas	Packaging	Application Areas	Packaging
Medical & Health	Not pervasive	Traditional plastic on rigid organic substrates	• Implantable • Concussion monitoring • Vital Signs monitoring • Telemetry	• Flexible substrates • Thin profiles, WLCSP
Aerospace & Defense	Not pervasive	• FOG and/or RLG • Traditional ceramic substrate based modules	Machine Health Attitude & Heading Navigation Stability	• SiP based modules • Substrate technology • Integration of µProcessor for intelligent processing • Integration of RF for communication

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In Summary…

- Heterogeneous Integration in MEMS and Sensors is not a function of scaling or miniaturization
- MEMS and sensors are evolving towards complex micro-systems that are self-contained hubs and nodes.
  - Sensors no longer expected to operate as standalone devices, but must work by integrating up the signal chain to include intelligent processing (µ-processing) and transmission (RF chips)
- Each application has varying drivers, but commonality are:
  - Low power
  - Reducing system complexity
  - Resolution, repeatability, reliability

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