Autonomous Vehicles: Successfully Integrating New Chips, Packages, & Modules

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22AUG16

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SCOPE

With autonomous vehicles currently being developed and prototyped, the requirements of miniaturization, higher functionality, size/weight, and high reliability cannot be compromised.

This workshop will focus on electrical, mechanical, and electro-optical aspects that define autonomous vehicle's electronic products success.

Key Takeaways:

- To provide an awareness of the specific chips, sensors, and modules in Autonomous Vehicles
- What are metrics for navigating the electronics miniaturization landscape (conversion costs, pros/cons, density vs. performance)?
- How will high-speed communications and other autonomous features be enabled?

OUTLINE

- **IC, MEMS, & Sensors Packaging in Autonomous Vehicles**
  - Chip/Package/Module Co-design
  - Miniaturization principles
  - Design for Manufacturability
- **High-speed communications enablers**
  - High bandwidth wireless
  - 2.5D & 3D package integration
  - Inclusion of advanced package technologies (e.g., Si photonic and glass technologies)
- **High-reliability requirements**
  - High power devices and packages
  - Package substrates, interconnections, & encapsulants
  - Reliability mechanisms
- **Unique packaging elements in Autonomous Vehicles**
  - LIDAR, radar, and camera packaging and systems

AUTOMOTIVE SENSORS OBSERVATIONS

"Just three types of MEMS devices used in the automotive industry account for more than **95 percent of market value**: **pressure sensors**, **accelerometers** and **gyroscopes**"

-- Richard Dixon, principal analyst, automotive sensors, IHS Markit

Source: "Automotive MEMS Sensor Unit-Shipments Rose in 2015, Even as Revenue Stalled," http://press.ihs.com/press-release/technology/automotive-mems-sensor-unit-shipments-rose-2015-even-revenue-stalled

"The auto industry is poised for more change in the **next five to ten years** than it's seen in the past 50."

-- Mary Barra, General Motors CEO

Source: Speech at The Code Conference, May 2015 – http://www.mobileworldlive.com/apple-says-car-ultimate-mobile-device

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OUTLINE

- Introduction
- IC, MEMS, & Sensors Packaging in Autonomous Vehicles
- High-Speed Communications Enablers
- High-Reliability Requirements
- Unique Packaging Elements in Autonomous Vehicles
- Summary

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WHERE SHOULD WE START?

REVOLUTIONS IN AUTOMOTIVE INDUSTRY

Electrical Vehicles (EVs)

Autonomous Driving (AD)

Car-sharing movement

REVOLUTION-AFFECTED INDUSTRIES

Vehicle manufacturing

Silicon Valley’s Internet business

Semiconductors

IMPORTANCE OF CHIPS IN AUTONOMOUS VEHICLES

80%

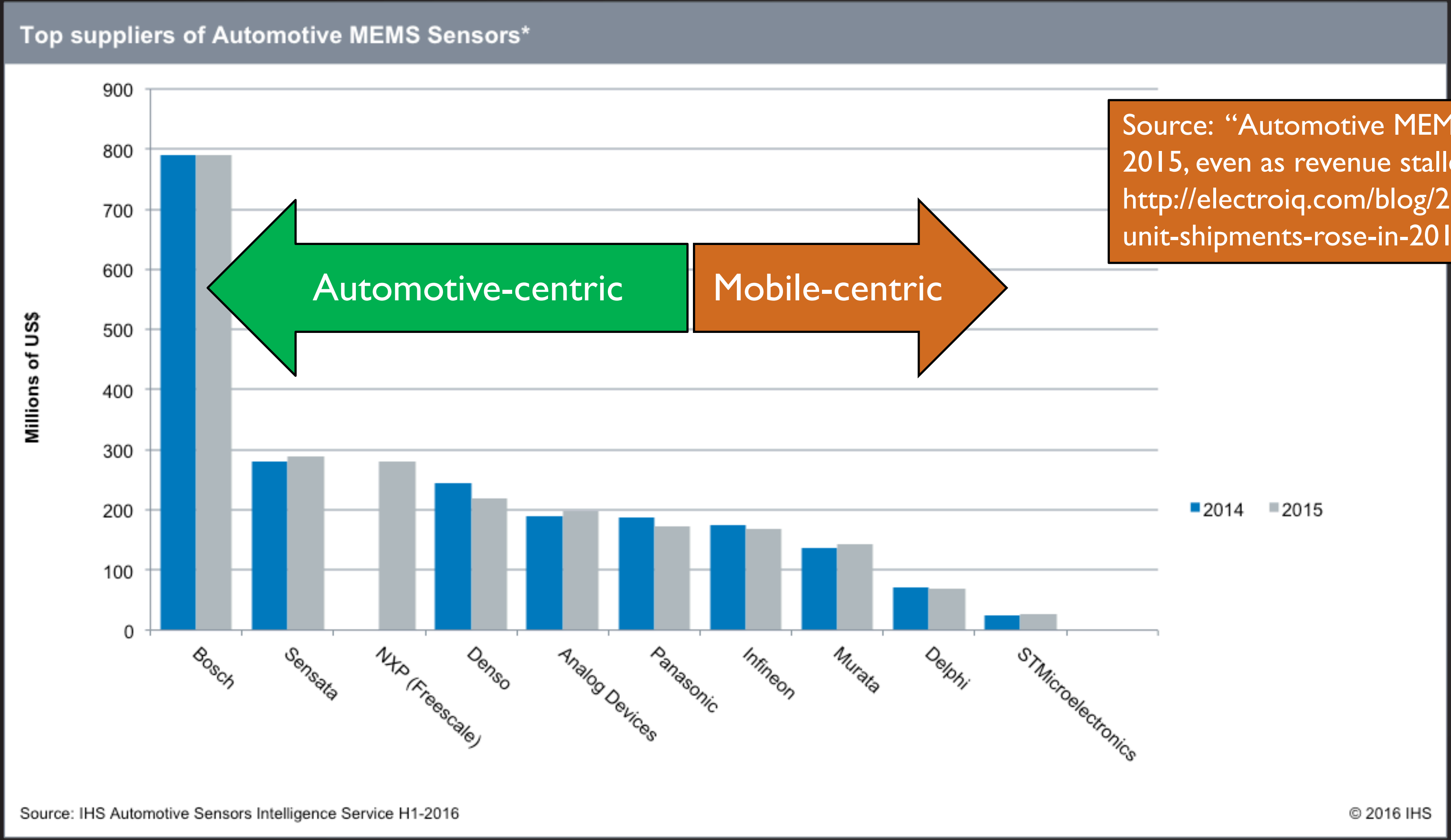
…of all innovations in a modern car depend on **semiconductors**.

Source: SEMI.org, "Innovation Driven by Semiconductors," SEMICON Europa 2015 to Showcase Automotive, MedTech and Industry 4.0, http://semi.org/en/node/56431

AUTOMOTIVE SENSORS EVERYWHERE

- Pressure sensor
- Manifold absolute pressure sensor
- Mass air flow sensor
- Knock sensor
- Atmospheric pressure sensor
- Oxygen sensor
- Rotational speed sensor
- Tank pressure sensor
- Pedal position sensor
- Angular position sensor
- Angular rate sensor
- Air quality sensor
- Humidity/Temp sensor
- Rain sensor
- Ultrasonic distance sensor
- Radar distance sensor
- Tilt sensor
- High pressure sensor
- Torque sensor
- Steering wheel angle sensor
- Acceleration sensor
- Seat occupancy sensor
- Yaw rate sensor
- Air bag accelerometer

AUTOMOTIVE MEMS SUPPLIERS



Source: "Automotive MEMS sensor unit-shipments rose in 2015, even as revenue stalled," http://electroiq.com/blog/2016/07/automotive-mems-sensor-unit-shipments-rose-in-2015-even-as-revenue-stalled/

CURRENT AND EMERGING AUTOMOTIVE MEMS & SENSORS

Current automotive MEMS (>95% of market value) are:

- Pressure sensors, accelerometers, & gyroscopes
- Their applications are continue to be electronic stability control (ESC), airbags, tire-pressure monitors (TPMS) and manifold absolute-pressure (MAP)

Emerging automotive MEMS are:

- LIDAR, CMOS Image Sensors (CIS), MEMS microphones, microbolometers, & scanning micromirrors.
- Their new applications are pedestrian detection, air-intake humidity measurement, hands-free calling microphones, night-vision systems, head-up displays, & adaptive LED headlights.

Source: Richard Dixon (IHS), "Automotive MEMS sensor unit-shipments rose in 2015, even as revenue stalled," http://electroiq.com/blog/2016/07/automotive-mems-sensor-unit-shipments-rose-in-2015-even-as-revenue-stalled/

FUTURE OF AUTOMOTIVE ELECTRONICS

- Increased electronics content in cars without increasing car size thus allowing more electronics to occupy the same or less space requiring **further miniaturization beyond current packaging approaches**.
- Integrated electronics with **100s of sensors and computing electronics** that are necessary to process the information.
- All-electric vehicles that require **ultra-high battery power** that is efficient and light-weight electric components for electric motors, inverters, converters, control and driver electronics and high- voltage batteries.
- Inclusion of **data security and privacy** in vehicle’s electronic systems.

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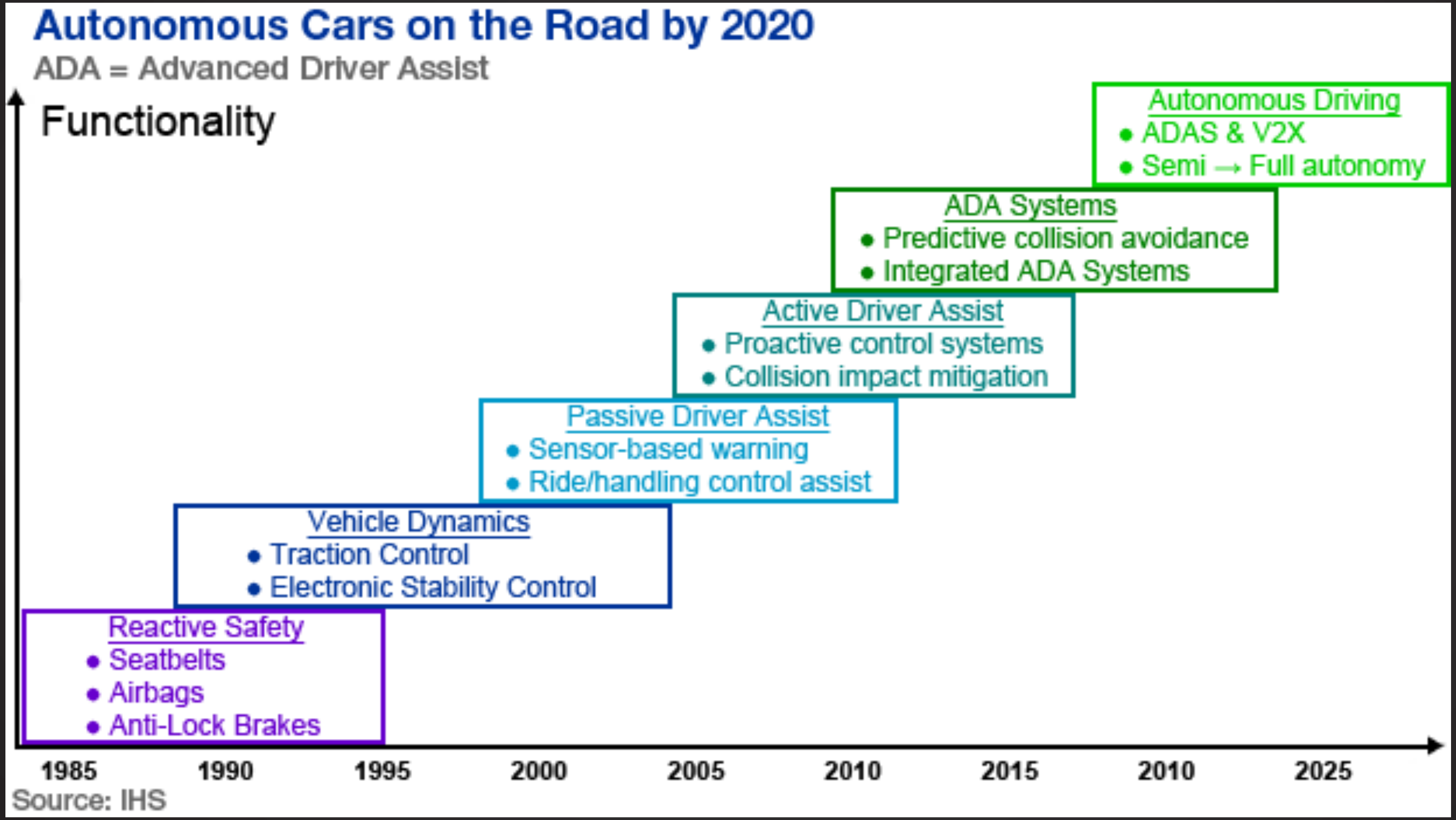
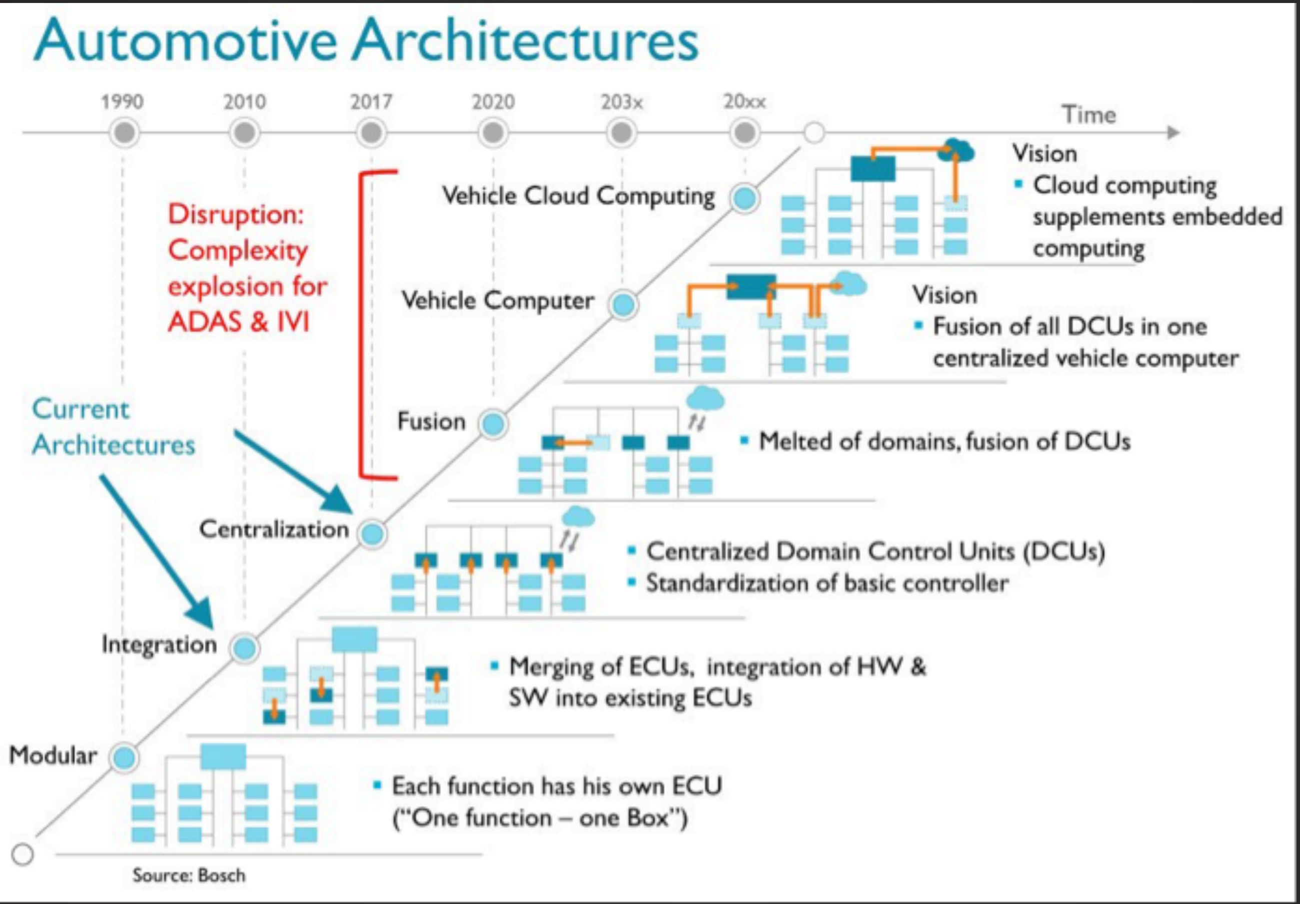
EVOLUTION OF AUTONOMOUS VEHICLES



Source: R. DeMeis, Autonomous Cars: How Soon and at What Cost?, http://electronics360.globalspec.com/article/2/autonomous-cars-how-soon-and-at-what-cost

AUTOMOTIVE TECHNOLOGY INTERCEPTS



Source: Brian Bailey, The Wild West of Automotive, http://semiengineering.com/the-wild-west-of-automotive/, originally from Robert Bosch.

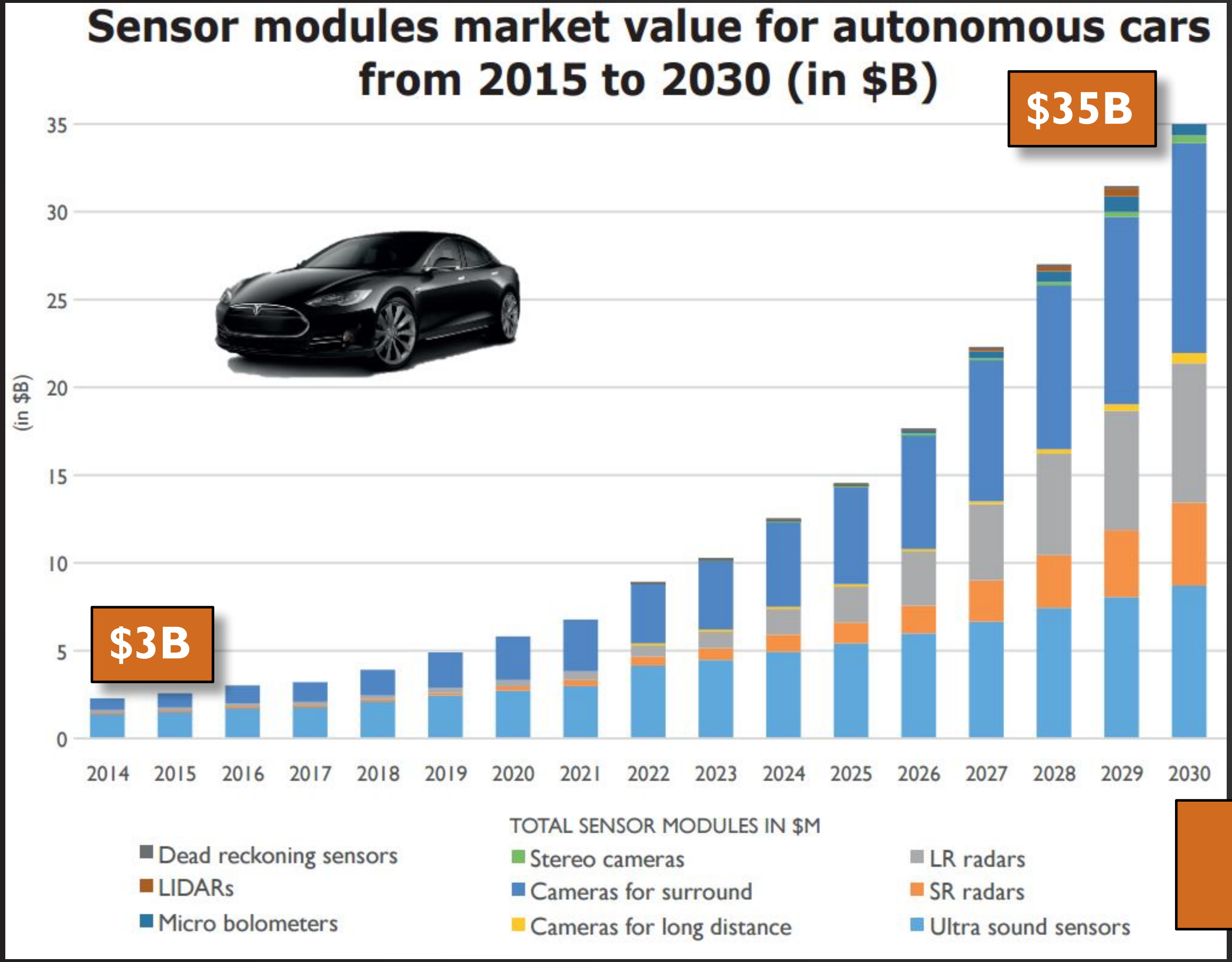
2015 TOP AUTOMOTIVE CHIP LEADERS

Market Share of Top 10 Automotive Semiconductor Suppliers ($ million)						
Y2015 Rank	Company Name	2014 Revenue	2015 Revenue	2014 Market Share	2015 Market Share	Growth (YoY)
1	NXP	1861	4178	6.4%	14.4%	124.5%
2	Infineon Technologies	2702	2850	9.3%	9.8%	5.5%
3	Renesas Electronics	3032	2671	10.5%	9.2%	-11.9%
4	STMicroelectronics	2144	2096	7.4%	7.2%	-2.2%
5	Texas Instruments	1605	1871	5.5%	6.4%	16.6%
6	Robert Bosch	1621	1478	5.6%	5.1%	-8.8%
7	ON Semiconductor	1069	1142	3.7%	3.9%	6.8%
8	Micron Technology	706	661	2.4%	2.3%	-6.4%
9	Toshiba	729	652	2.5%	2.2%	-10.6%
10	Osram	568	646	2.0%	2.2%	13.7%
	Others	12946	10785	44.7%	37.2%	-16.7%
	Total	28983	29030	100.0%	100.0%	0.2%

Source: IHS

Source: "Automotive semiconductor market grows slightly in 2015 while ranks shift," http://electroiq.com/blog/2016/06/automotive-semiconductor-market-grows-slightly-in-2015-while-ranks-shift/

AV SENSOR MODULES MARKET REVENUE



< Micro bolometers

< Stereo cameras

< Surround cameras

< Long distance cameras

< Long Range Radars

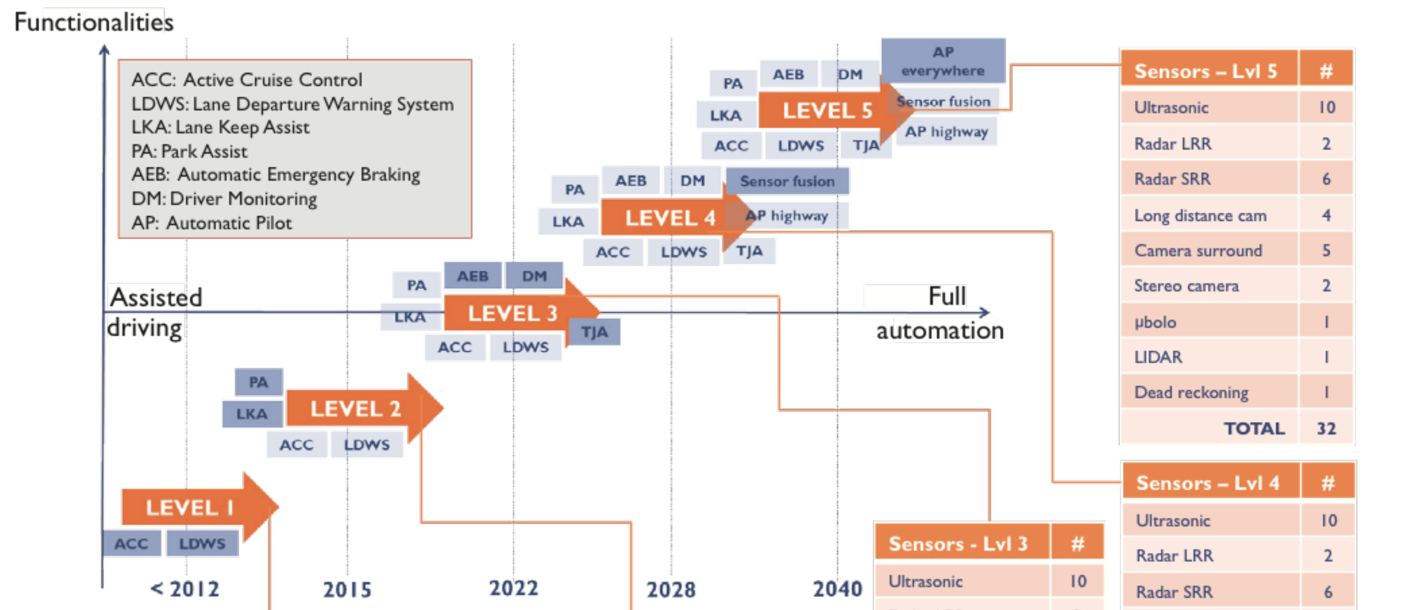
< Short Range Radars

< Ultrasound Sensors

Source: Yole Développement, "Sensors and Data Management for Autonomous Vehicles," 2015.

AV SENSOR ROADMAP

Sensor technology roadmap and autonomous functions associated



Sensors - Lvl 1	#
Ultrasonic	4
Radar LRR	1
Camera for surround	1
TOTAL	6

Sensors - Lvl 2	#
Ultrasonic	8
Radar LRR	1
Radar SRR	4
Camera for surround	4
TOTAL	17

Sensors - Lvl 3	#
Ultrasonic	10
Radar LRR	2
Radar SRR	6
Long distance cam	2
Camera surround	5
Stereo camera	1
µbolo	1
LIDAR	1
Dead reckoning	1
TOTAL	29

Sensors – Lvl 4	#
Ultrasonic	10
Radar LRR	2
Radar SRR	6
Long distance cam	2
Camera surround	5
Stereo camera	1
µbolo	1
LIDAR	1
Dead reckoning	1
TOTAL	29

Sensors – Lvl 5	#
Ultrasonic	10
Radar LRR	2
Radar SRR	6
Long distance cam	4
Camera surround	5
Stereo camera	2
µbolo	1
LIDAR	1
Dead reckoning	1
TOTAL	32

(Yole Développement, October 2015)

A car level 3 will embed for $2200 of sensors for AV

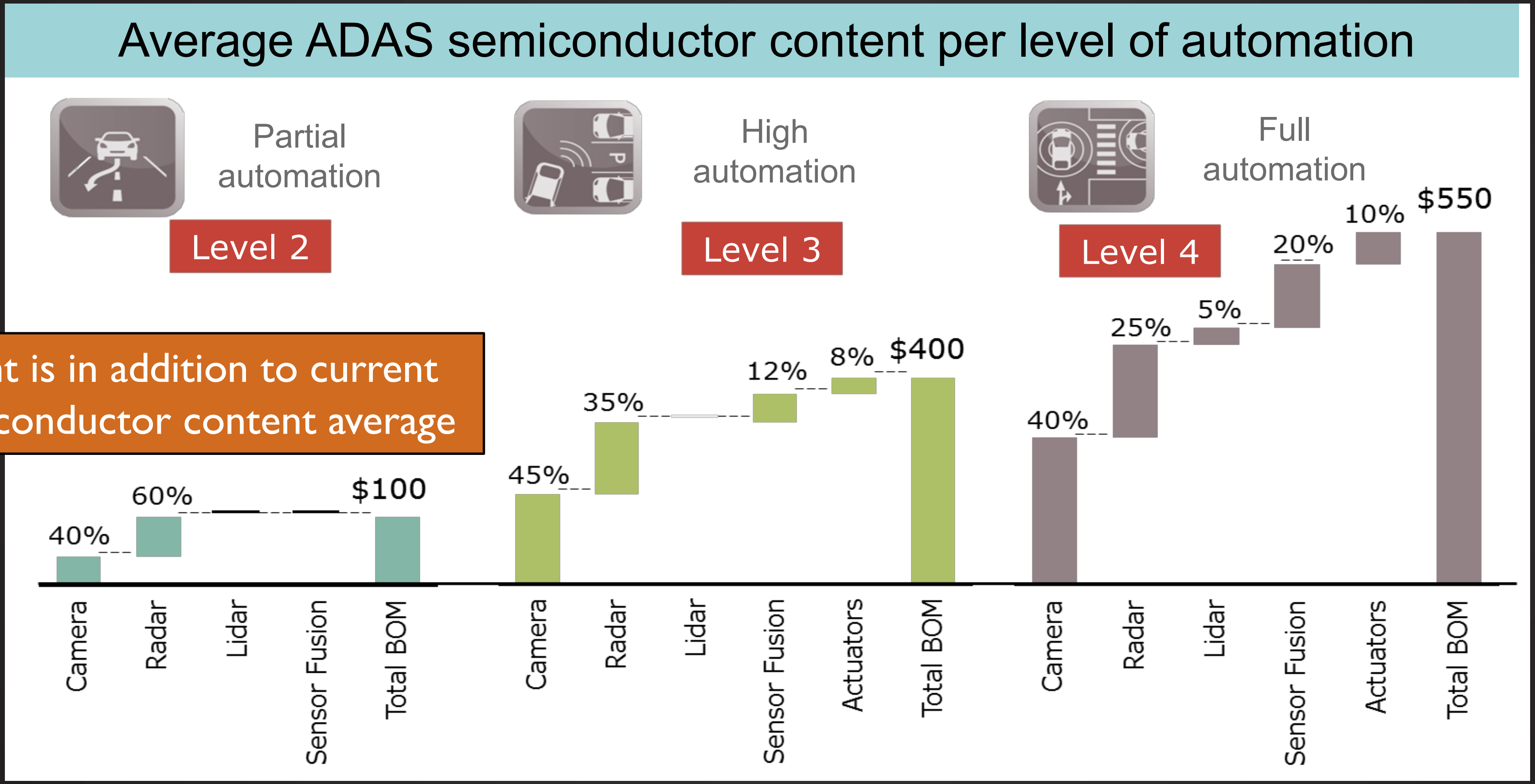
http://i-micronews.com/component/hikashop/product/sensors-and-data-management-for-autonomous-vehicles-report-2015.html

ADAS IN CHINA

Company	Target Market	Processing Platform	Camera Resolution	ADAS Algorithm	How to Collect Vehicle Data	Product Standard
Mobileye (Israel)	1. OEM market 2. Aftermarket	EyeQ®	640*480 (38° visual angle)	1. Vehicle detection 2. Pedestrian detection 3. Lane detection 4. Traffic sign detection 5. General object detection	CAN	UN-ECE, etc.
Letv (China)	1. Original equipped on LeSEE self-driving car 2. Aftermarket	Ambarella A12	4M (160° visual angle)	1. Vehicle detection 2. Lane detection	1. GPS+G-sensor (Le DashCam 1S) 2. CAN (LeSEE)	Unknown
Neusoft (China)	OEM market	1. NEC 2. Intel	Unknown	1. Vehicle detection 2. Pedestrian detection 3. Lane detection 4. Traffic sign detection		Unknown
INVO (China)	OEM market	Unknown	648*486 (40° H 38° V visual angle)	1. Vehicle detection 2. Lane detection	CAN	GB5768, etc.
Minieye (China)	OEM market	Unknown	Unknown	1. Vehicle detection 2. Pedestrian detection 3. Lane detection	CAN	ISO 15623, etc.
AIDRIVING (China)	Aftermarket	Common Android SoCs	640*480 (65° visual angle)	1. Vehicle detection 2. Pedestrian detection 3. Lane detection	1. OBD socket 2. CANBUS gateway	Unknown

Source: "Who Will Become the Mobileye in China?," http://www.cnpals.com/2016/05/02/who-will-become-the-mobileye-in-china/

AUTO SEMICONDUCTOR CONTENT GROWTH DUE TO ADAS



ADAS content is in addition to current $300/car semiconductor content average

Source: Infineon, SEMI's Semicon Europa's Fab Managers Forum.

TWO LEVELS OF AUTONOMOUS DRIVING

Partial Autonomous Driving

- An incremental sensing approach embraced by traditional manufacturers.
- It relies on **high sensitivity sensors combined with low-resolution maps**, and then improves map quality using the sensors embedded on each vehicle.
- This solution allows partial automation in every situation as a ‘first step’.

Full Autonomous Driving

- Exploited by Google and Baidu, based on **3D localized maps** with high levels of detail, down to centimeter accuracy.
- The **maps are combined with fewer sensors** than Partial AD, often using Lidar.
- This solution allows full automation in specific environments and will work very rapidly, however it requires hard work to keep the maps updated.

BRINGING ABOUT NEWER PACKAGE TECHNOLOGIES

As society and technology needs grow, More then Moore principles allow for meeting those needs. In order to bring about new package technologies, one must do the following:

- New materials
- New assembly & packaging processes
- New manufacturing equipment
- New integration & miniaturization methods

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SIP CHALLENGES

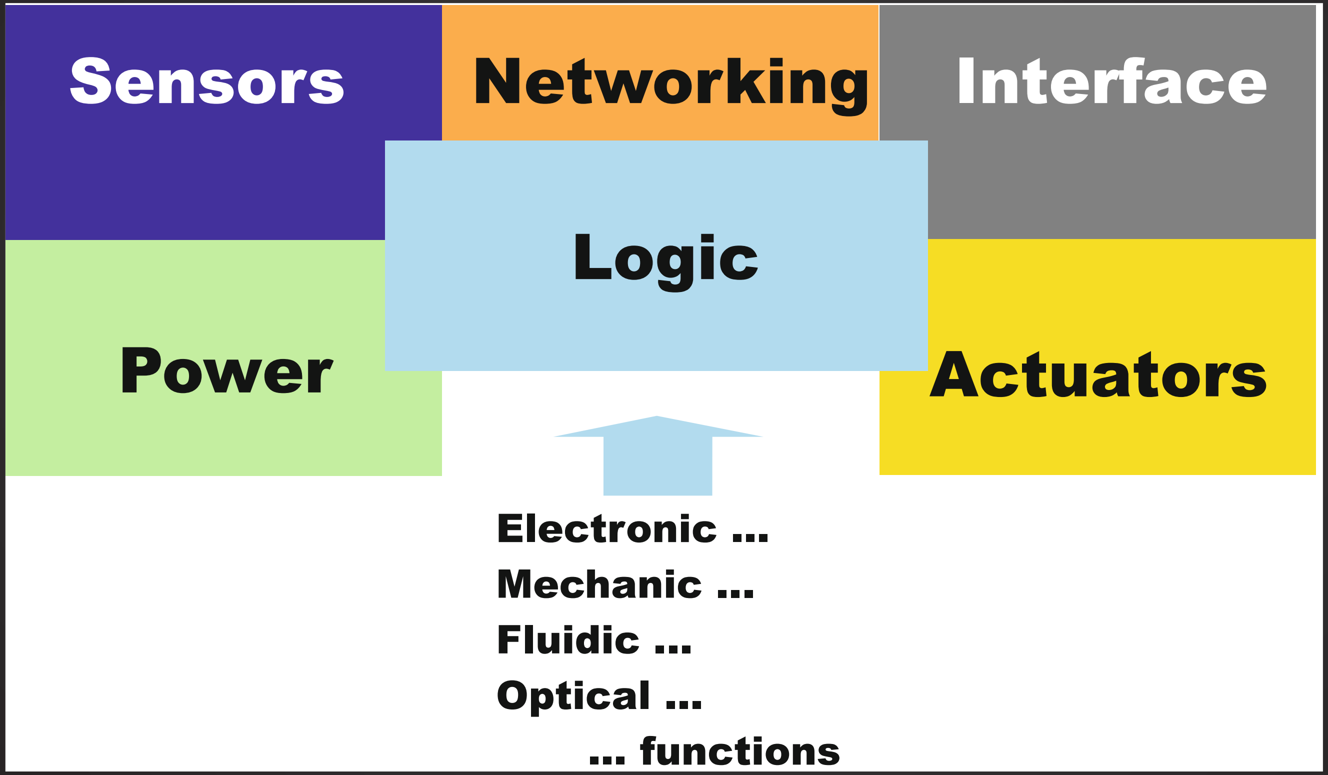
This currently applied approach will not be sufficient to meet the future integration requirements of advanced SiP solutions.

The very high level of miniaturization and extreme reliability required in future SiPs will mean that issues such as thermal and mechanical stress management will need to take into account everything between the point at which heat is generated and the outside of the package.

It will be further complicated by integration of special functions into the package, such as sensors, actuators, RF interfaces or power supply components, which may be especially sensitive to heat, stress etc.

In addition the application environment in which the SiP will ultimately be used will also need to be taken into account.

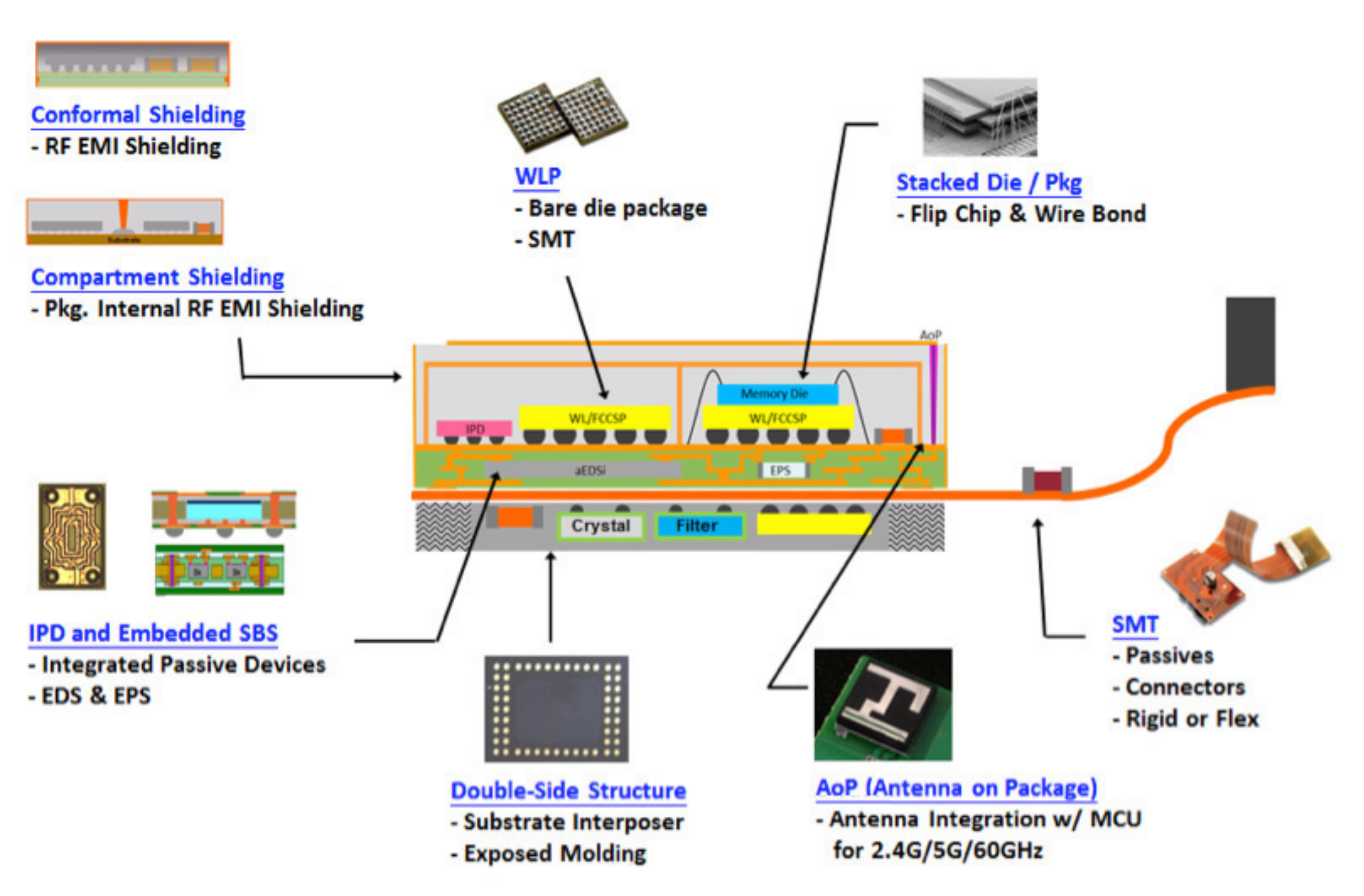
HETEROGENEOUS INTEGRATION



Functional blocks for heterogeneous system integration

Source: K-J. Wolter, System Integration by Advanced Electronics Packaging

ADVANCED PACKAGING TECHNOLOGY



Source: C. Zinck (ASE), "MEMS & Sensors packaging: The challenges ahead," http://embedded-computing.com/guest-blogs/mems-sensors-packaging-the-challenges-ahead/

SYSTEM IN PACKAGE (SIP) TECHNOLOGY

System-in-Package (SiP) is defined as two or more dissimilar die assembled into a standard footprint package to create a functional system or subsystem.

- SiP contains other components such as passives, filters, MEMS, sensors, and antennas.
- Characteristics of a SiP vary widely and the major attributes can differ depending on application (see chart below).

Markets	**Key metrics**
Wearable electronics	Low power, cost, miniaturization, and high yield assembly
Wireless	Integration, form factor, cost, and shielding
Automotive electronics	High power capability, reliability, testability, and form factor
Power electronics	Power efficiency, miniaturization, and EMI shielding

SYSTEM IN PACKAGE (SIP) TECHNOLOGY

System in Package:

…is a package or module that contains a functional electronic system or subsystem that is integrated and miniaturized through IC assembly technologies.

…involves heterogeneous integration of diverse functional parts into a standard package format. It can include passives components and mixed assembly technologies.

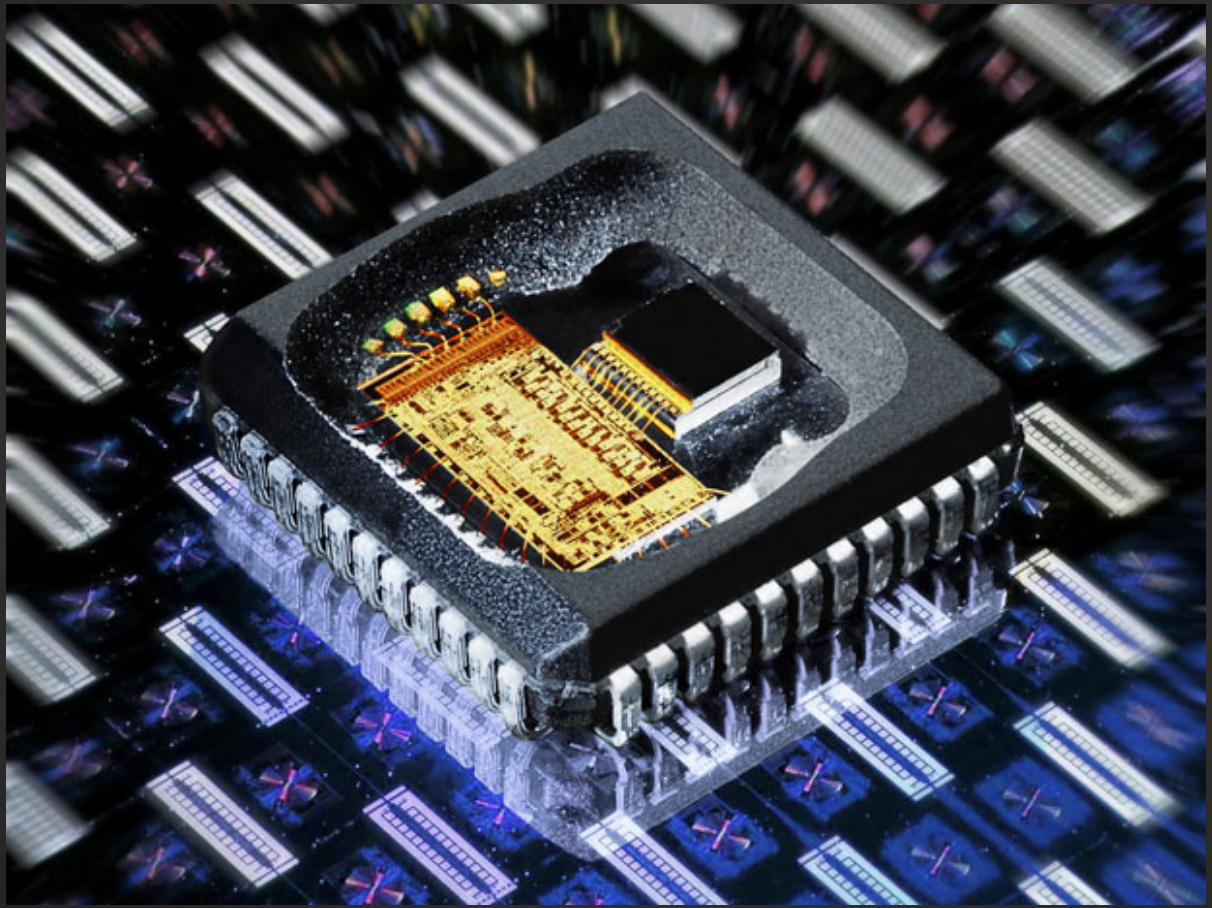
…is two or more components with different functionalities packaged as a system or subsystem.

…defined as multi-component, multi function products in an IC package. They require high-precision assembly technologies, which leverage Amkor's strengths.

Bill Chen, ASE: "**Heterogeneous Integration** refers to the integration of separately manufactured components into a higher level assembly (SiP) that in the aggregate provides enhanced functionality and improved operating characteristics."

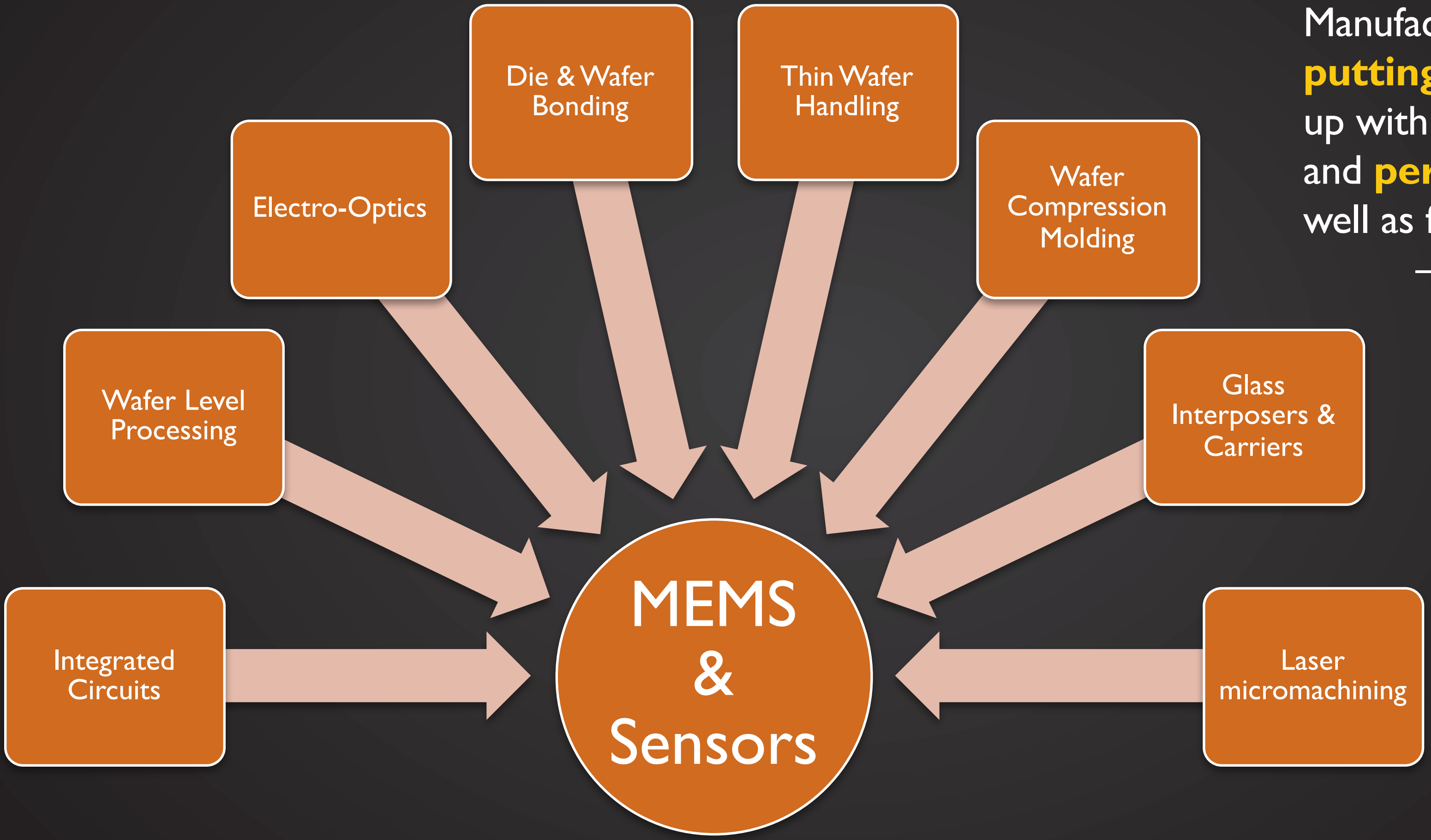
Source: 2016 MAPS Device Packaging Conference, 15-17MAR16, Fountain Hills, AZ

SIP: BOSCH YAW RATE SENSOR



Source: Top 10 Suppliers of Car MEMS Sensors, http://spectrum.ieee.org/cars-that-think/transportation/sensors/top-10-suppliers-of-car-mems-sensors

INTERPLAY OF PACKAGING DISCIPLINES



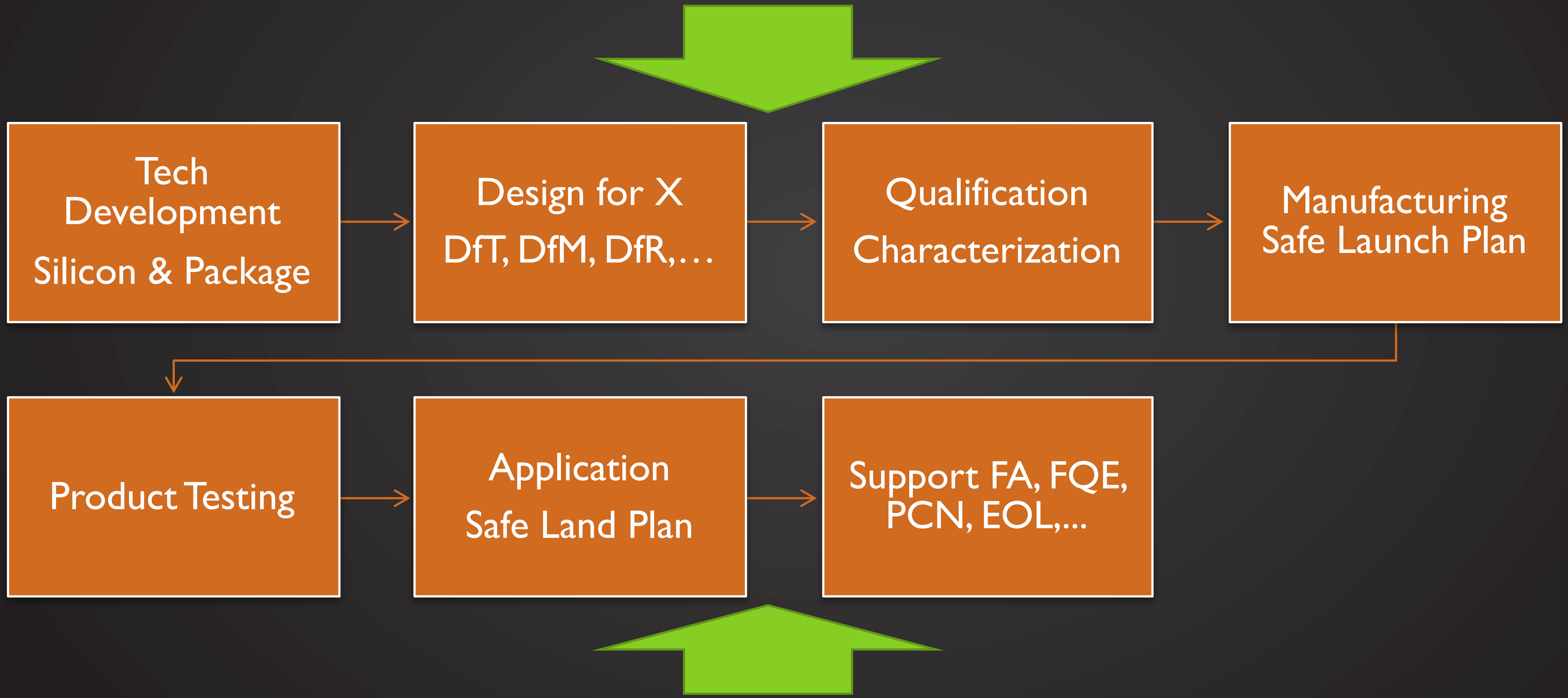
"Manufacturing is more than just **putting parts together**. It's coming up with **ideas, testing principles**, and **perfecting the engineering**, as well as final assembly."

– James Dyson, British inventor

IC, MEMS, & Sensors Packaging in Autonomous Vehicles

FROM TECHNOLOGY TO APPLICATION

Automotive Requirements: Reliability, Zero Defects, Supply Guarantee,…



Standards (ISO 26262, AEC-Q100/101/200, TS 16949,…)

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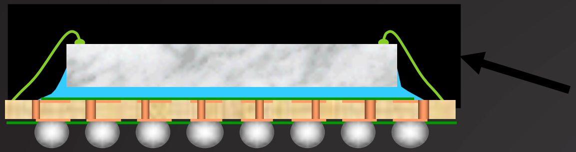
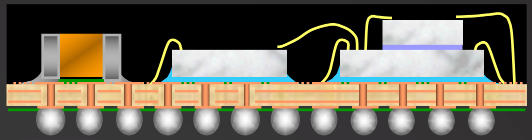
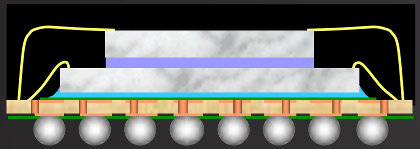
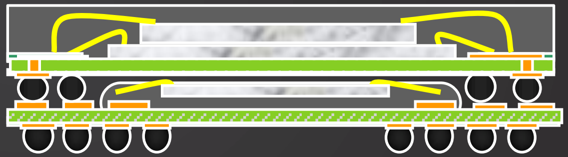
TYPICAL IC & MEMS PACKAGE TYPES

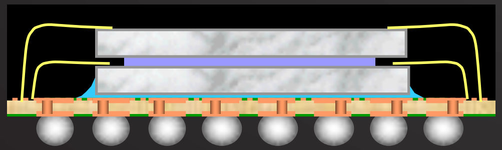


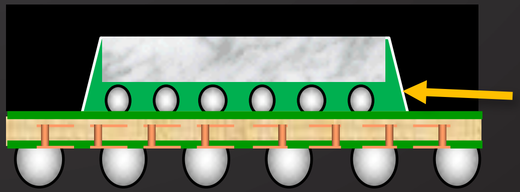
Ball Grid Array (BGA)


System in Package (SiP)


Stacked Die Package


Package on Package (PoP)


Same Size Stacked Die Package



Molded Flip Chip CSP

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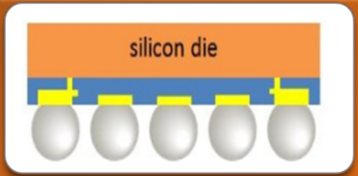
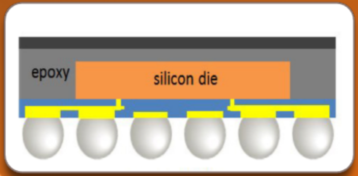
CHIP- AND WAFER-SCALE PACKAGE TECHNOLOGIES



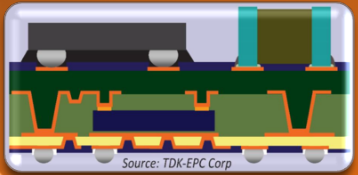
Fan-in Wafer Level Package (FI-WLP)

- True chip-scale package
- Cannot be molded
- Silicon is lossy substrate for RDL



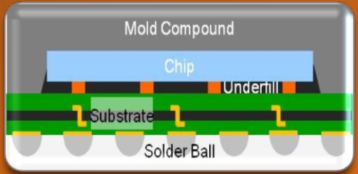
Fan-out Wafer Level Package (FO-WLP)

- Low-profile package
- Almost entirely wafer-level assembly (incl. molding)
- Usually mobile end-products



Embedded Die Package

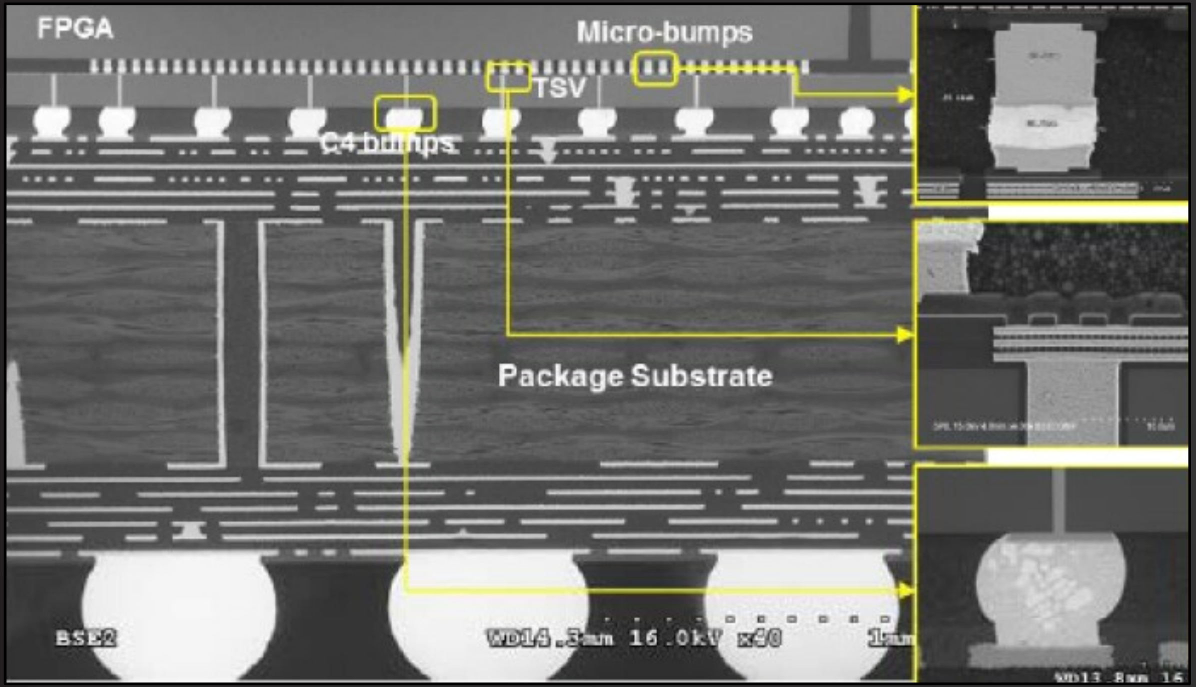
- Power chips & modules
- Mixed analog-digital
- Strong relationship with PCB manufacturer



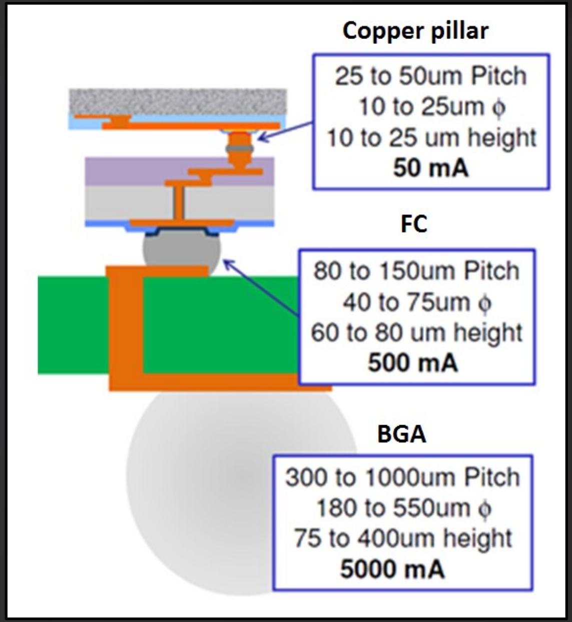
Flip Chip - Chip Scale Package (FC-CSP)

- Direct competition with FOWLP
- Losing ground due to thicker package

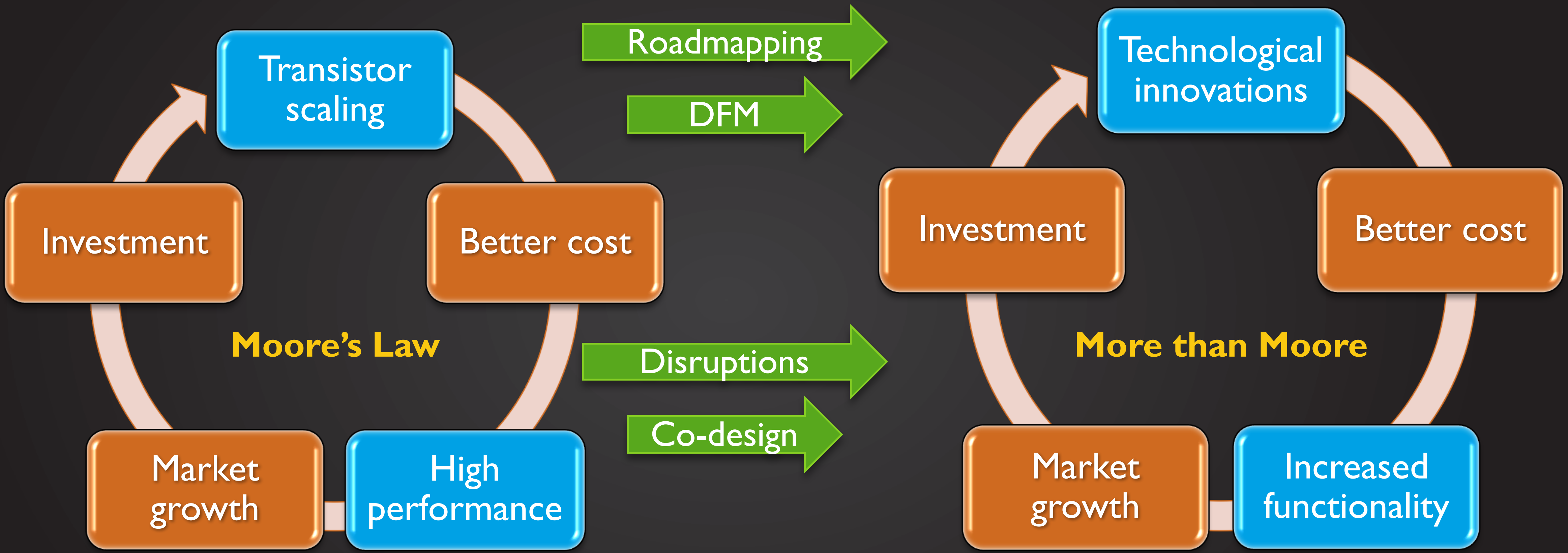
PACKAGE INTERCONNECT SCALING



Hierarchy & Characteristics

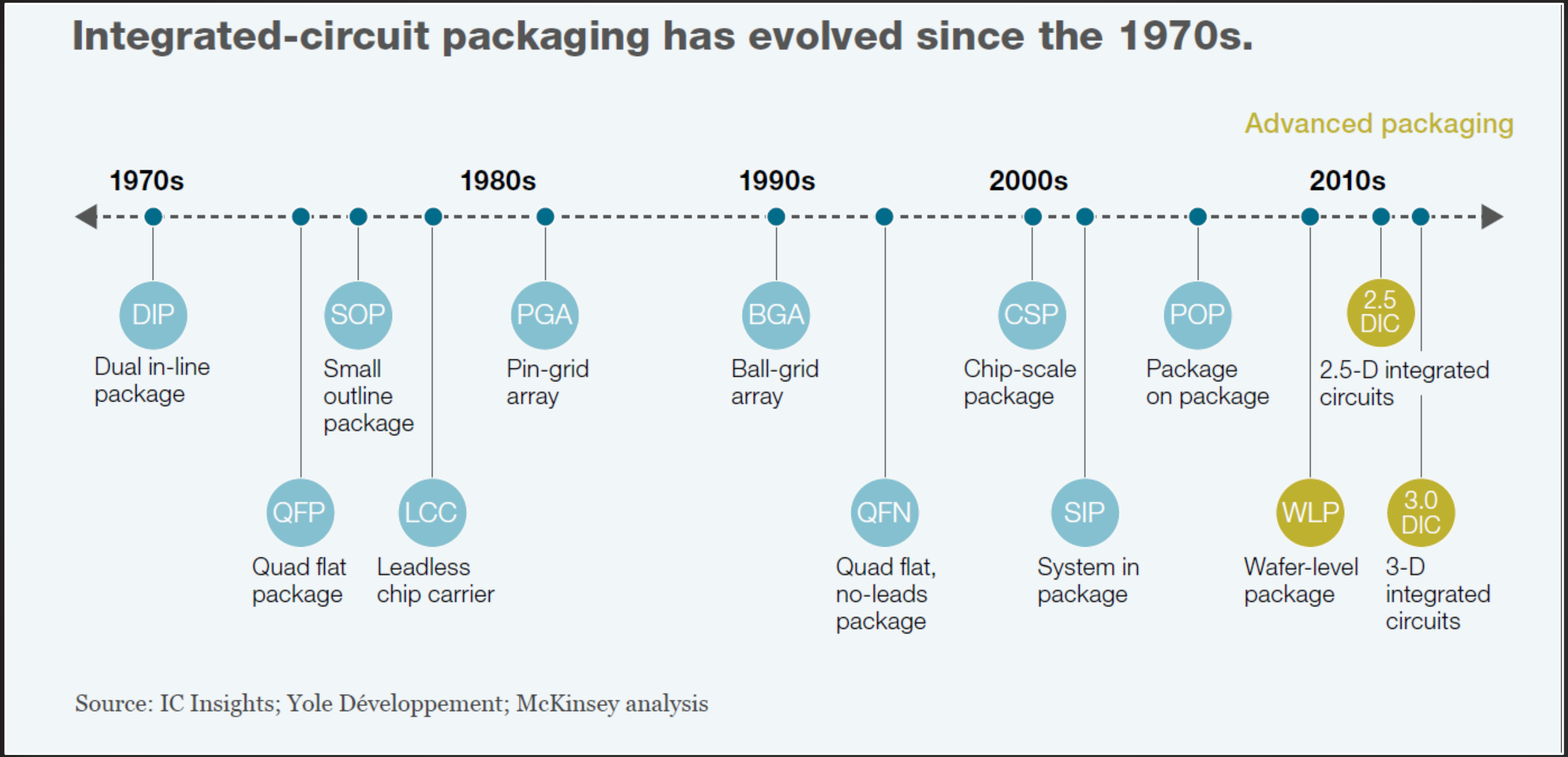


WHY IS PACKAGING MORE IMPORTANT NOW?



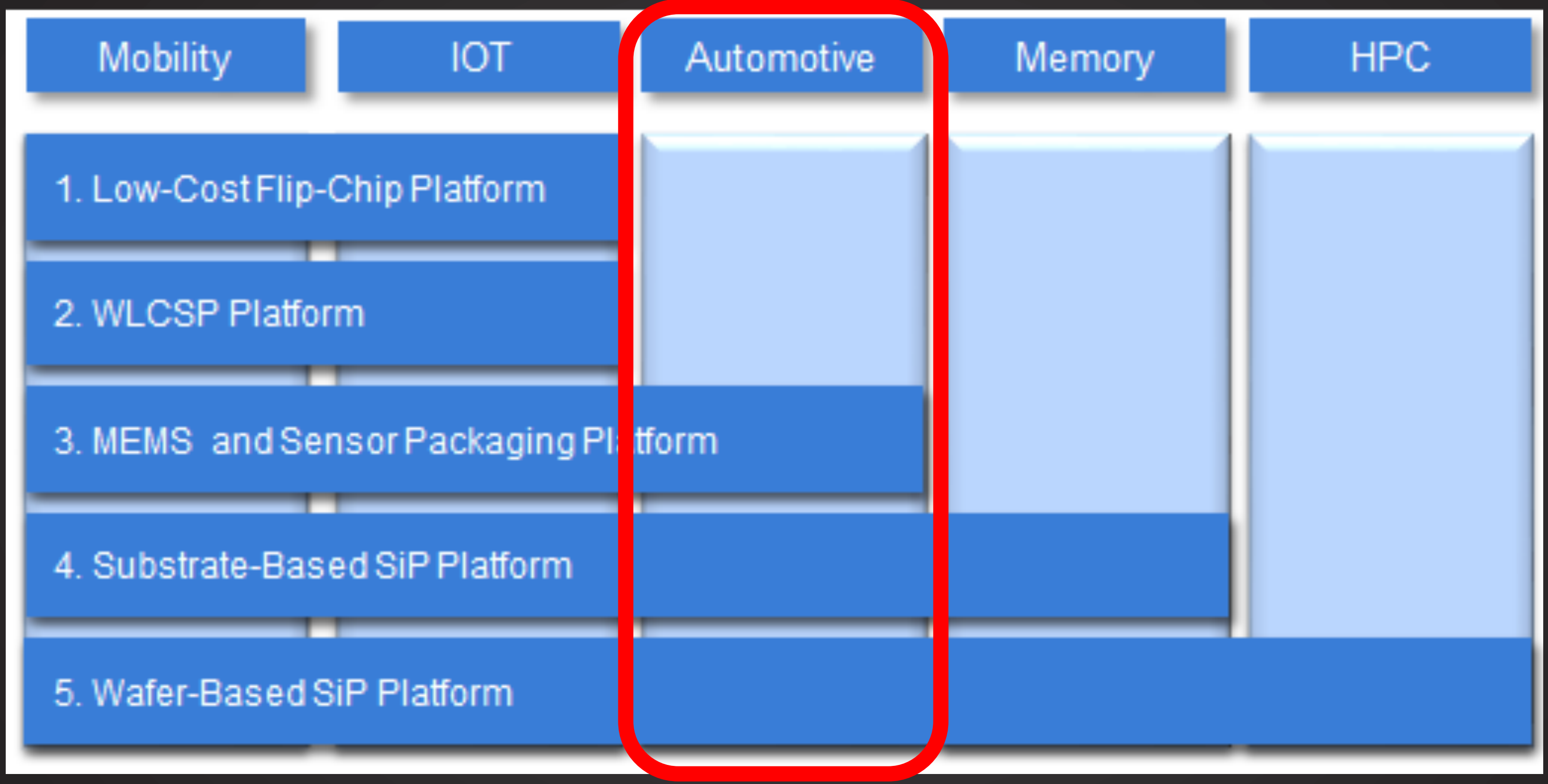
More than Moore is working because of **package technological innovations** and product differentiation like **2.5/3D package integration**.

WHAT IS ADVANCED PACKAGING?



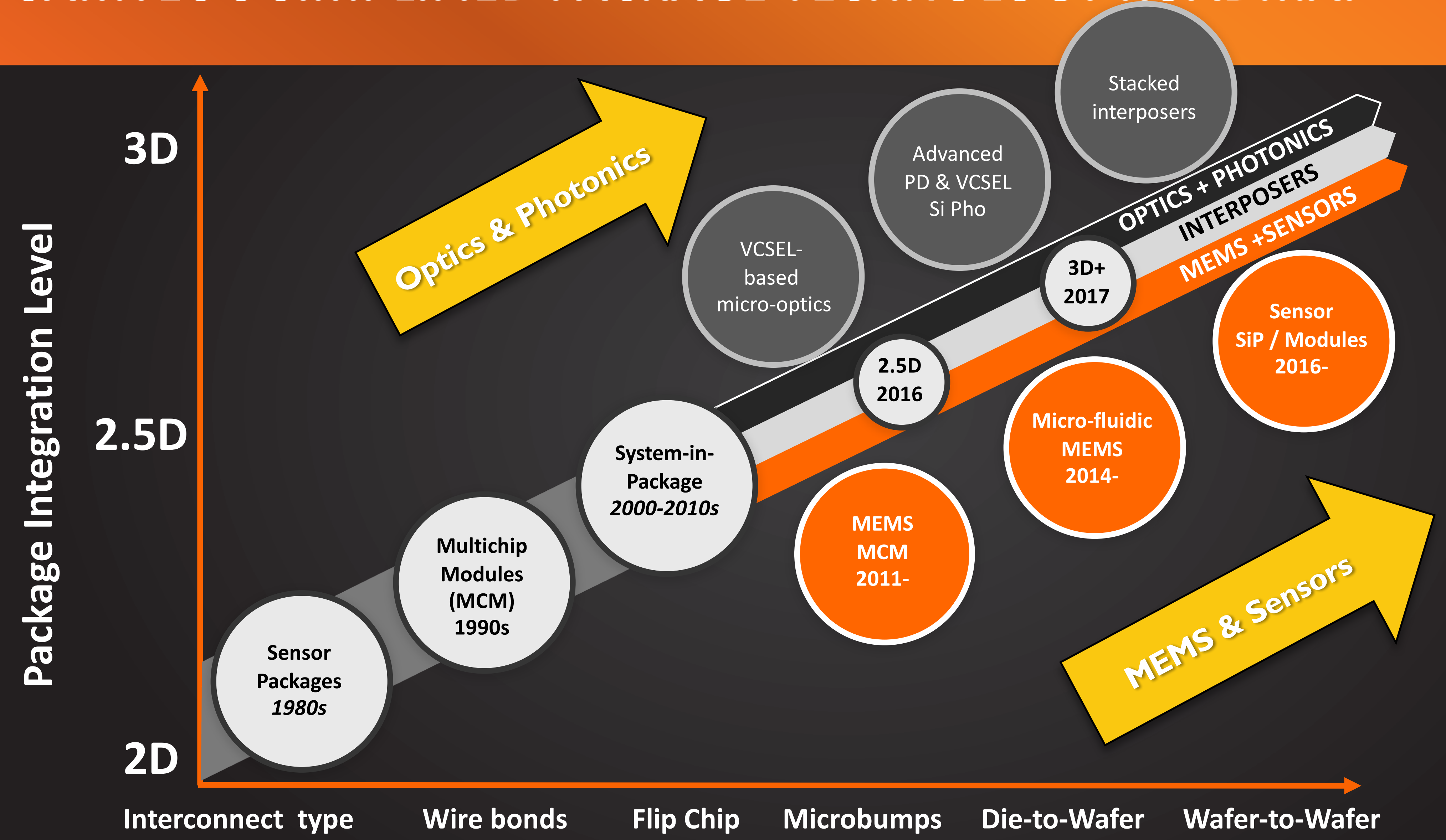
Source: McKinsey Report - Advanced-packaging technologies: The implications for first movers and fast followers

ADVANCED PACKAGING PLATFORMS



Source: R. Alapati, "Convergence on the "Big Five": Focus on Laminate-based Advanced SiP," 30JUN16, http://www.3dincites.com/2016/06/convergence-on-the-big-five-focus-on-laminate-based-advanced-sip

SAMTEC'S SIMPLIFIED PACKAGE TECHNOLOGY ROADMAP



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CHIP/PACKAGE/MODULE CO-DESIGN REQUIREMENTS

High-Frequency Designs

- 400 MHz buses becoming common
- On-chip exposure to package noise
    - Simultaneous switching noise
    - Package resonance

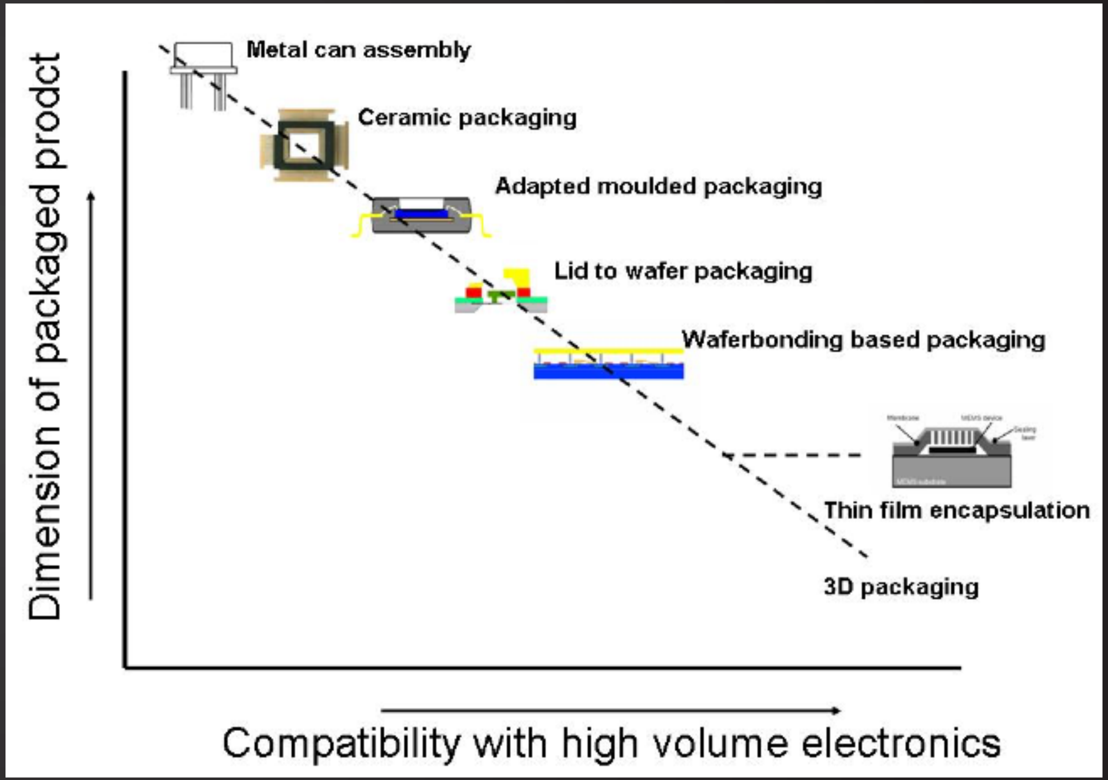
Tighter Turnaround Time

- Package design convergence
- System design convergence

High Density Packaging

DEVICE PACKAGING INFRASTRUCTURE

- Device Packaging
  - System in Package (SIP)
    - Multichip Module (MCM)
  - Single Chip Package
    - Metal can package
    - Ball Grid Array (BGA)
    - Ceramic Package
  - Wafer Level Package (WLP)
    - 2.5D Integration
    - 3D Integration



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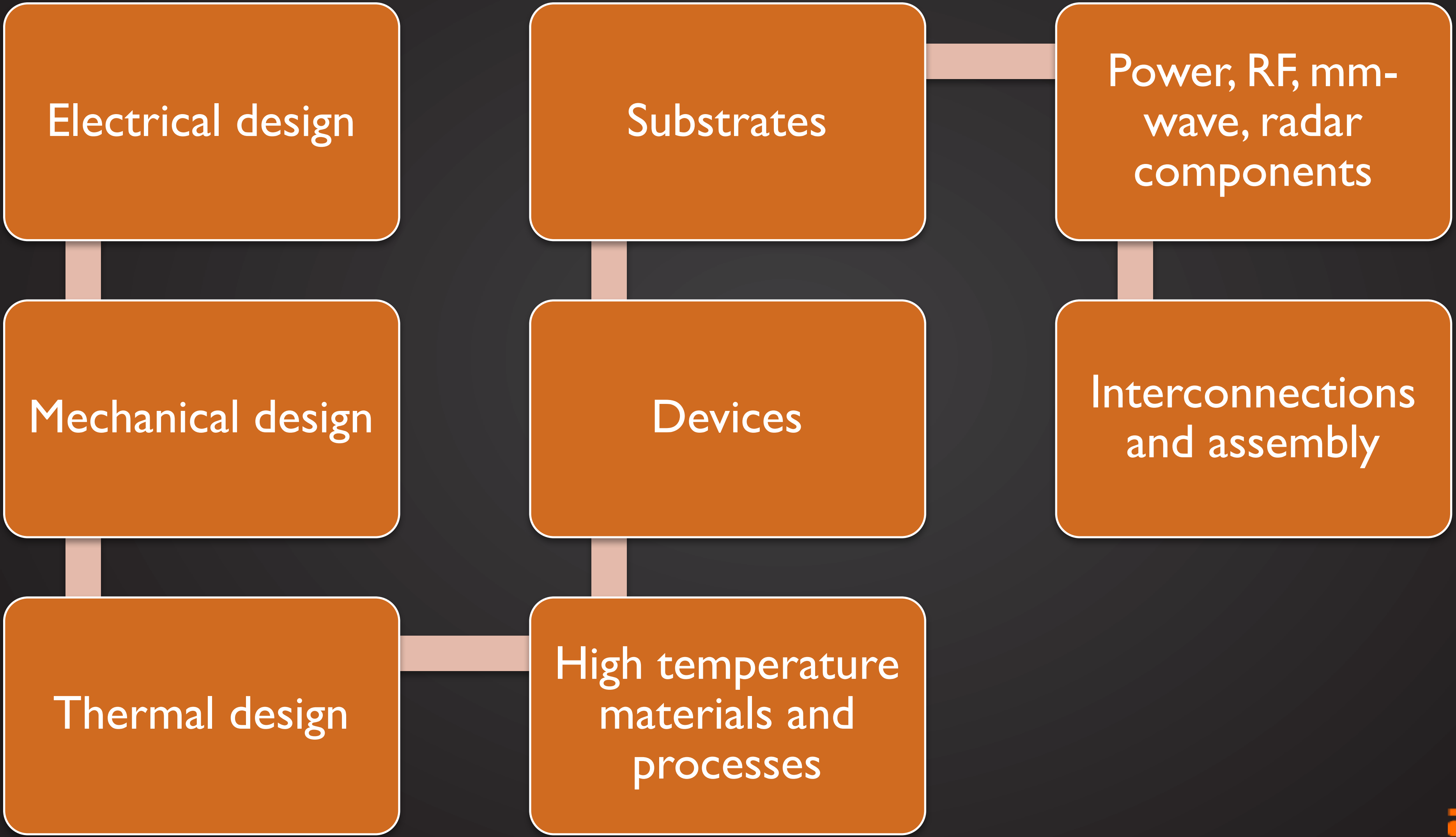
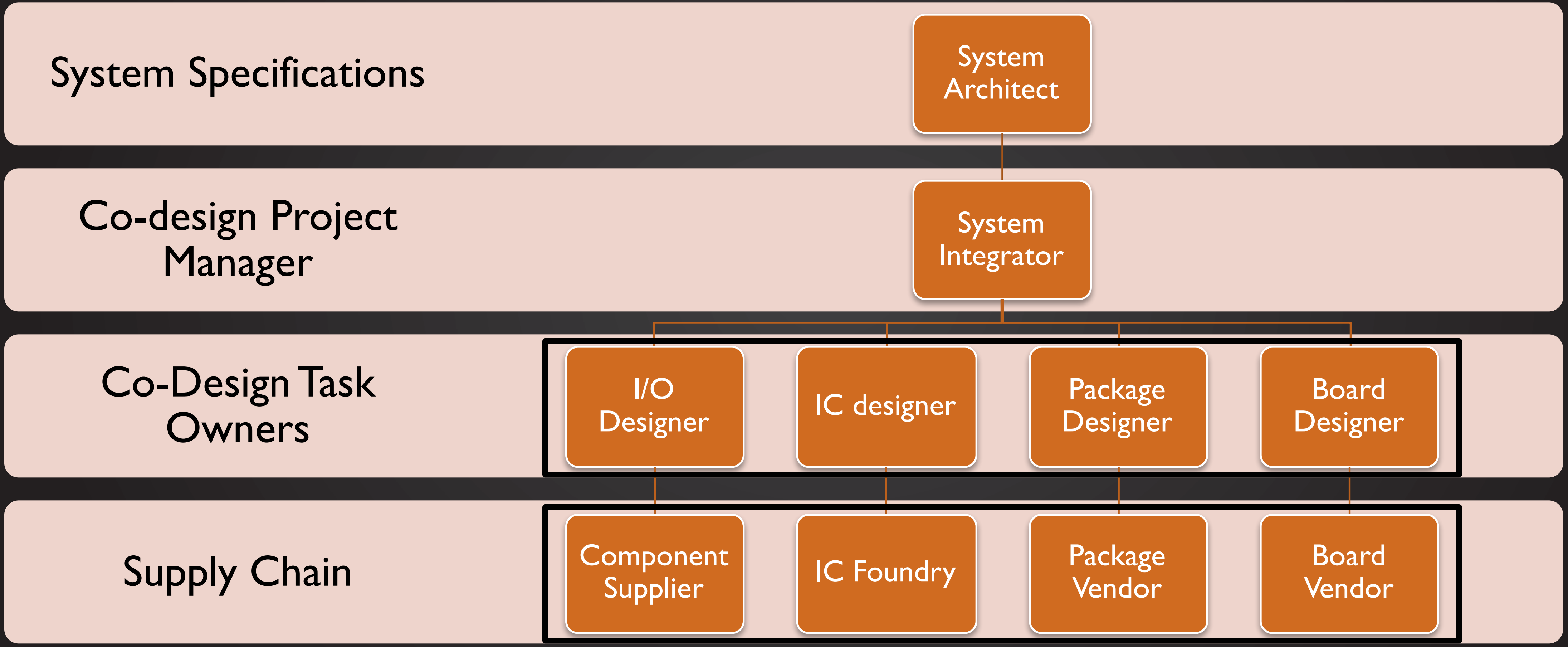
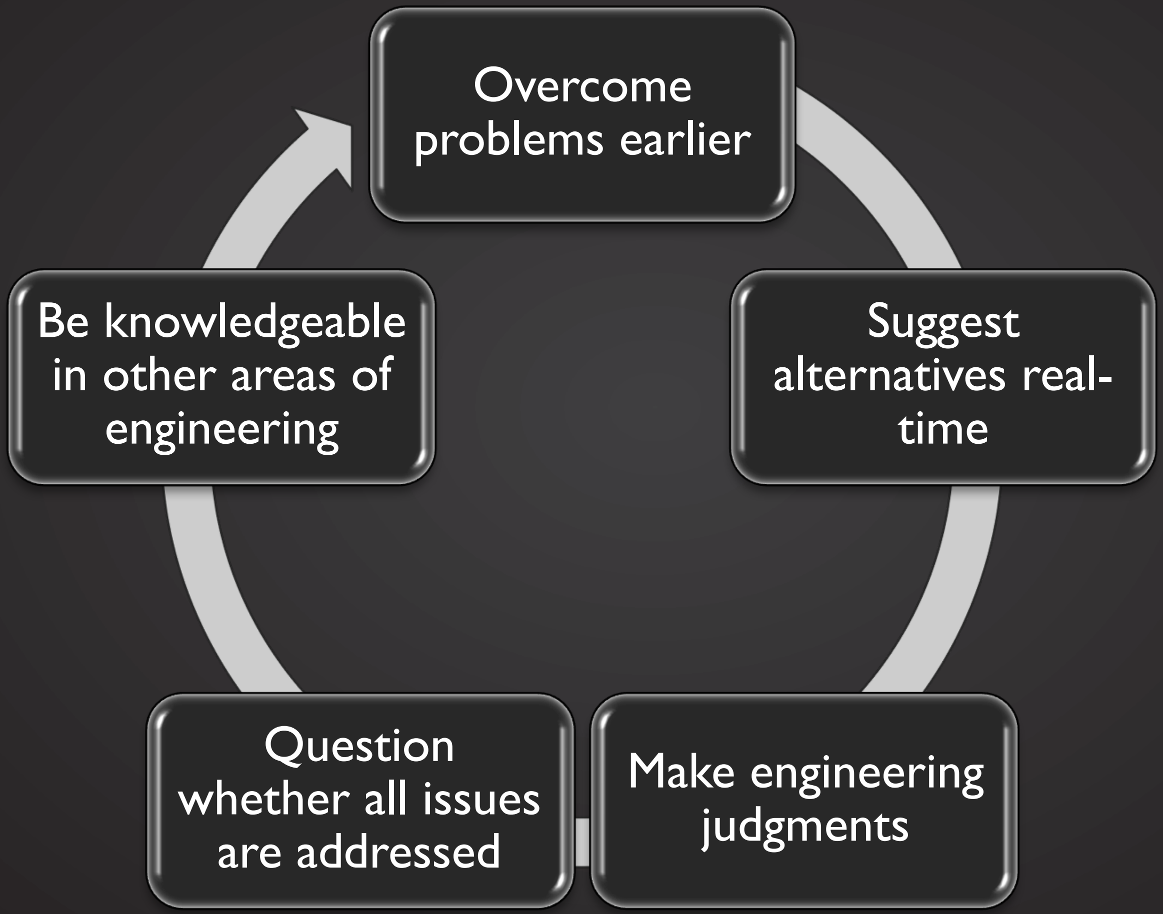
PACKAGE DEVELOPMENT ENGINEERING ACTIVITIES



CHIP-PACKAGE-SYSTEM CO-DESIGN HIERARCHY



WHY CHIP & PACKAGE CO-DESIGN?



WHEN CO-DESIGN IS IN PLACE…

Shorter design cycles.

Redesigns are minimized or eliminated.

Improved end **performance**.

Better products result.

Advantages are so compelling that most design teams use some form of co-design.

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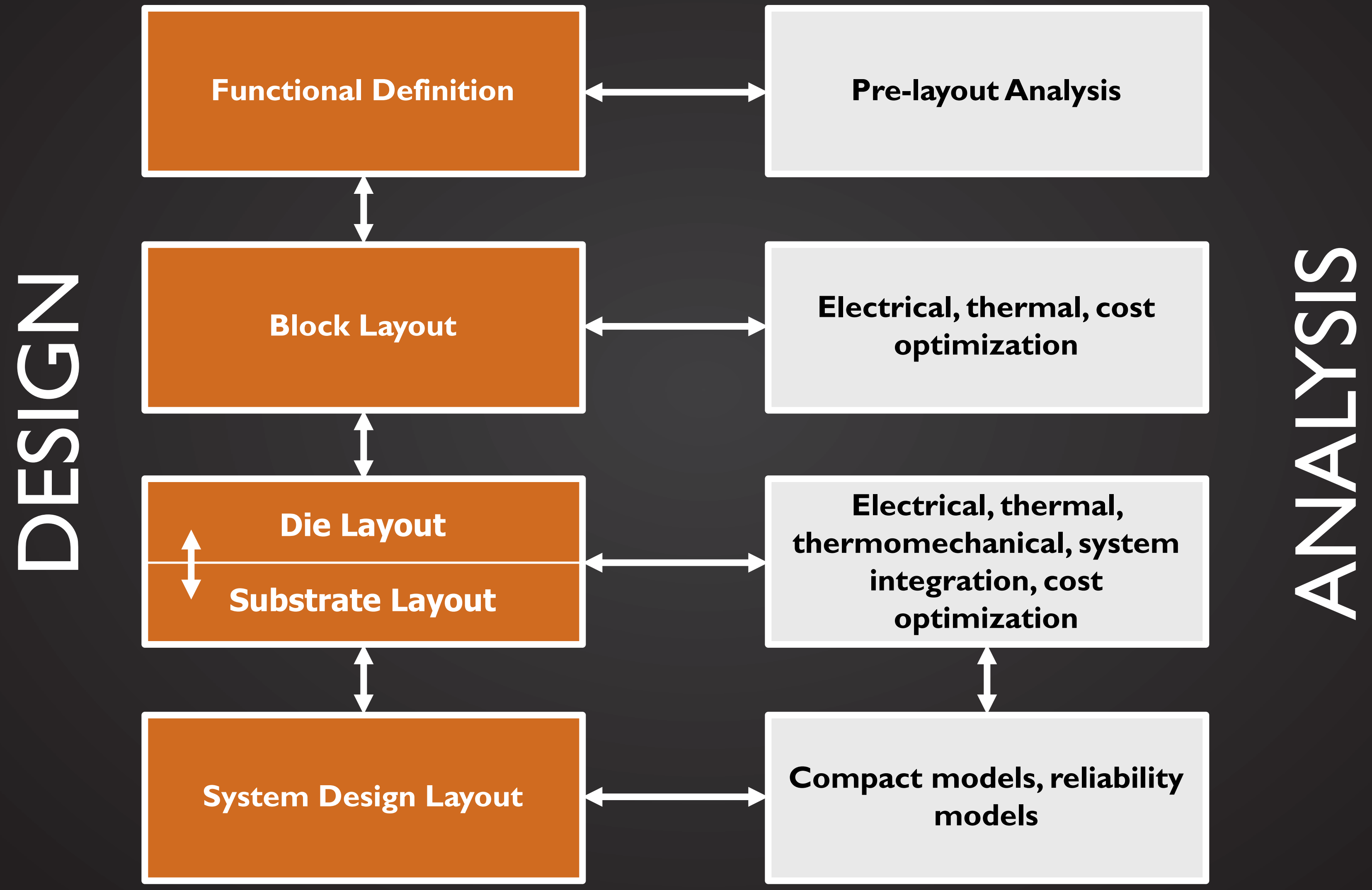
CHIP-PACKAGE-SYSTEM CO-DESIGN FLOW



DEVELOPMENT TRENDS OF ADAS APPLICATIONS

Higher integration level

- More performance with less space

System solutions

- System integration on package level

New memory solutions

- 3D memory (e.g., Hybrid Memory Cube (HMC), High Bandwidth Memory (HBM), 3D NAND
- Alternative memory technologies (e.g., Magnetic RAM , Resistive RAM , Phase Change RAM)

Engineering Challenges

- Higher performance & Reliable over lifetime
- System cost reduction
- New players with new responsibilities (e.g., ISO 26262)
- New challenges for failure analysis

ADVANTAGEOUS OF USING GLASS CORE TECHNOLOGY

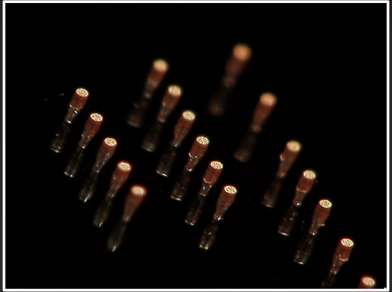
Glass is a **superior dielectric** & **low insertion loss**
- RF, BLE, Millimeter wave

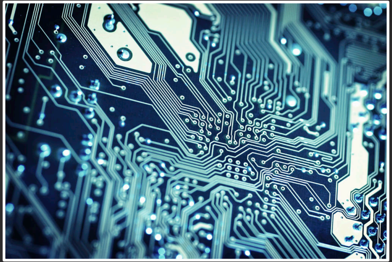
Produced in **large panels** add to lowering cost
- Manufacturing costs and scale

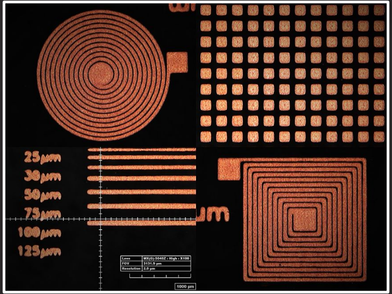
Hermetically sealed vias
- Reliable MEMS & Sensors packaging

Active elements can be processed on surface
- Enhanced signal integrity and wireless transmission

Glass can be **chemically and optically etched**
- Opportunities in biosensors and optical/photonic devices







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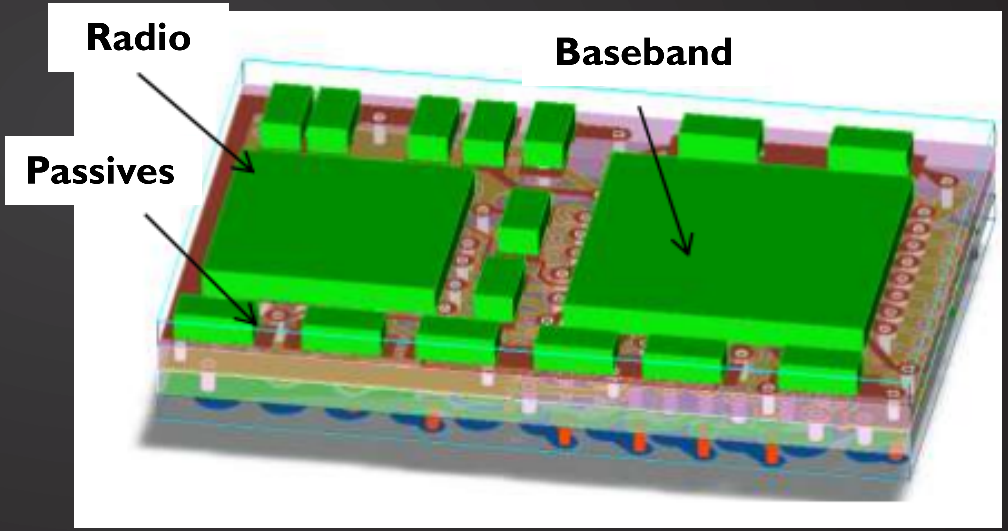
PACKAGE INTEGRATION: WIRELESS AND IOT MODULES

Taking discrete components and placing them on a common interposer platform.

Glass interposers provide a low-loss, flat, fine-pitch (10-25um L/S) module platform.



Source: Anysilicon.com, RF Package Design Focusing Portability

AUTONOMOUS VEHICLE ELECTRONICS PACKAGING INITIATIVES

High Temp Electronics

Glass substrates

Interconnects

Passives

Encapsulation

High Power Electronics

Control and safety electronics

High-power modules

Thermal technologies

Power module reliability

MEMS & Sensor Electronics

Miniaturized wireless 3D-Glass BGA sensor interface

Packaging platform for sensor arrays

Camera electronics

Packaging platform for sensor fusion

Sensor packages for high ambient temperatures

Communication Electronics

Digital, RF and mm-wave electronics

Mixed signal electrical design

mm-wave Glass module

3D Package for high bandwidth

3D Glass photonics

EMI shielding

Source: R. Tummala, et al., "New era in automotive electronics, a co-development by Georgia tech and its automotive partners," 2016 Pan Pacific Microelectronics Symposium (Pan Pacific), pp. 1-4.

GLASS CORE TECHNOLOGY

- Glass Core Technology
  - Glass Interposers
  - Microstructured Glass Substrates
  - Hermetic Glass Package
  - MEMS & Sensors platforms
  - Optical/Photonics Integration

EXAMPLE: AUTOMOTIVE LIGHTING

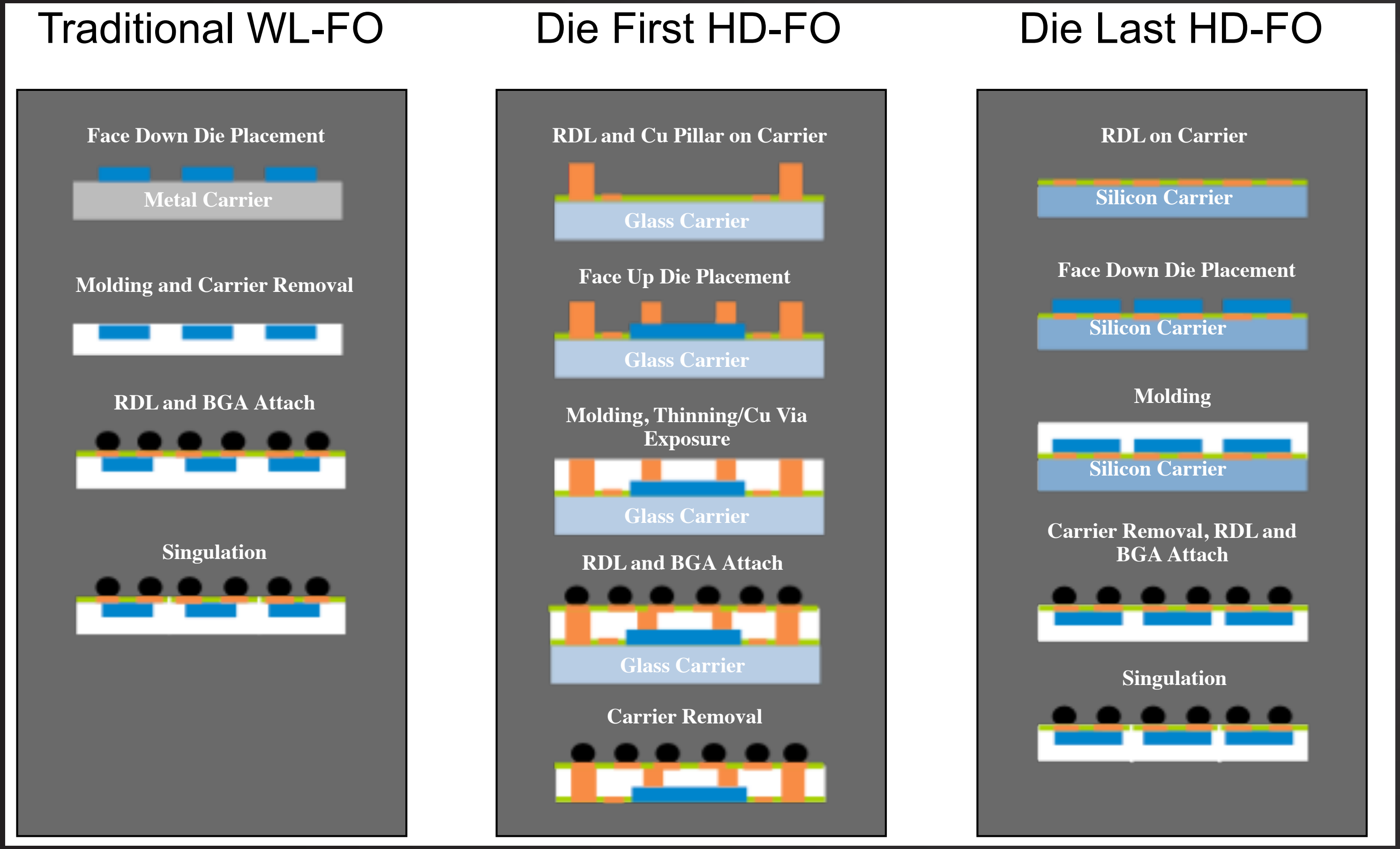
Device Technologies & Applications

- LED: GaN-on-Si based devices
- Laser: High beam range with new materials
- OLED: organic semiconductors for new design trends
- Digital Micromirror Device: hundreds of thousands of individually adjustable micromirrors

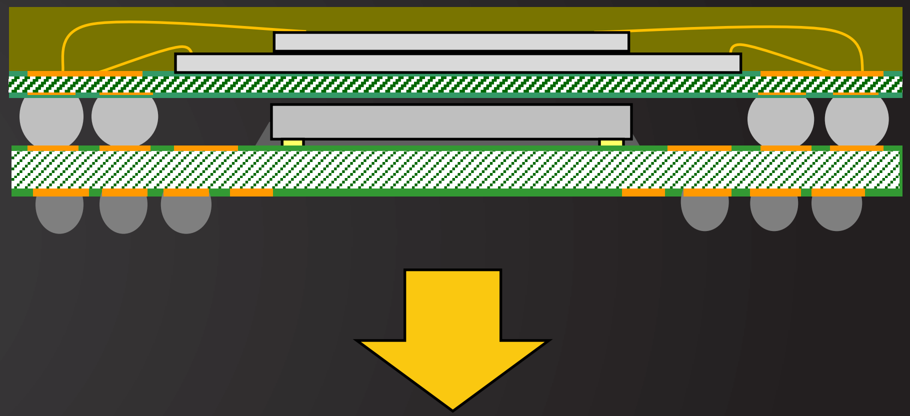
Engineering Challenges

- Thermal management on device, package, and system levels
- System packaging / device packaging
- Automotive qualification standards to cover environmental stress

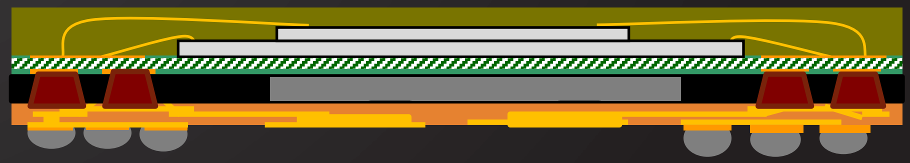
VARIOUS FAN-OUT WAFER LEVEL PACKAGE PROCESS FLOWS



Today's Package-on-Package (1.0mm)



FO-WLP as Bottom PoP (<0.8mm)



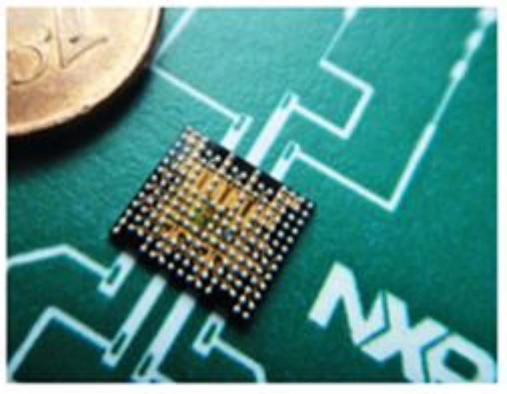
Source: GlobalFoundries, adapted from Amkor, ASE, SPIL, STATS ChipPAC, TechSearch International, Inc., IFTLE, TSMC websites.

FO-WLP SUPPLIERS STATUS

- Amkor Technology
- ADL Engineering
- ASE
- Deca Technologies
- NANIUM
- NEPES
- Powertech Technology
- SPIL
- STATS ChipPAC
- Samsung
- TSMC
- New suppliers in China

RADAR FO-WLP PACKAGING

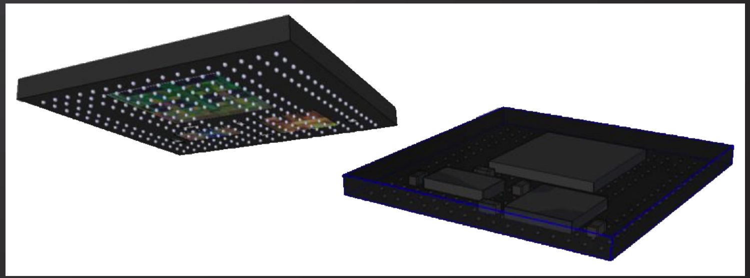
NXP Radar Module in FO-WLP



Source: NXP

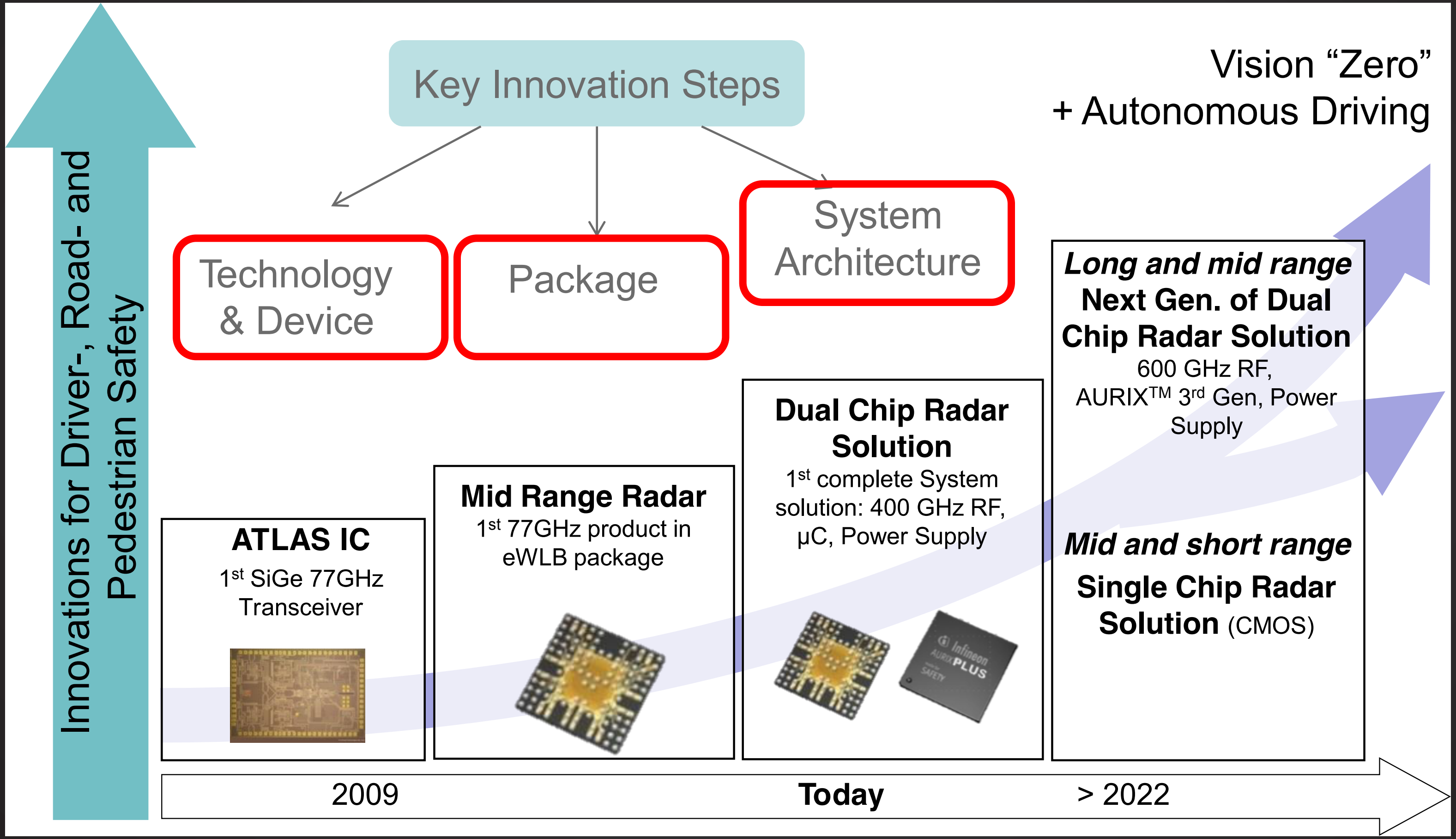
Freescale 77GHz Radar System

Continental announced it is integrating Freescale's 77GHz radar technology into its next generation short- and mid-range automotive radar modules



Source: Freescale

SYSTEM COST FOR RADAR SIGNIFICANT DECREASE



Source: Infineon, 2015 Semicon Europa, Fab Managers Forum

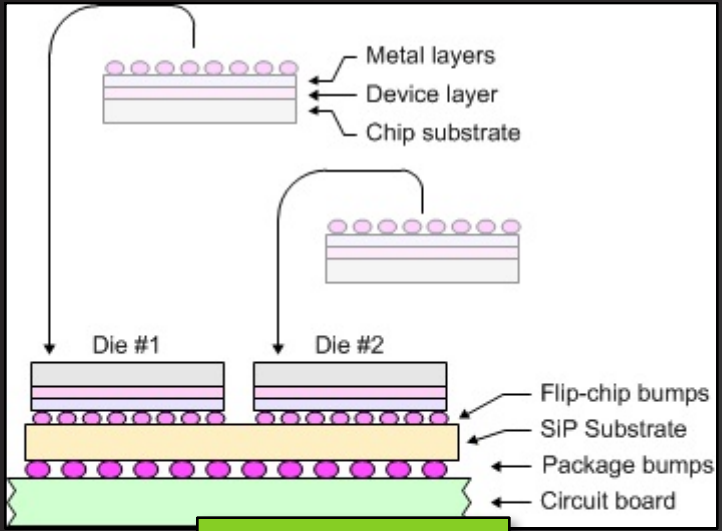
High-Speed Communications Enablers

HIGH BANDWIDTH WIRELESS

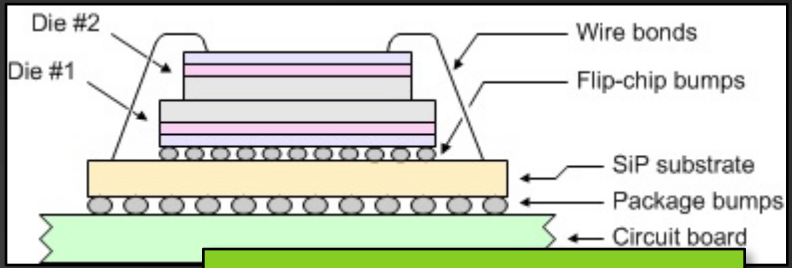
There is a changing landscape and the diverse requirements for the next generation self-driving cars.

Technology developments are supposed to mimic high bandwidth centralized or de-centralized computing and 5G-like communication technologies that are expected outside the car.

PACKAGE INTEGRATION NOMENCLATURE

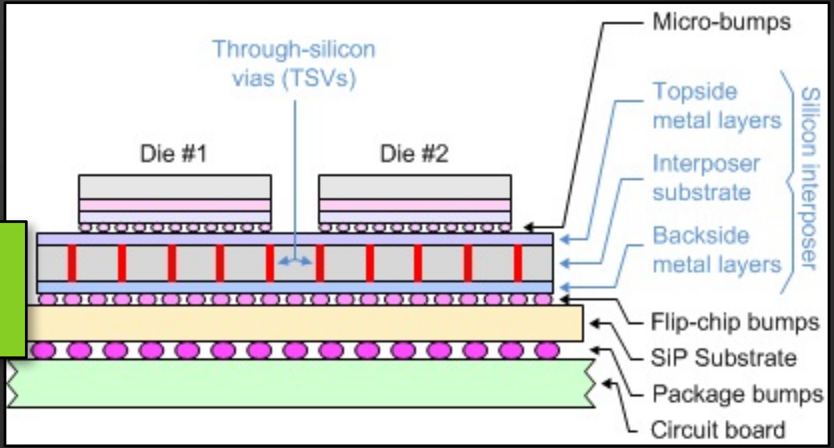


2D SiP



Stacked Die or 3D SiP

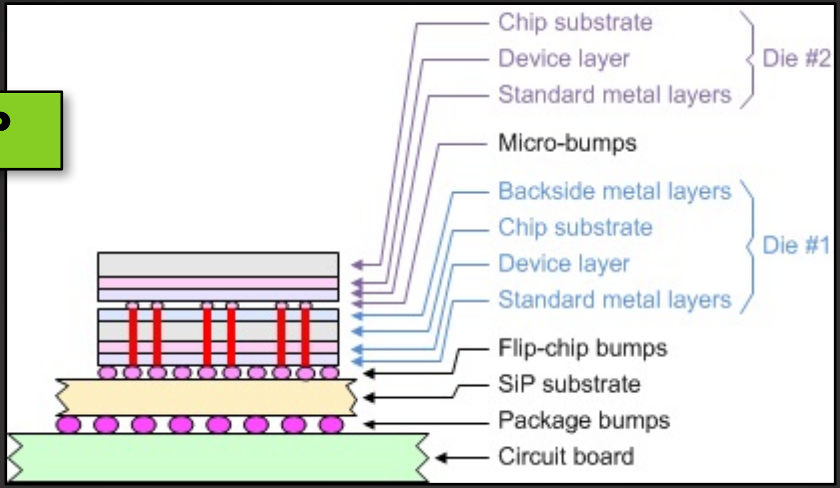
2.5D SiP w/ Si or Glass interposer and TSVs

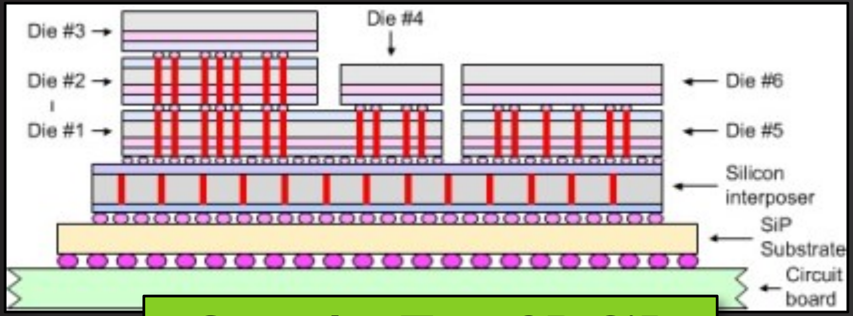


Source: C. Maxfield, "2D vs. 2.5D vs. 3D ICs 101," http://www.eetimes.com/design/programmable-logic/4370596/2D-vs--2-5D-vs--3D-ICs-101

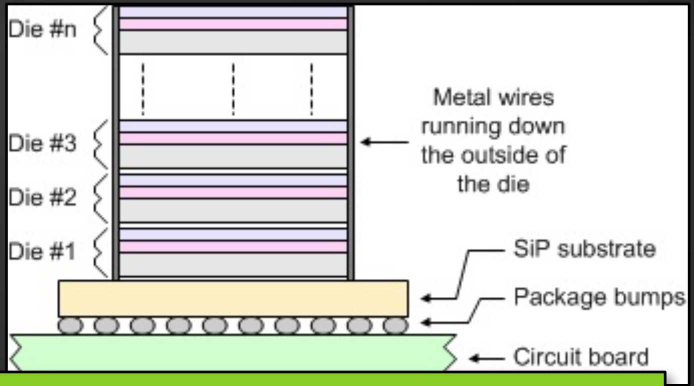
ADVANCED PACKAGE INTEGRATION

True 3D SiP





Complex True 3D SiP



Vertical Chip Interconnect

Source: C. Maxfield, "2D vs. 2.5D vs. 3D ICs 101," http://www.eetimes.com/design/programmable-logic/4370596/2D-vs--2-5D-vs--3D-ICs-101

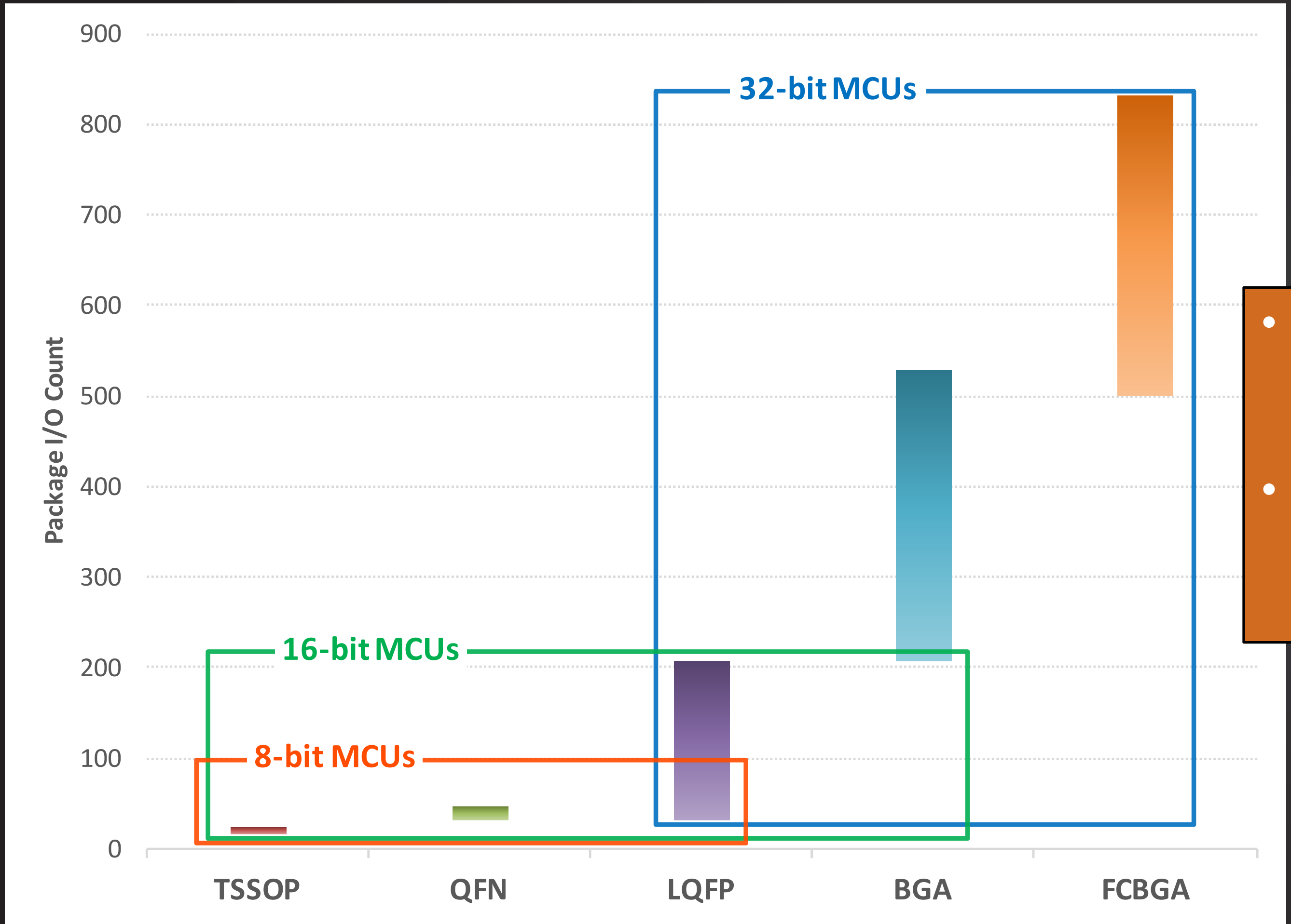
INFINEON AURIX™ AUTO MICROPROCESSOR: 32-BIT TRICORE™ MCUS

	TQFP-80	TQFP-100	LQFP-144 TQFP-144	LQFP-176	LFBGA-292	BGA-416	LFBGA-516
9x Series up to 8MB					TC297 300MHz	TC298 300MHz	TC299 300MHz
7x Series up to 4MB				TC275 200MHz	TC277 200MHz		
6x Series up to 2.5MB			TC264 200MHz	TC265 200MHz	TC267 200MHz		
3x Series up to 1MB		TC233 200MHz	TC234 200MHz		TC237 200MHz		
2x Series up to 1MB	TC222 133MHz	TC223 133MHz	TC224 133MHz				
1x Series up to 512KB	TC212 133MHz	TC213 133MHz	TC214 133MHz				

- Package options include leadframe (QFP) and area array (BGA) packages
- Infineon has introduced two Pb-free BGA (LFBGA) device families

Source: Infineon Technologies.

AUTOMOTIVE MCUS BY PACKAGE TYPE & PERFORMANCE



Source: TechSearch International, Inc.

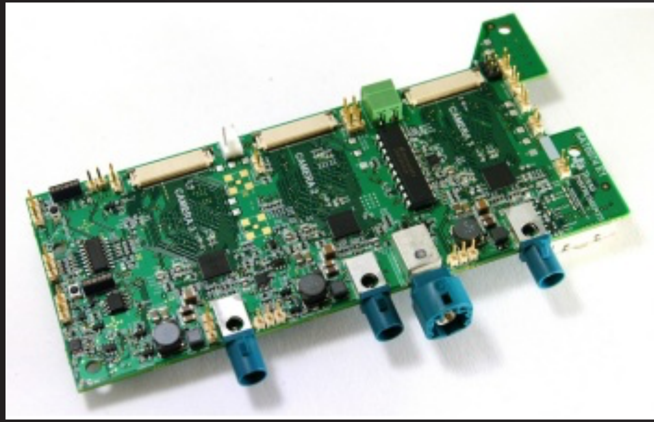
- ADAS functions are driving higher performance processors with higher pin counts
- Flip Chip BGA (FCBGA) devices creeping into AEC-Q100 grade 1 for ADAS applications

ADAS SENSOR FUSION (1)

Given that there are now multiple sensors in a vehicle, different types of data will be coming into the vehicle and must be sorted out to give the driver the safety information they need.

Sensor Fusion is the name of the game. Because there are different kinds of radar sensors and image sensors, there is an effort to centralize these ADAS functions, which in many applications are distributed within the car.

These include radar ECU modules, image processing ECU modules, and back ECU modules.



TIDA-00271 - ADAS Sensor Interconnect Reference Design Board for Remote Camera and Radar Modules

AV SENSOR FUSION (2)

There are a lot of distributed System-on-Chips (SoCs) in Autonomous Vehicles.

There is a trend to consolidate them in one module package.

As a result, massive sensor data from different sensors resides in the module.

Strong requirement to handle all of that sensor data input.

This data needs to be consolidated.

Host processors would hand off data to a separate embedded processor.

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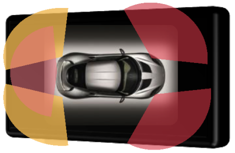
High-Reliability Requirements

AUTOMOTIVE DEVICE PACKAGING RELIABILITY REQUIREMENTS

- An increased number of **“not designed for automotive”** semiconductors are being used in applications
- **Zero defect quality** and **15+ year reliability** at the ECU level
- Shortcomings can be mitigated by collaboration among automotive OEMs, Tier 1 suppliers, and component makers by 1) **modifying vehicle** and/or 2) **changing device mission profile**, and 3) **adding system level solutions** such as redundancy, external component protection, and/or cooling

DIS	Chassis & Safety	ADAS	Body	Powertrain
Grade 3 & 2 -40°C to +105°C	Grade 1 -40°C to +125°C	Grade 1 -40°C to +125°C	Grade 1 -40°C to +125°C	Grade 1 & 0 -40°C to +150°C



Package STRESS	ABV	TEST METHOD			Duration			
		Standard	Condition	Unit	Grade 3	Grade 2	Grade 1	Grade 0
Temperature Cycling	TC	AEC-Q100, JESD22-A104	-50 ~ +175C	cycles				1000
			-50 ~ +150C		500	500	1000	2000
High Temperature Storage Life	HTSL	AEC-Q100, JESD22-A103	+175C	hours			500	1000
			+150C		500	500	1000	2000

Source: Freescale.

AUTOMOTIVE ELECTRONIC COMPONENT QUALITY

Automotive components, like any other devices, need to **comply with certain specifications or standards**.

Most well-known technical specification for automotive suppliers is **ISO/TS 16949 quality management system (QMS)**, prepared by the International Automotive Task Force (IATF), in conjunction with the International Organization for Standardization (ISO).

Automotive Electronics Council's **AEC-Q100 standard** provides a guideline for failure mechanism-based stress tests for qualification of automotive integrated circuits.

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AEC-Q100 QUALIFICATION GROUPS

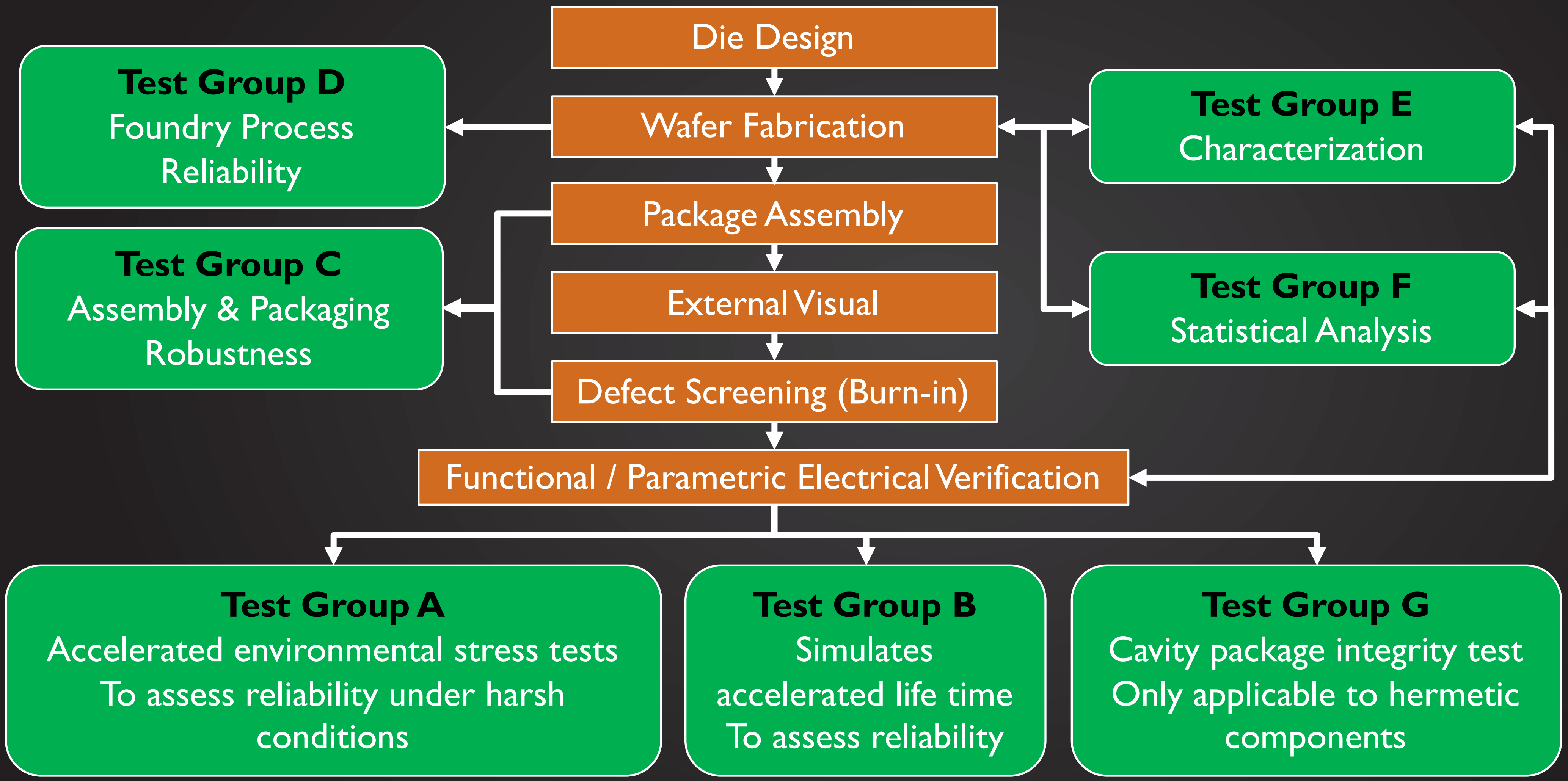
In the AEC-Q100 document, a comprehensive set of qualification tests is recommended for different grades (segregated according to different operating temperature) and/or different packaging (plastic or hermetic).

It stipulates the quantity, coupled with variability, of samples required per stress test.

The qualification groups, see next slide), involve accessing the assembly and packaging parameters before performing electrical testing.

Parts are then subsequently subjected to various electrical, environmental, as well as mechanical stresses, to ascertain the reliability of the parts for automotive applications.

AEC-Q100 QUALIFICATION GROUPS



AEC-Q100 QUALIFICATION GROUPS (1)

Starting at the foundry level, **Test Group D** evaluates reliability of foundry process and its design rules.

- These tests are typically performed by wafer foundry and reliability is checked through critical data monitoring using wafer level reliability (WLR) (e.g., electro-migration and hot carrier injection).

For assembly packaging, in-process tests under **Test Group C** include wire pull tests, physical dimensions validation, and solderability verification to ensure package assembly robustness.

Test Groups E and F assess the performance of the parts in terms of statistical distributions and electrical characteristics.

Test Group G is classified as cavity package integrity tests, which recommends specialized tests applicable only to hermetic components (e.g., leak rate).

AEC-Q100 QUALIFICATION GROUPS (2)

Test Group B simulates accelerated lifetime to assess reliability.

- A common test in Test Group B is the High Temperature Operating Life (HTOL), where parts are biased under high temperature over time to screen for potential failure modes during actual operation. Biasing conditions are carefully considered to ensure electro-optical devices and silicon ICs are well-assessed.
- The packaging was also designed to cope with heat dissipation from the chip set.

Test Group A utilizes various accelerated environmental stress tests.

- Common tests are Temperature Cycling (TC) and Autoclave (AC), to evaluate reliability under harsh environments with temperature and/or humidity extremes.

HIGH-POWER DEVICES AND PACKAGES

- Long life under extreme temperature ranges, high humidity, high number of extreme temperature cycles, instable voltage conditions, and harmful chemicals & gases, every failure is returned.
- Power devices and packaging focus on emerging developments in wideband gap devices (e.g., GaN) and the associated ultra-high power density and high temperature packaging required for next generation of automotive applications.
- Issues of thermal management are challenging and the needed device-package integration (co-design) into automotive systems.
- These packaged devices are used in AC/DC converters for battery chargers, DC/AC inverters for driving motors, and DC/DC converters for running peripheral devices (e.g. entertainment system).

AUTOMOTIVE VS. STANDARD QUALIFICATION CONDITIONS

Topic	Automotive	Commercial/Industrial
Stress Conditions	Depending on desired temperature grade Grade 0: -40ºC to 150ºC Grade 1: -40ºC to 125ºC Grade 2: -40ºC to 105ºC Grade 3: -40ºC to 85ºC Grade 4: 0ºC to 70ºC	Qualified to Grade 1, possibly accelerated
Electrical Test	Room temperature, and hot and cold temperature extremes per temperature grade	Room temperature
ESD-CDM	Corner pins = 750 V min. and all other pins = 500 Vmin. different test method and tester	All pins =250 V min.
Physical Dimensions	Cpk > 1.33 and Ppk >1.67 across all dimensions	Meet datasheet spec
Unique Stress Tests to Automotive Qualification	1. Power Temperature Cycle 2. Bond Pull after Temperature Cycle 3. Early Life Failure Rate	None
Composition of Qualification Lots	3 non-consecutive wafer lots, and 3 non-consecutive assembly lots for all qualification types	Wafer fab technology qualification = 3 wafer lots, and package qualification = 3 assembly lots

Source: Texas Instruments, "Get Your Motor Running: AEC-Q100 automotive grade drivers," https://e2e.ti.com/blogs_/b/motordrivecontrol/archive/2013/08/23/get-your-motor-running-aec-q100-automotive-grade-drivers

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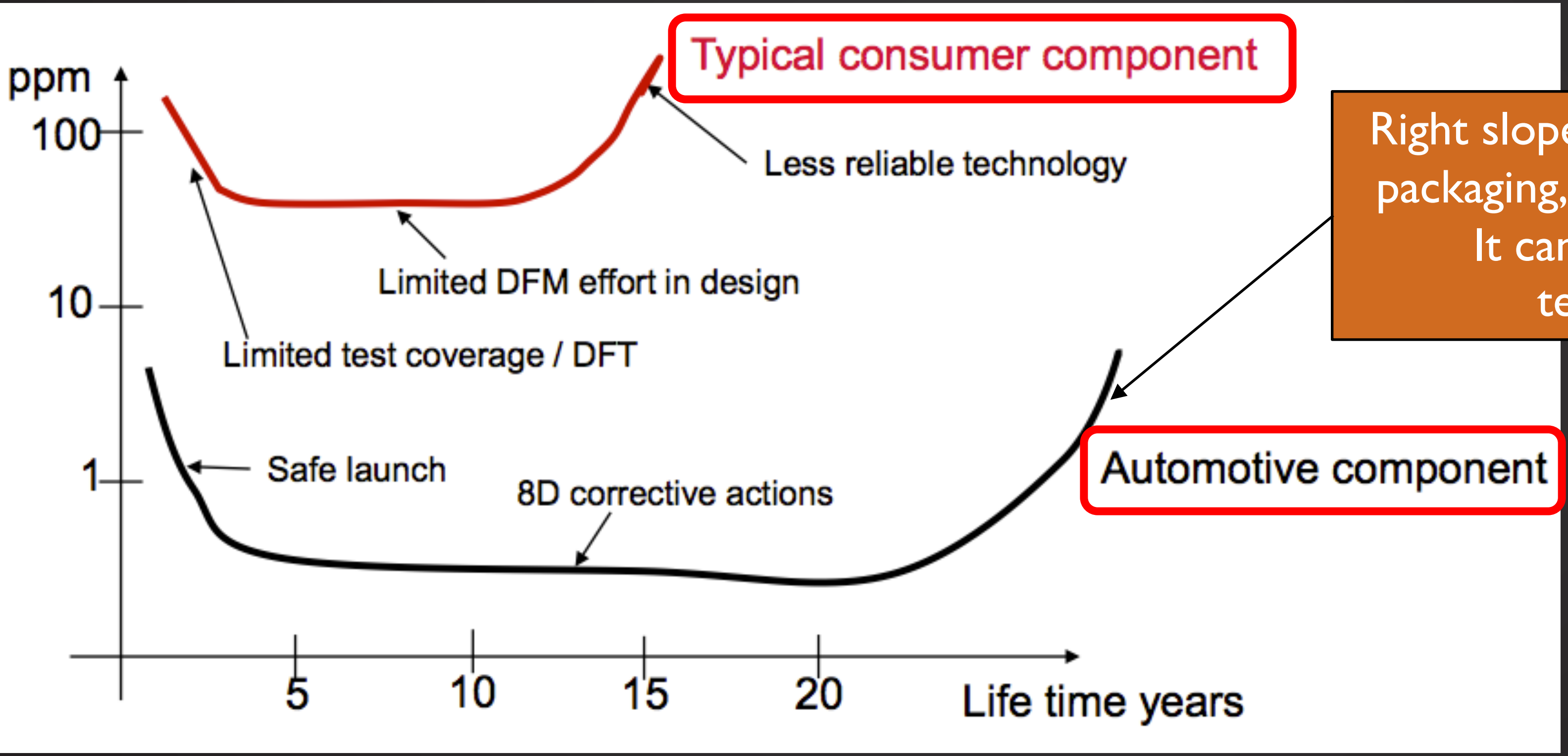
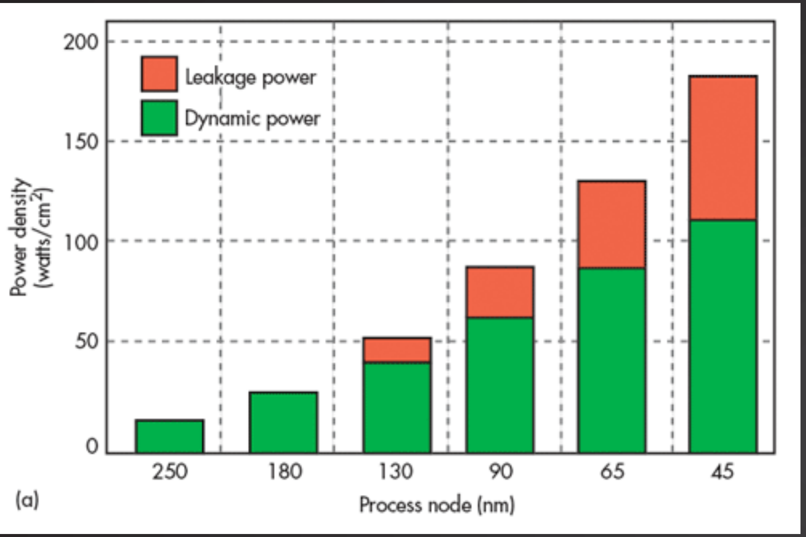
TYPICAL AUTOMOTIVE 125˚C MISSION PROFILE

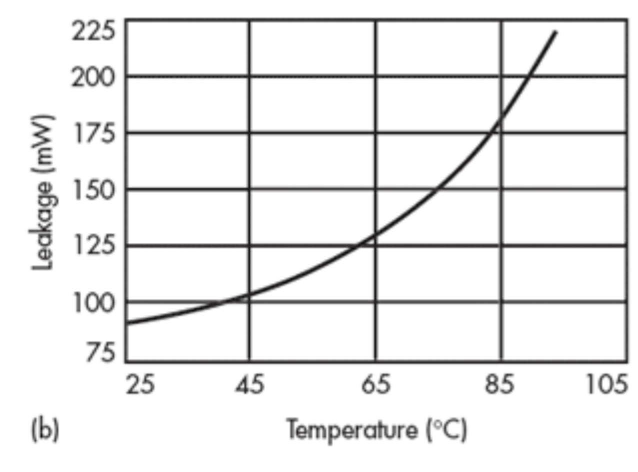


Right slope is frozen after technology, packaging, and product development. It can only be influenced by temperature profile.

Source: Freescale

WE HAVE SEEN THE ENEMY AND THE ENEMY IS HEAT





Note that leakage rises exponentially with temperature in a vicious cycle.

Power Density → Leakage Power → Hotspot Risks → Intra-die Temperature Variations → Reliability Concerns

Source: James Maliniak, "We Have Seen The Enemy, And The Enemy Is Heat,"
http://electronicdesign.com/article/power/we-have-seen-the-enemy-and-the-enemy-is-heat14949

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HIGH TEMPERATURE OPERATION

Grade	Minimum	Maximum	Application
Grade 0	-40C	150C	Automotive (under-hood)
Grade 1	-40C	120C	Automotive (in-cabin/vehicle)
Grade 2	-40C	105C	Industrial
Grade 3	-40C	85C	Commercial
Grade 4	0C	70C	

- AEC-Q100 defines five different temperature grades that specify ambient operating temperature range as part of stress test conditions for a given electronic device or Integrated Circuit (IC).
- Devices for automotive applications, here the infotainment system, shall pass at least grade 1 qualification.
- Therefore, special design at IP and SoC level, package selection as well as PCB design and technology selection shall be done accordingly.

DEVELOPMENT OF POWER ELECTRONICS SOLUTIONS

New interconnect & packaging

- Planar electronics, sintering, 3D integration

New device materials

- Wideband gap semiconductors (e.g., SiC, GaN)

Cooling technologies

- 3D cooling, high temperature electronics

System integration

- Modular power electronics, logic integration, ultra-low inductance

Engineering Challenges

- Design to costs, power-to-weight ratio, power density, design to reliability, system efficiency
- Create automotive standards for electric mobility (first steps VW82324-LV324)

AUTOMOTIVE COMPONENTS RELIABILITY MECHANISMS

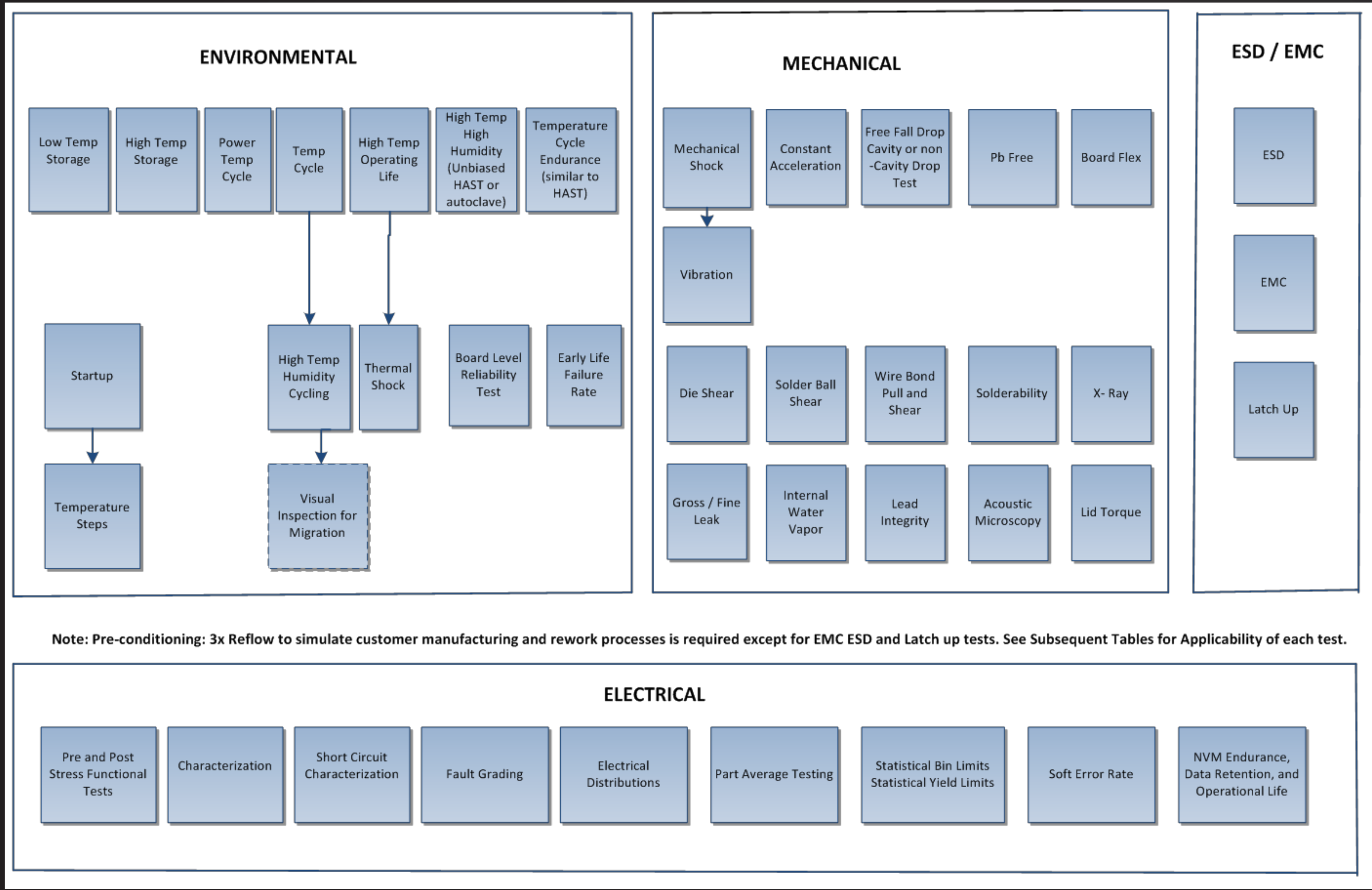
Semiconductor Supplier Considerations

- -40°C to 125°C : Not many semiconductor suppliers can do this
- Stable supply of a product for 15 years is also a factor

Electric cars requiring high power result in having high-temperature electronics that include:

- Innovative and emerging high-performance device
- Dielectric, interconnection, passive and molding compound materials
- Structures to achieve ultra-high high reliability with continuous operation of up to 250°C for 8000 hours

TYPICAL RELIABILITY TEST SEQUENCES



EXAMPLE: SIP RELIABILITY PROCESS

Reliability concerns implies that details matter

- Some SIP and modules are relatively simple and AEC-Q100 can apply as is.
- Complex SIP and modules will require a **thorough FMEA approach** to understand and then quantify the risk.
  - Multiple materials
  - Multiple silicon sources
  - Thermal management

Characterization concerns

- SIP and module “solution” complicates
  - Fault grading understanding
  - Performance interactions

Unique Packaging Elements in Autonomous Vehicles

ADVANCED DEVICE AND PACKAGE TECHNOLOGIES

A variety of **next generation self-driving sensing technologies** beyond those that are currently used for:

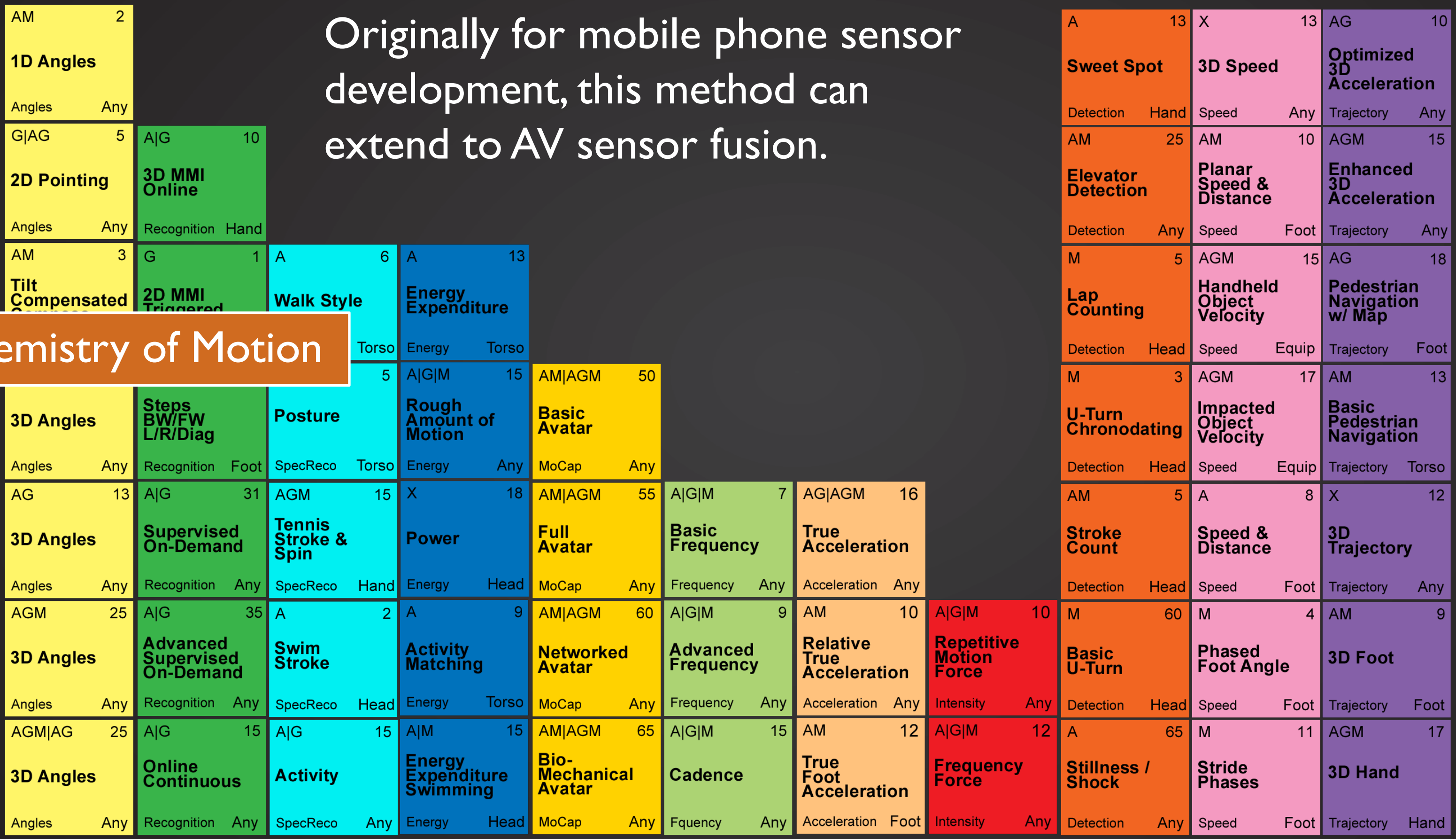
- Forward collision warning
- Lane departure prevention
- Parking assist
- Rear-cross traffic alert
- Adaptive cruise control
- Blind spot detection
- Rear and forward cameras

Next generation of Long Range Detection radars based on advances:

- SiGe device technologies
- Package integration
- Miniaturized and high performance LiDAR modules with advances in 3D photonics with faster reaction time
- Miniaturized 3D mono and stereo cameras.

SENSOR FUSION – PERIODIC TABLE APPROACH

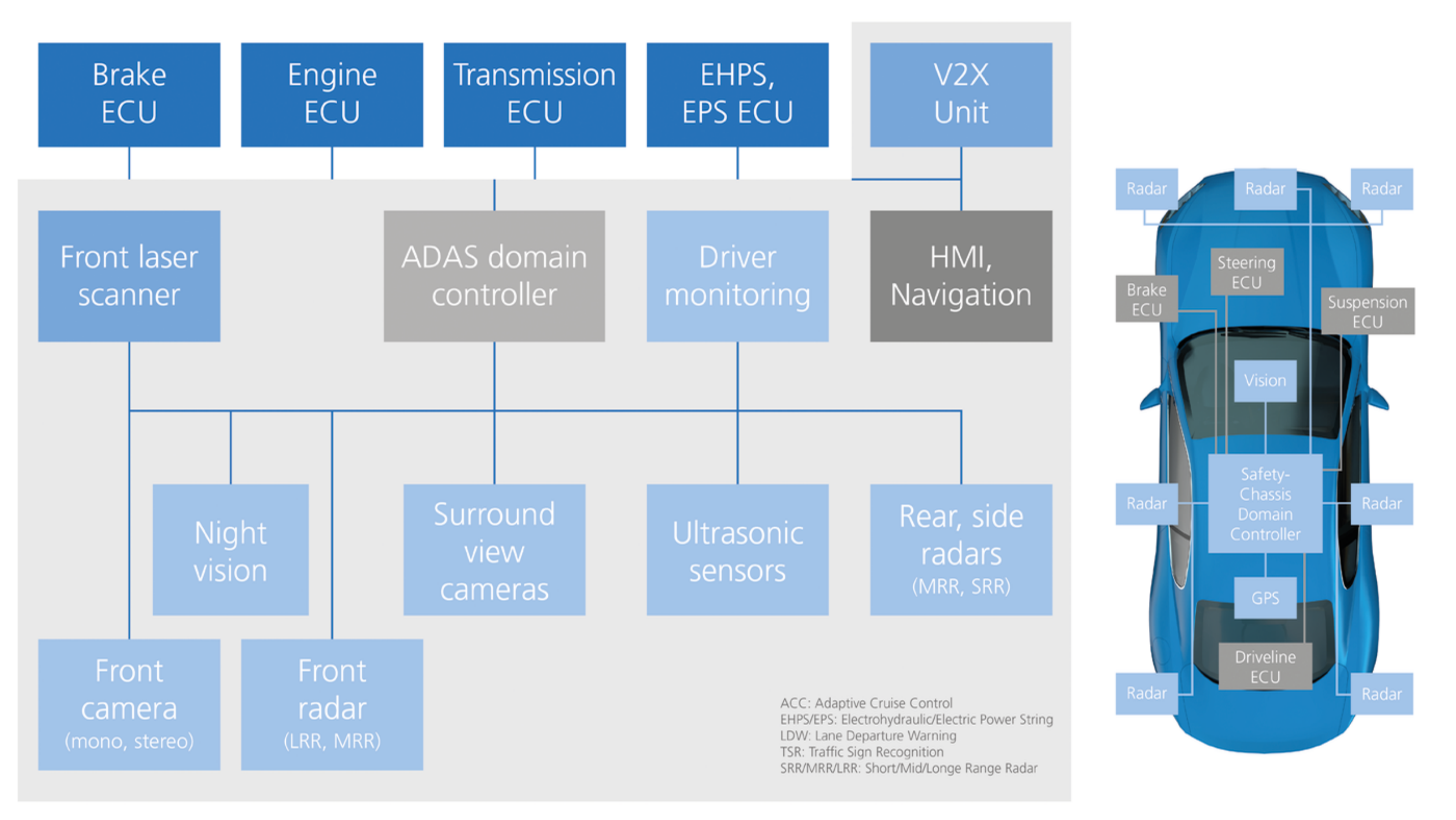
Originally for mobile phone sensor development, this method can extend to AV sensor fusion.



Movea: The Chemistry of Motion

Source: Bryon Moyer, Sensor Chemistry, http://www.eejournal.com/archives/articles/20120423-movea

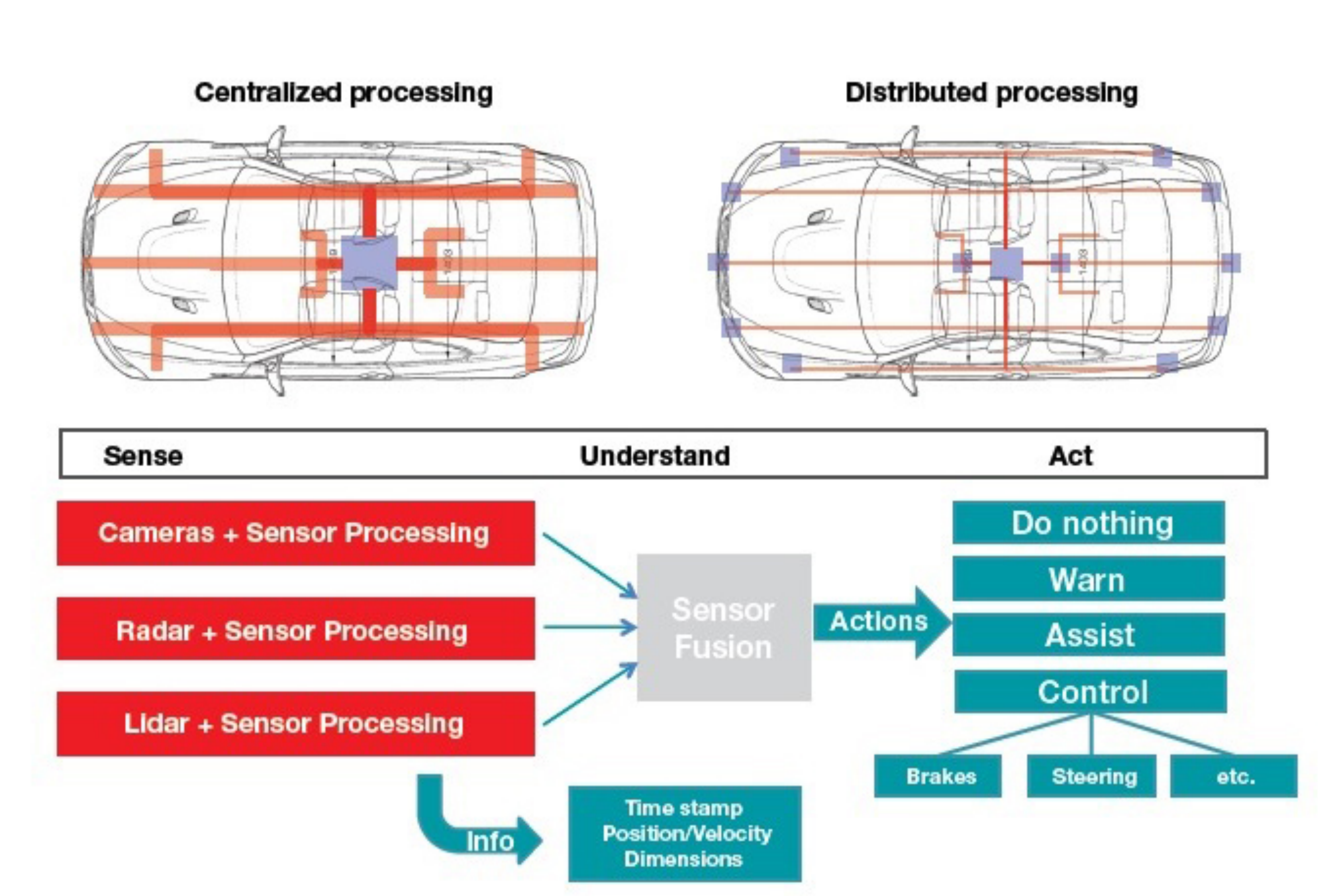
AUTONOMOUS VEHICLE SENSOR FUSION



Much like non-automotive MEMS & Sensors applications, FUSION provides more intelligence and comprehensive actuation of entire vehicle.

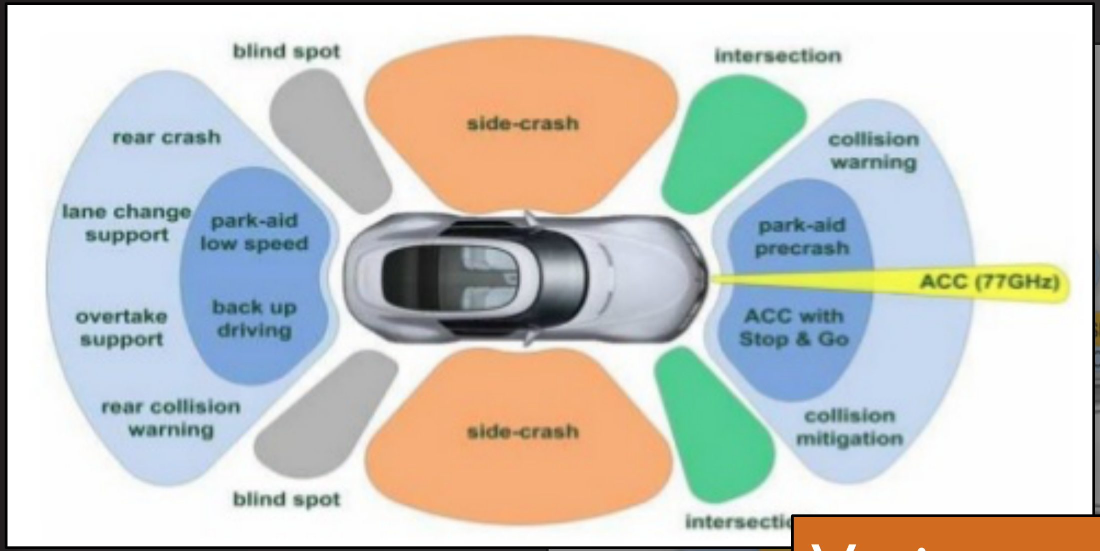
Source: M. Muli, (dSPACE), "Autonomous Technology Is Disrupting Conventional Automotive Development – Are You Prepared?," https://www.dspace.com/en/inc/home/news/blog-inc-1605.cfm

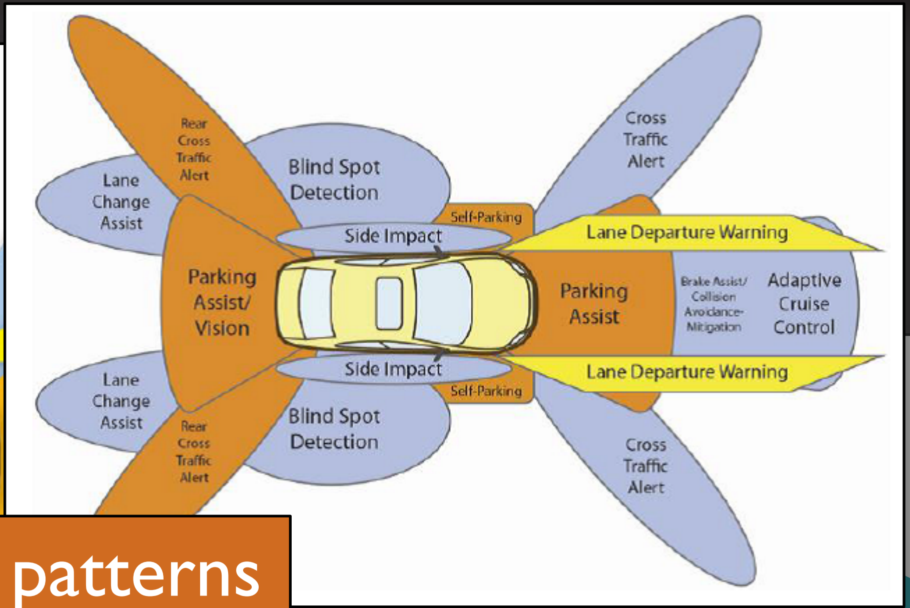
SENSOR FUSION: SENSE, UNDERSTAND, & ACT

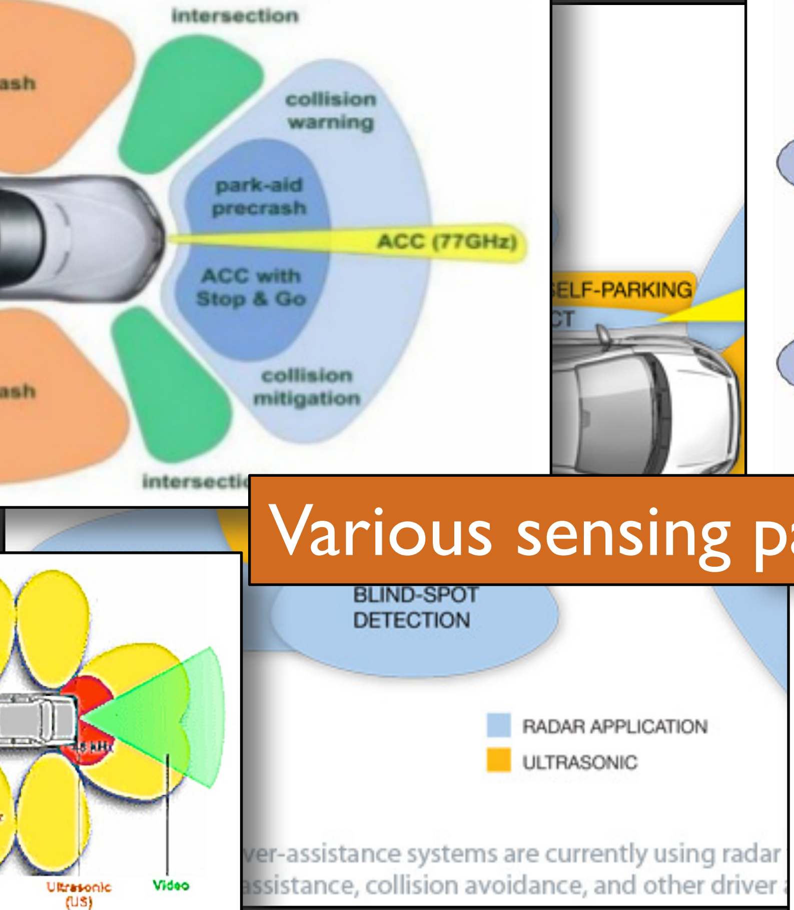


Source: H. Estl (TI), "Self-Driving Evolves Through Advanced Driver Assistance," http://electronics360.globalspec.com/article/6010/self-driving-evolves-through-advanced-driver-assistance

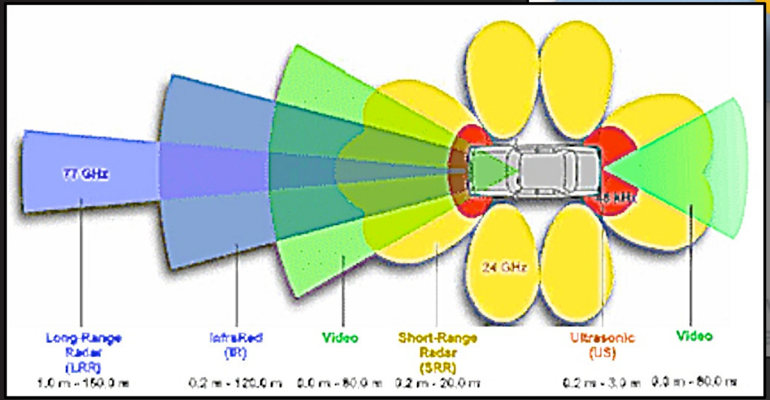
AUTONOMOUS VEHICLE SENSING PATTERNS

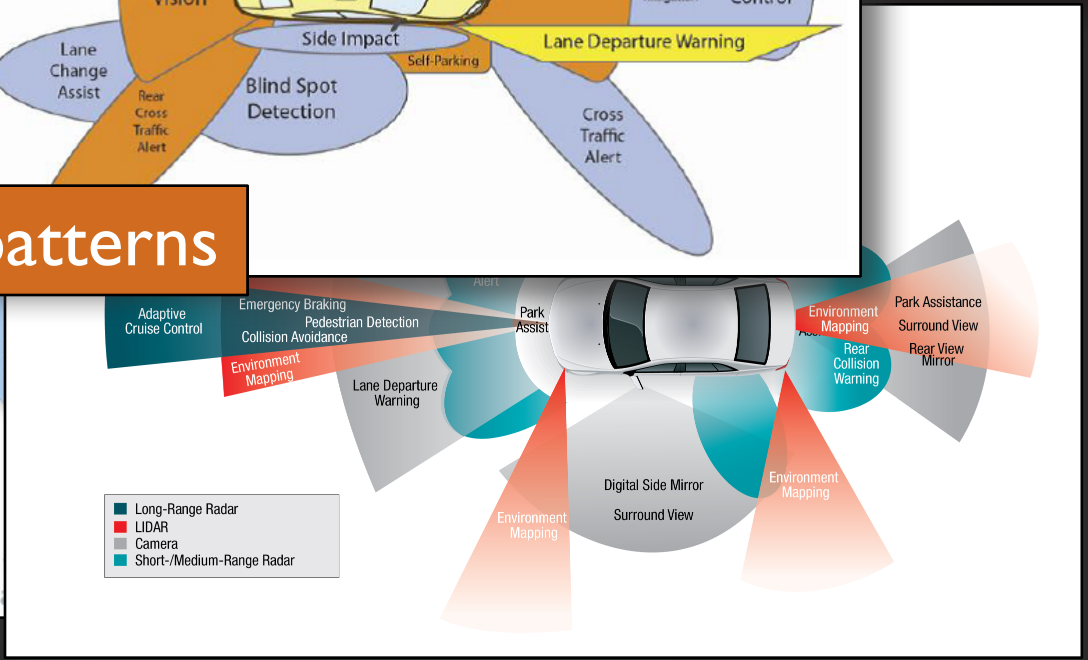






Various sensing patterns





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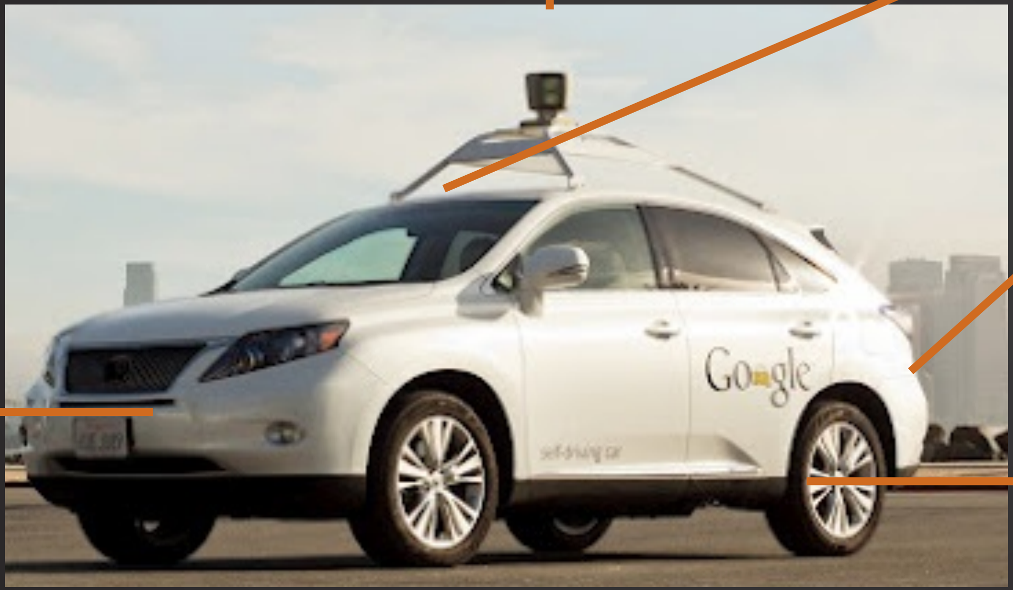
GOOGLE CAR: SENSORS AND TECHNOLOGIES USED

GPS helps navigation of the vehicle and also transmits vehicle data for the purpose of diagnostics & prognostics

360 Degree Laser detection (LIDAR)

Lidar senses the driving environment around, including tracing lane markings and road-width

A Stereo- or a Mono-vision camera for forward-looking functions such as traffic sign recognition, traffic signal recognition, peer vehicle movement & trajectory projection, besides pedestrian and obstacle detection.



RADAR Sensor

Source: Frost & Sullivan analysis.

3 RADAR Sensors
(Bow-mounted stereoscopic sensors)

Forward sensing radar monitors the distance of the vehicles and obstacles in front

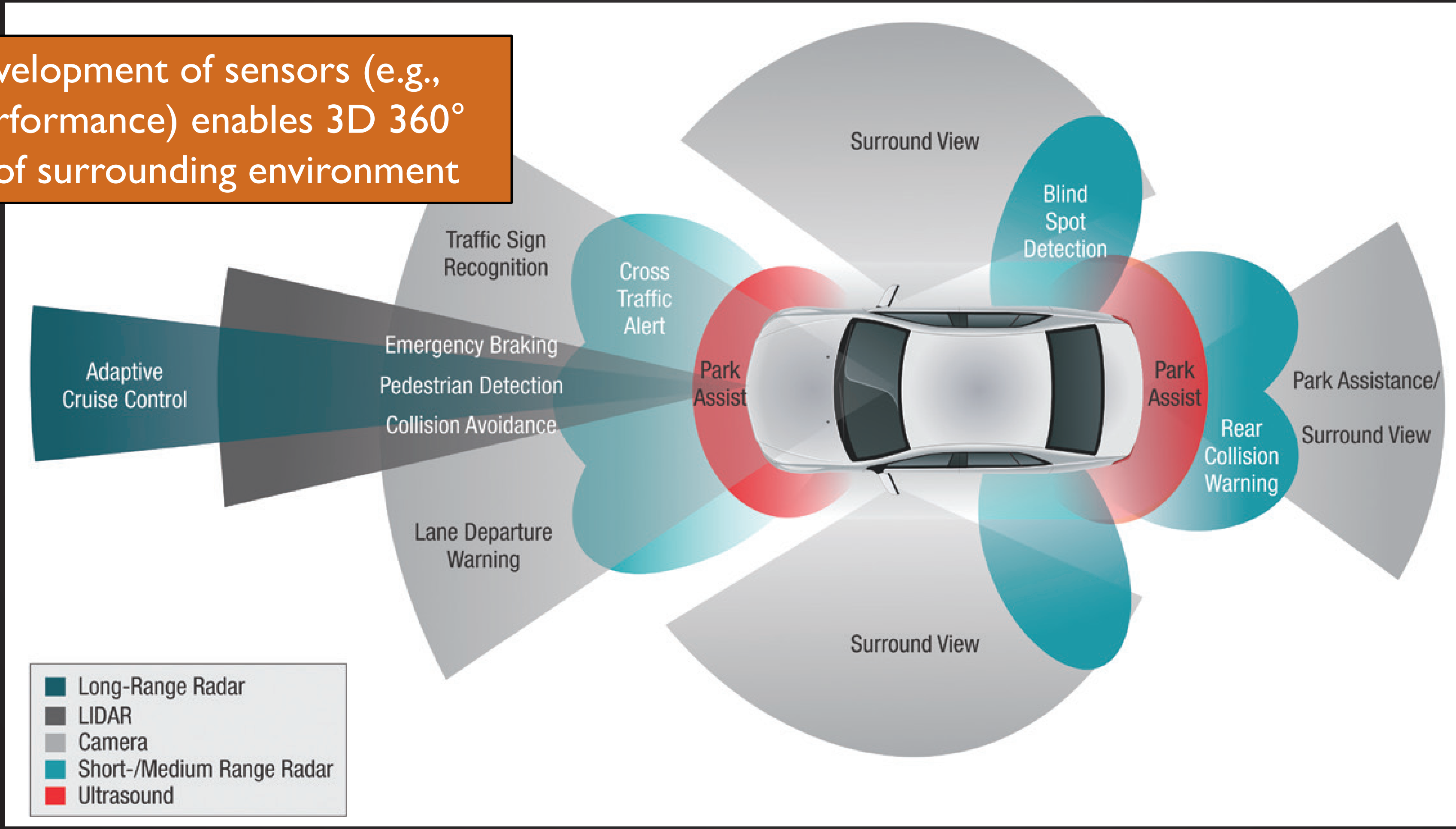
Position Estimator

Data from various sensors and vision inputs are fed into a central control unit that controls vehicle dynamics module and drive commands. Algorithm to be sophisticated to understand driving environment's direct and indirect messages in terms of traffic and maneuvering

Ultrasonic sensors may be used to measure the position of objects very close to the vehicle, such as curbs and other vehicles when parking

RECOGNIZING SURROUNDING ENVIRONMENT

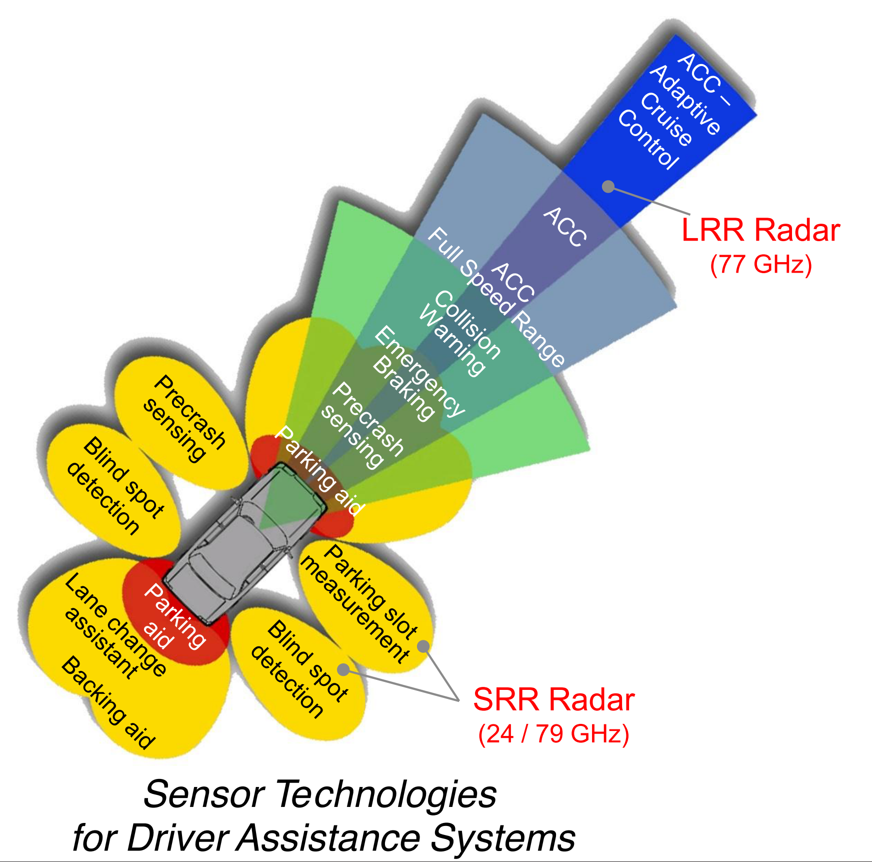
Further development of sensors (e.g., functions, performance) enables 3D 360° recognition of surrounding environment



Source: Texas Instruments, Advanced Driver Assistance (ADAS) Solutions Guide (2015)

AUTOMOTIVE DRIVER ASSISTANCE & AUTONOMOUS DRIVING

- Infineon's CEO provides drivers ADAS:
  - Traffic fatalities (1.3 million deaths per year; 90% caused by human errors)
  - Less accidents, lower insurance rates
  - Less traffic congestion (U.S. commuters spend 38 hours per year in traffic jams; cost of $121 billion/year)
  - Increased commuter productivity
  - Improved fuel efficiency (up to 50%)
- Many safety features for automotive
  - **Sensor technology** to collect and process information
  - **Computing for data analysis**
- Packaging trend is leaning toward Fan Out Wafer Level Package (FO-WLP)
  - Many packages are SiP used for radar modules
  - FO-WLP format (Freescale, Infineon, NXP)



Source: Freescale

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LIDAR SYSTEMS

- **Light Detection And Ranging** (LIDAR), which is mounted on vehicle roof is most important device in Autonomous Vehicles.
  - LIDAR consists of: Emitter, mirror and receiver
  - Emitter sends out a LASER beam that bounces off a mirror that is rotating along with cylindrical housing at 10 revolutions per minute.
  - After bouncing off objects, the LASER beam returns to the mirror and is bounced back towards the receiver, where it can be interpreted into data.
  - Autonomous Vehicle can then generate a map of its surroundings and use the map to avoid objects.
- Current LIDAR suppliers
  - Velodyne : http://velodynelidar.com
  - Ibeo: http://bayern-innovativ.de
  - Quanergy: http://lidarusa.com
  - Leddartech: http://leddartech.com
  - Phantom Intelligence: http://phantomintelligence.com

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LIDAR PRINCIPLES

LIDAR rapidly developing for automotive applications – will add to robustness under poor lighting conditions for pedestrians & other vulnerable road users.

Most LIDAR systems used in autonomous cars are based on Time of Flight (TOF) range measurements.

Today's systems are typically several cm^3 in size and offer 10's of cm ranging resolutions at an object distance of 10m.

For better ranging resolutions, high speed detectors and electronics are required.

TYPICAL LIDAR PACKAGING

Laser performance requirements

Range: Maximum distance for target of defined size and reflectivity (Typ. 30 – 300m)

Wavelength: 905 / 1550 nm

Peak Power & Pulse Width: High power / short pulse width for Eye Safety (Typ. 75W ; < 5ns)

Package: Small package w/ Integrated driver

PHOTODIODE REQUIREMENTS

Sensitivity : High (50 A/W) -> APD ; Low (0.5 A/W) -> PIN Photodiode

Wavelength : 905 / 1550 nm; compatible with laser peak wavelength

Cost: APD typically 20X more than Photodiode

Package : Single / Array; depends on system design

Photodiode Type	Characteristics
Photodiode	Fast switching time (10 ns) ; linear response ; small temp. coefficient ; Preferred in Flash LIDAR
Phototransistor	High photocurrent ; small package ; cheaper ; higher temp. coefficient
Avalanche Photodiode (APD)	High SNR / voltage supply / temperature sensitivity / Price ; Preferred in Scanning LIDAR
Single Photon Multiplier	Higher gain than APD at lower operating voltage; Dynamic range / recovery time poor - improving

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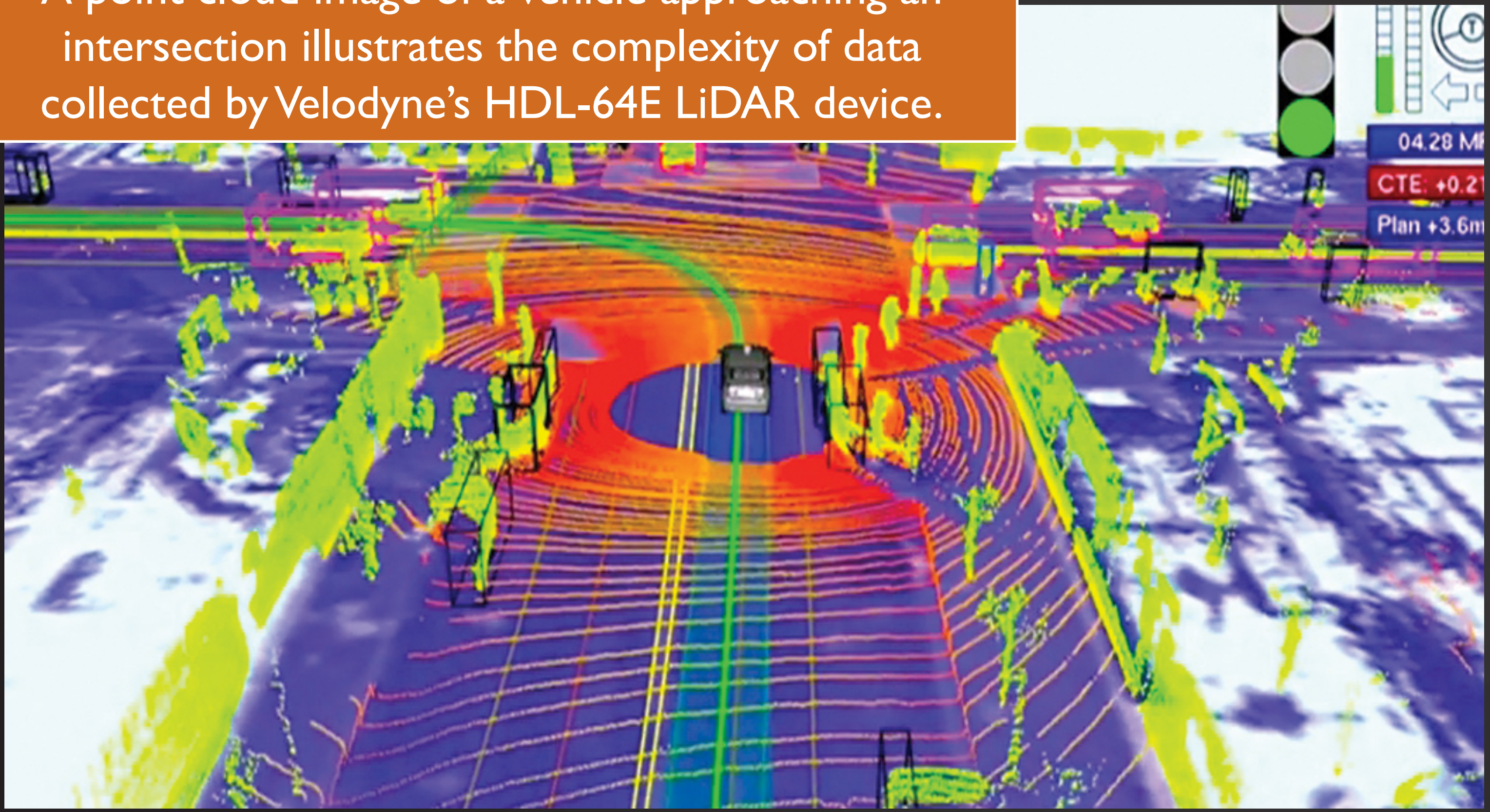
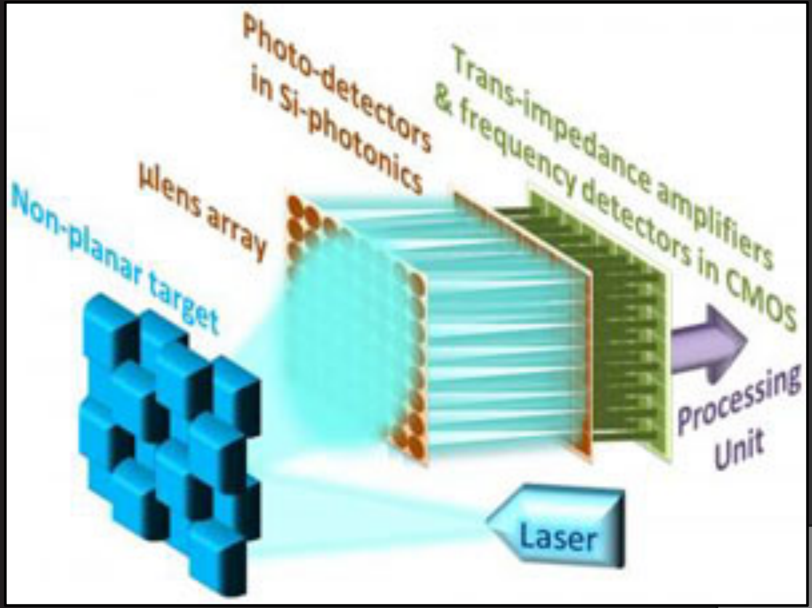
LIDAR POINT CLOUD IMAGING & EQUIPMENT

A point cloud image of a vehicle approaching an intersection illustrates the complexity of data collected by Velodyne's HDL-64E LiDAR device.

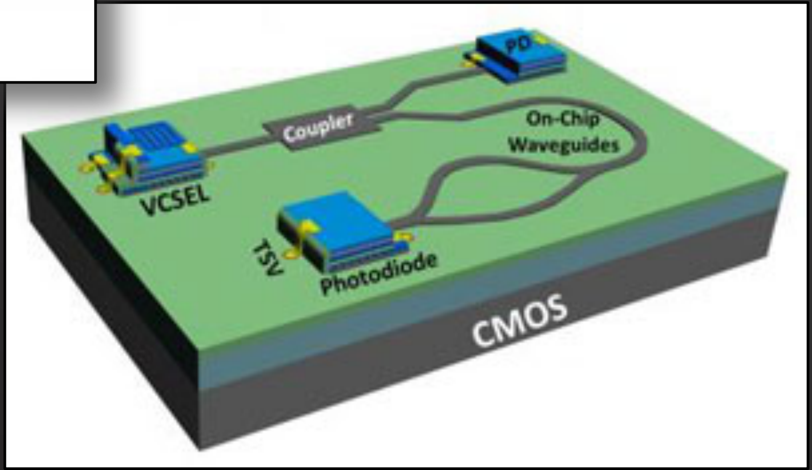


Source: "LiDAR Boosts Brain Power for Self-Driving Cars," http://eijournal.com/resources/lidar-solutions-showcase/lidar-boosts-brain-power-for-self-driving-cars

LIDAR R&D: DEVICE & PACKAGE MINIATURIZATION



This conceptual image shows an integrated 3-D camera with multiple pixels using the frequency-modulated continuous wave (FMCW) LIDAR 3D imaging technology. Courtesy of Behnam Behroozpour, UC Berkeley.



This 3-D schematic shows MEMS-electronic-photonic heterogeneous integration. Courtesy of Niels Quack, UC Berkeley.

TYPICAL RADAR PACKAGING

Purpose: Object-detection system that uses radio waves to determine the range, angle, or velocity of objects.

Range: 24-77GHz frequency

Less unaffected by: adverse weather conditions, pollution, external illumination

Data streams: from radar signals contain distance, speed, object recognition (in the future).

RADAR PACKAGING ATTRIBUTES

As cost decreases, radar systems (e.g., for blind-spot detection), are being installed in more classes of vehicles.

Automotive radar systems can be classified in two sets:

- **Long-range radar (LRR)** - $125-150 (up 200m)
- **Medium/short-range radar (SRR)** - $50-100 ASP (0.2 to 30m)

LRR systems are always mounted in front of car and look forward.

- These systems see distances of more than 100 m and are typically used for adaptive cruise control, brake assistance and collision warning.

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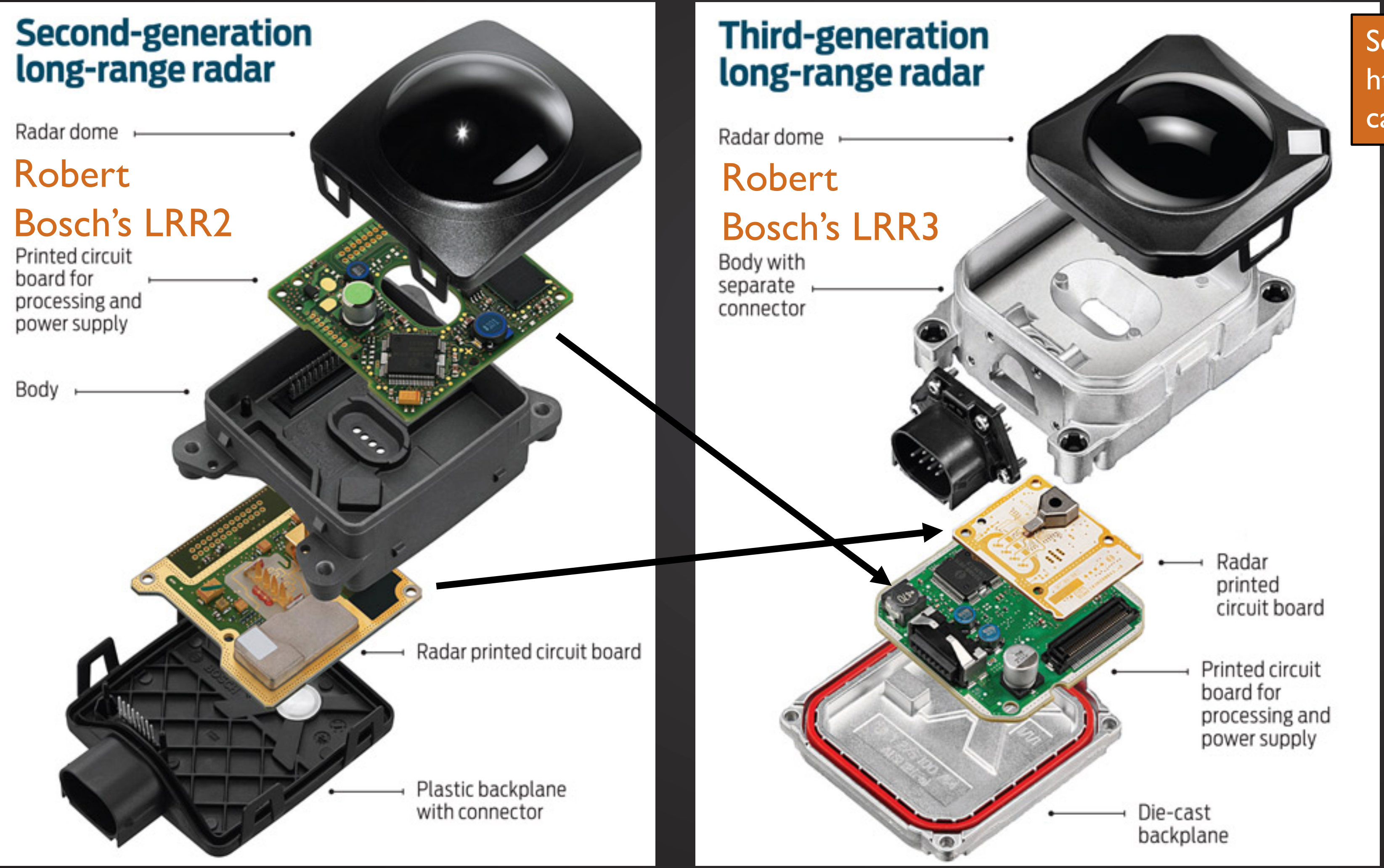
RADAR PACKAGING



Source: R. Stevenson, "Long-Distance Car Radar," http://spectrum.ieee.org/transportation/advanced-cars/longdistance-car-radar, 29SEP11.

Device technologies (GaAs -> SiGe)

↓

Higher bandwidth & performance

↓

Package Integration

↓

Processor, power, and radar PCB miniaturization

LRR PACKAGE-RELATED DRIVING FACTORS

Driving factors in the development of long-range radar systems include:

- A reduction in system **size**
- Lower system **power dissipation** (allowing for smaller packages and less cooling effort)
- **Low-noise** components and design (for high signal performance)
- **Antenna designs** that allow more resolution and better object detection/differentiation capabilities
- **Digital Signal Processors** (DSPs) to run the complex software algorithms

ADAS VISION ECOSYSTEMS

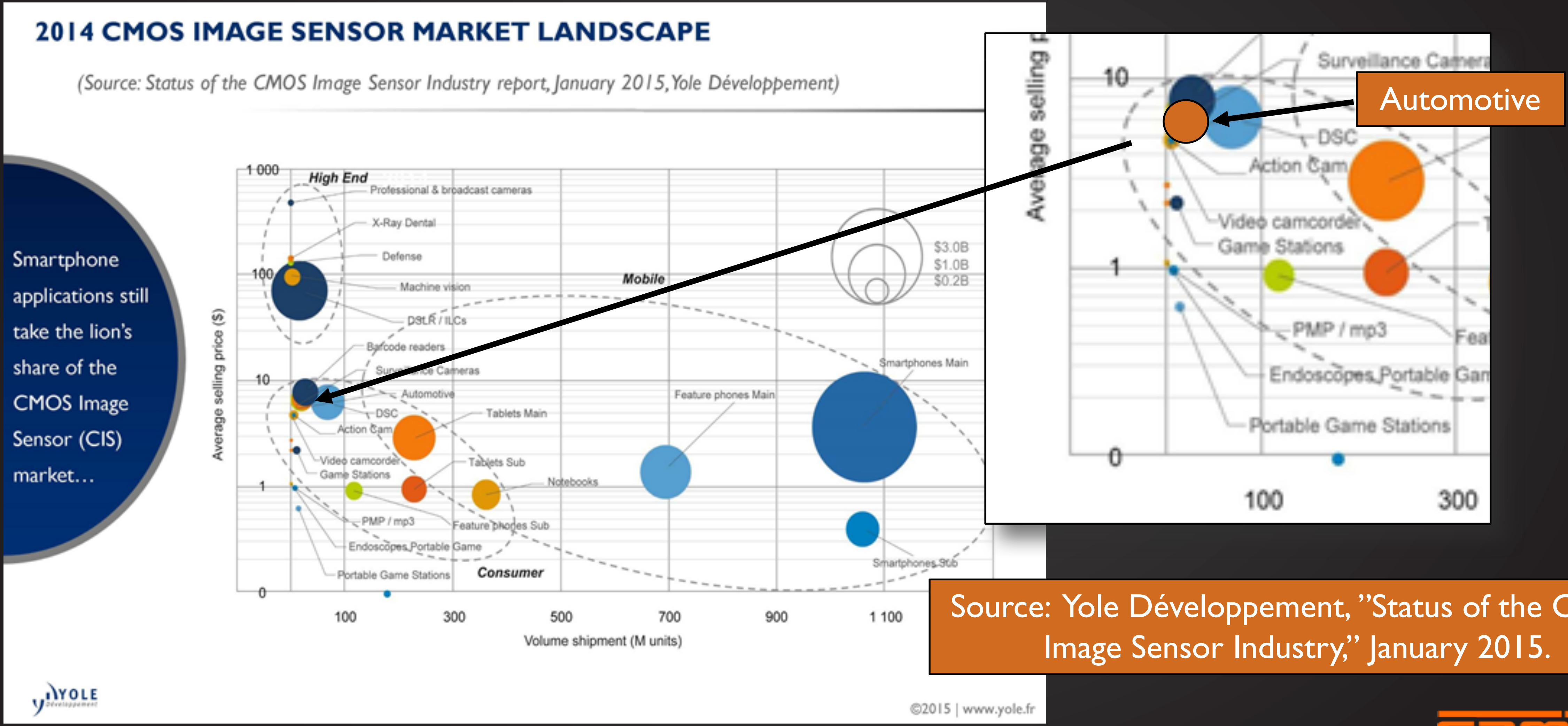
ADAS vision system vendors

- Magna, Clarion, TRW (ZF), Hitachi, Continental, Autoliv, Valeo, and Panasonic.

CMOS Image Sensor (CIS) vendors

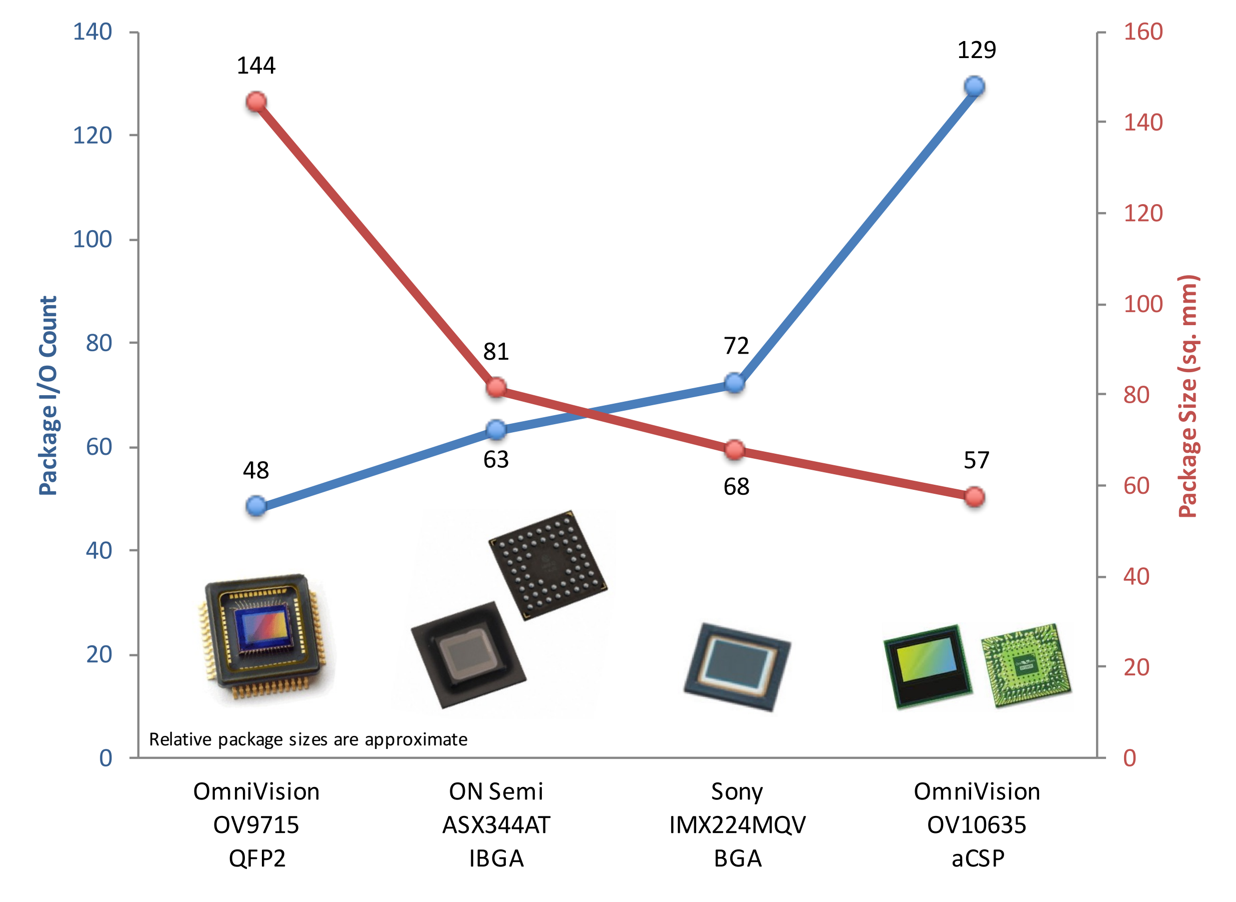
- OmniVision, On Semiconductor, ST Microelectronics, and Melexis

AUTOMOTIVE CAMERA PRODUCT ASP & VOLUMES



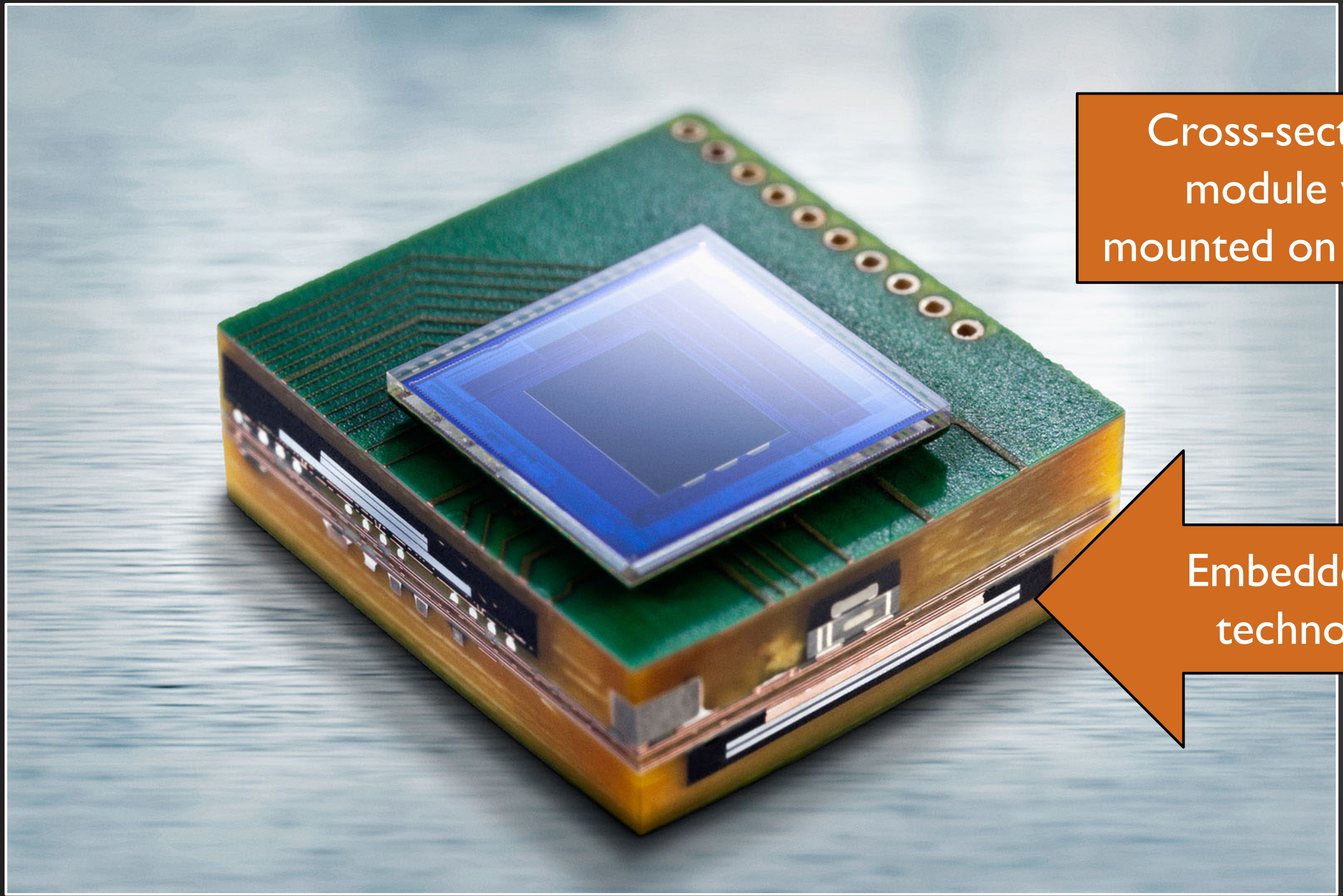
Source: Yole Développement, "Status of the CMOS Image Sensor Industry," January 2015.

AUTOMOTIVE IMAGE SENSOR PACKAGING TRENDS



Source: TechSearch International, Inc., adapted from company data.

SMART CAMERA SYSTEMS

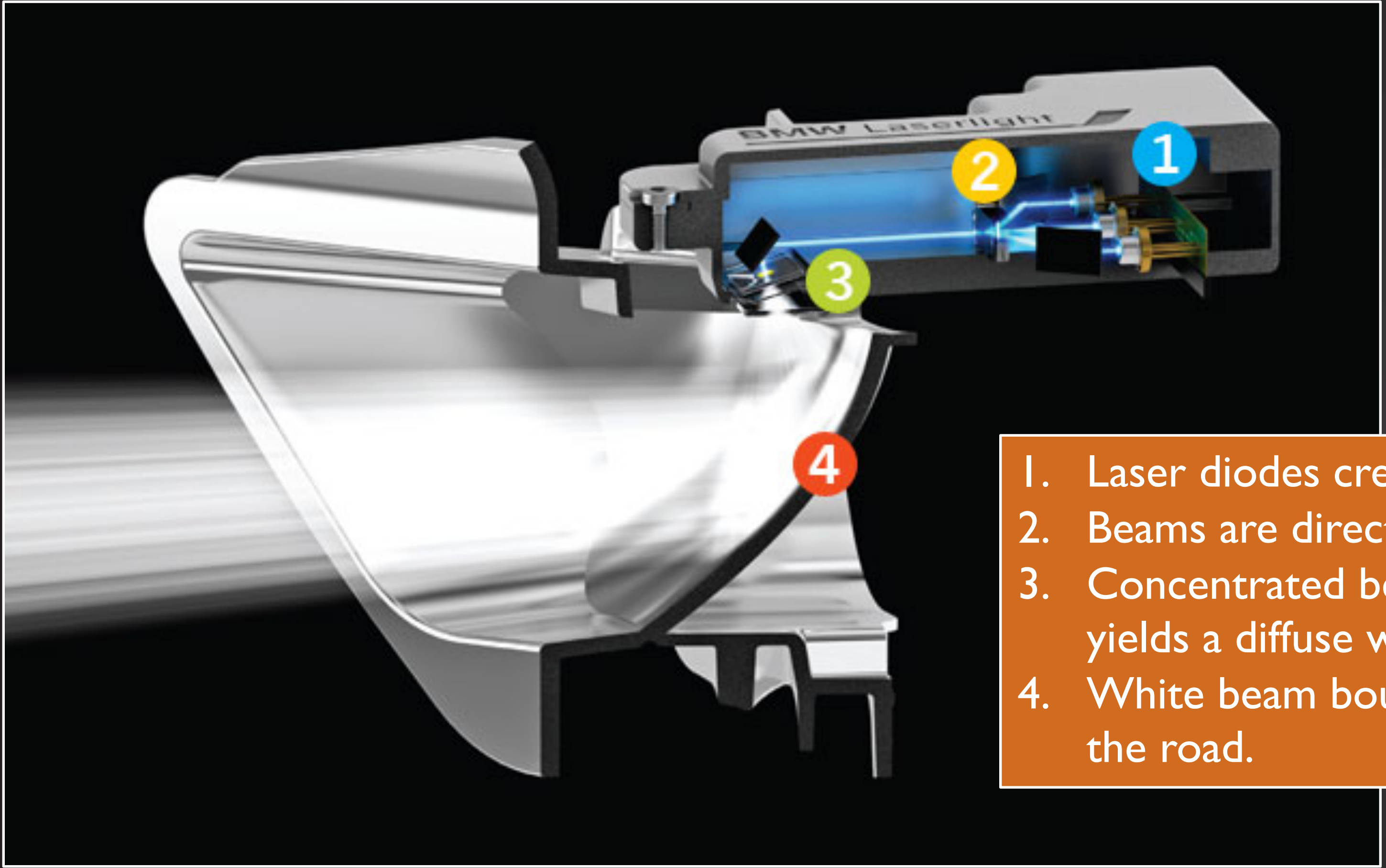


Cross-section of microcamera module with image sensor mounted on Printed Circuit board.

Embedded die technology

Source: Fraunhofer IZM, https://www.fraunhofer.de/en/press/research-news/2014/october/miniature-camera-may-lead-to-fewer-accidents.html

ADVANCED LASER HEADLIGHTS



1. Laser diodes create three separate beams of blue laser light.
2. Beams are directed through a prism, merging into a single beam.
3. Concentrated beam passes through a phosphorous lens that yields a diffuse white light, which is safer for human eyes.
4. White beam bounces off a reflector and past a clear lens onto the road.

Source: B. Wasef, "How It Works: The BMW i8's Laser Headlights," Popular Mechanics, http://www.popularmechanics.com/cars/a10841/how-it-works-the-bmw-i8s-laser-headlights-16905044/

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AUTOMOTIVE MEMS & SENSOR PACKAGING TRENDS

- Packaging is still an **enormously important component** of MEMS & Sensors manufacturing.
- Technology and economics are **driving convergence and consolidation** between front-end and back-end manufacturing.
- **Prior concepts and processes** inhibiting front-end and back-end convergence and consolidation are fading.
- In the future, the MEMS & Sensors packaging landscape **will look different** from today.

ADAS IMPACT ON SEMICONDUCTOR INDUSTRY

- ADAS is driving **more semiconductor content** into automobiles
  - Higher level of ADAS = more electronics
- To achieve autonomous driving will need **redundant systems** similar to airplanes
  - Predicted to be 2X, not 3X as in the case of aircraft
- One method of redundancy leads to **sensor fusion** where multiple types of sensor input would be fused together to form decision
  - Example: LIDAR + Radar could be used for front collision avoidance
  - This drives higher I/O counts and greater processing power for microcontrollers
  - Shifts from localized MCU to centralize fusion
  - Shifts from MAP-BGA (Mold Array Process-Ball Grid Array) to FC-BGA (Flip Chip-Ball Grid Array)
- **Image sensors fused with processors** desirable
  - Localized processing of pedestrian recognition, etc.
  - Faster image processor speeds drives move to advanced process nodes
  - Stacked die attractive, if meets reliability requirements

Source: TechSearch International, Advanced Packaging Update (APU-1-1015).

CONCLUSIONS

- Semiconductors and their integration are **sources of automotive innovation**.
- Automotive innovation needs **newest technologies**.
- **Combined sensing and imaging systems** will provide a more comprehensive solution (e.g., LiDAR and CMOS camera).
- **Redundancy** (several 360° sensors) are required to ensure fail-safe autonomous action.
- Each phase of Autonomous Vehicle innovation imposes different challenges on **semiconductors**, **packaging**, and **integration**.
- System-, module-, package-, and device-level integration are **future ADAS challenges**.
- Complete supply chain has to **cooperate at a different level** to make tomorrow's automotive applications reliable and fail safe.

ADAS SENSOR PACKAGING TRENDS

Next Gen MEMS & Sensors packaging must continue to leverage:

- New materials, processes, technologies, and equipment
- Co-design actions involving chips, package, and systems
- Design for Manufacturability principles
- Innovation & brainstorming

*You can't connect the dots **looking forward**;*
*you can only connect them **looking backward**.*
*So you **have to trust** that the dots will somehow connect in your future…*
This approach has never let me down,
*and it has made **all the difference** in my life."*
– Steve Jobs, Entrepreneur

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SUMMARY: FUTURE CARS WILL SLOWLY EVOLVE…

FROM

Traditional mechanical, fuel-powered, and high-powered electronic vehicles

→

THROUGH

Development of new chips, packages, software, and systems

→

INTO

Electrical-powered, ultra-sensitive machines that can anticipate many critical situations

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ACKNOWLEDGEMENTS

Samtec Microelectronics would like to recognize:

- Yole Développement (www.yole.fr)
- IHS's Automotive Sensor Intelligence Service (https://technology.ihs.com/Services/548196/automotive-sensor-intelligence-service)
- TechSearch International (www.techsearchinc.com)
- SEMI (www.semi.org)
- JEDEC (www.jedec.org)
- MEMS & Sensors Industry Group (www.memsindustrygroup.org)

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R. Stevenson, "A driver's sixth sense," in IEEE Spectrum, vol. 48, no. 10, pp. 50-55, October 2011.

R. Tummala, et al., “New era in automotive electronics, a co-development by Georgia tech and its automotive partners,” 2016 Pan Pacific Microelectronics Symposium (Pan Pacific), pp. 1-4.

Thank you for your attention!