Measurements Systems and Sensors for Autonomous Vehicle and Smart Mobility

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Recent plenary or invited talks & tutorials

- Saponara, S., “Measurement Performance of Sensor Systems towards Autonomous Vehicles”, **IEEE Distinguished Lecture 2017-2020**
- Saponara, S., “Measurement Systems and Sensors for Autonomous Vehicles”, **IEEE I&M Video Tutorial-Expert Series**
- Saponara, S., “Advanced Sensing Electronic Systems for Electrified and Autonomous Vehicles”, Webinar for the **IEEE Transportation Electrification Council**, 25th Jan.2018
- Saponara et al., “Design exploration for millimeter-wave short-range industrial wireless communications“ , **Best Session Presentation Award**, IEEE IECON 2016
- Saponara S., et al., “Real-time FPGA-based radar imaging for smart mobility systems”, **Invited talk** at SPIE Photonics Europe 2016
- Saponara, S., “On-board sensors and instrumentation for driver-assisted/autonomous vehicles”, **Tutorial** IEEE I2MTC 2017
- Saponara S, “Advances in technologies and architectures for low-power and highly integrated ubiquitous radars”, **Plenary talk** at IEEE Radar Conference 2012
- Saponara S, “Hardware accelerators for real-time and video-camera based automotive driver assistance systems”, **Invited talk** at AEIT Workshop 2016
- Saponara S, “Recent Advances in Circuits & Systems for Driver-Assisted/Autonomous Vehicles and Smart Mobility”, **Tutorial** at IEEE NGCAS 2017

Bibliography

- F. Pieri, C. Zambelli, A. Nannini, P. Olivo, S. Saponara, "Consumer electronics is redesigning our cars? challenges of integrated technologies for sensing, computing and storage", IEEE Consumer Electronics Magazine 2017
- S. Saponara, G. Ciarpi, "IC design and measurement of an inductorless 48V DC/DC converter in low-cost CMOS technology facing harsh environments", IEEE Transactions on Circuits and Systems I, 2017
- S. Saponara, P. Tisserand, P. Chassard, Dieu My Ton, "Design and Measurement of Integrated Converters for Belt-driven Starter-generator in 48 V Micro/mild Hybrid Vehicles", IEEE Transactions on Industry Applications, 2017
- S. Saponara, F. Giannetti, B. Neri, G. Anastasi, "Exploiting mm-Wave Communications to Boost the Performance of Industrial Wireless Networks", IEEE Transactions on Industrial Informatics, 2017
- S. Saponara, G. Ciarpi, "Design and experimental measurement of EMI reduction techniques for integrated switching DC/DC converters", IEEE Canadian Journal of Electrical and Computer Engineering, 2017
- S. Saponara, B. Neri "Radar sensor signal acquisition and multi-dimensional FFT processing for surveillance applications in transport systems ", IEEE Trans. on Instrumentation and Measurement, 2017
- S. Saponara, B. Neri, "Design of compact and low-power X-band Radar for mobility surveillance applications", Computers and Electrical Engineering, 2016,
- A. Sisto, L. Pilato, R. Serventi, S. Saponara, L. Fanucci, "Application specific instruction set processor for sensor conditioning in automotive applications", Microprocessors and Microsystems, 2016
- S. Saponara, et al., "Predictive Diagnosis of High-Power Transformer Faults by Networking Vibration Measuring Nodes With Integrated Signal Processing", IEEE Trans. on Instr. and Measurement, 2016
- M. Turturici, S. Saponara, et al., "Low-power DSP system for real-time correction of fish-eye cameras in automotive driver assistance applications", Journal of Real-Time Image Processing, 2014

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- Saponara S, Pasetti G, Tinfena F, Fanucci L, D'Abramo P, "HV-CMOS design and characterization of a smart rotor coil driver for automotive alternators", IEEE Trans. on Industrial Electronics 2013
- Baronti F., Lazzeri A., Roncella R., Saletti R., Saponara S., "Design and Characterization of a Robotized Gearbox System Based on Voice Coil Actuators for a Formula SAE Race Car". IEEE/ASME TRANSACTIONS ON MECHATRONICS, 2013
- Saponara S, Pasetti G, Costantino N, Tinfena F, D'Abramo P, Fanucci L, "A Flexible LED Driver for Automotive Lighting Applications: IC Design and Experimental Characterization". IEEE TRANSACTIONS ON POWER ELECTRONICS, 2012
- Baronti F, Petri E, Saponara S, Fanucci L, Roncella R, Saletti R, D'Abramo P, Serventi R, "Design and Verification of Hardware Building Blocks for High-Speed and Fault-Tolerant In-Vehicle Networks", IEEE Trans. on Industrial Electronics 2011
- Costantino N, Serventi R, Tinfena F, D'Abramo P, Chassard P, Tisserand P, Saponara S, Fanucci L, "Design and Test of an HV-CMOS Intelligent Power Switch With Integrated Protections and Self-Diagnostic for Harsh Automotive Applications", IEEE Trans. on Industrial Electronics 2011
- Saponara S, Petri E, Fanucci L, Terreni P, "Sensor Modeling, Low-Complexity Fusion Algorithms, and Mixed-Signal IC Prototyping for Gas Measures in Low-Emission Vehicles", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 2011
- Saponara S, Casarosa G, Hambloch P, Ciuchi F, Fanucci L, Sarti B, "Modeling, Sensitivity Analysis, and Prototyping of Low-g Acceleration Acquisition Systems for Spacecraft Testing and Environmental-Noise Measurements", IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 2011
- Marsi S, Saponara S, "Integrated video motion estimator with Retinex-like pre-processing for robust motion analysis in automotive scenarios: algorithmic and real-time architecture design", Journal of Real-Time Image Processing, 2010

Open special issues on the theme

- **IEEE Transactions on Industrial Informatics IF 6.79**
- **http://www.ieee-ies.org/images/files/tii/ss/2017/CfP-Embedded_and_Networked_Systems_for_Intelligent-Vehicles_and_Robots.pdf**

- **Sensors IF 2.67**
- **http://www.mdpi.com/journal/sensors/special_issues/Smart_Mobility**

- **Energies IF 2.26**
- **http://www.mdpi.com/journal/energies/special_issues/e_transportation_smart_microgrid**

- **Applied Sciences IF 1.67**
- **http://www.mdpi.com/journal/applsci/special_issues/dc_hybrid**

- **Journal of Real-Time Image Processing IF 2.02**
- **http://static.springer.com/sgw/documents/1608235/application/pdf/JRTIP-SpecialIssue-ITS_clean.pdf**

Outline

- Innovation and trends of circuits & systems for smart vehicles and int. transport systems (ITS)
- Remote sensing (Radar) for smart vehicle & ITS
- Sensing technology for navigation
- Computing & memory needs
- Mixed-signal ICs for smart vehicles
- Image processing for smart vehicles and ITS
- Conclusions

Trends in smart vehicles and ITS

Vehicles are becoming electrified, shared, autonomous

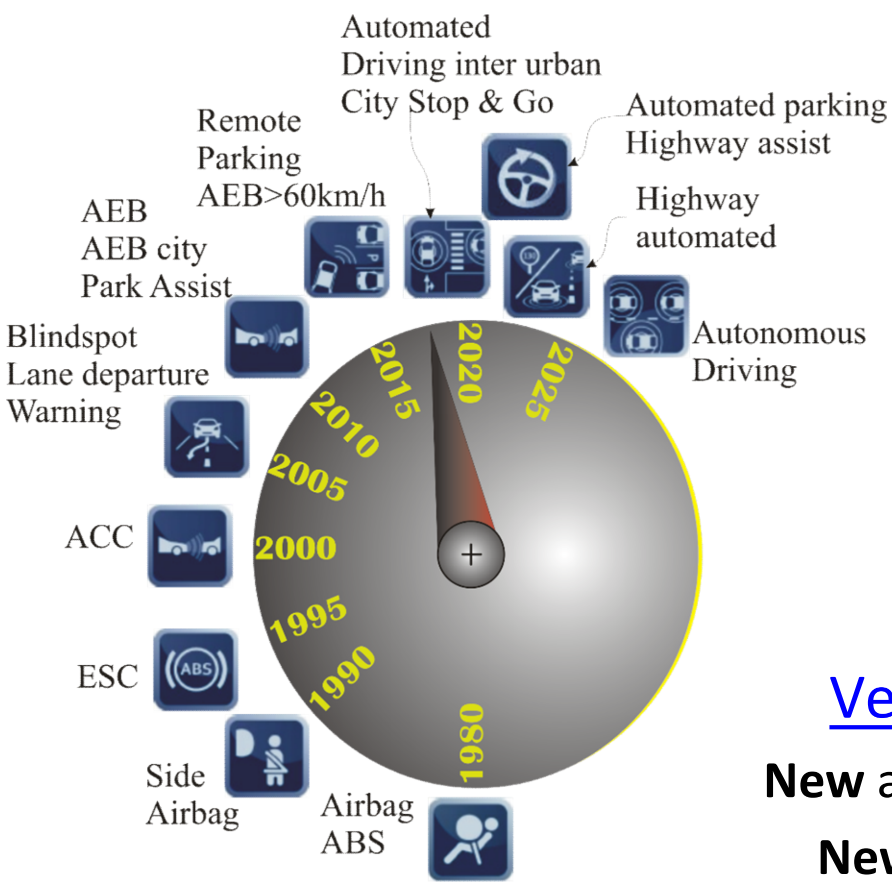
Spin-off of the research results towards Robotics and Industry4.0

Huge potential market (90M of new vehicles/year, 35M of e-bikes/year, worldwide)

Huge investments from Semiconductor and ICT companies and joint alliances with OEM companies
(ref. interview Bozzotti, CEO-STM, Sole24ore 26Nov2017)

INTEL estimates the vehicle systems, data and services market to be up to $70 billion by 2030
VW group announced $34 billion of investments in electrified and autonomous vehicles 2018-2022

Autonomous vehicles



Revolution of people/goods mobility

Safer, car accidents kill 1.25 M people today

Inclusive, mobility for all (elderly, disabled), free time,…

Efficient, less CO2, no energy/time wasted in traffic jam (US congestion cost/year: $200B and 62 h in traffic jam)

Digital lifestyle & sharing economy

Synergy with **Industry 4.0**

Vehicle & ICT/Electronics convergence

New automotive **players** (Intel, Google, Tesla, Uber)

New alliances (BMW/Intel, Audi/Nvidia/Bosch)

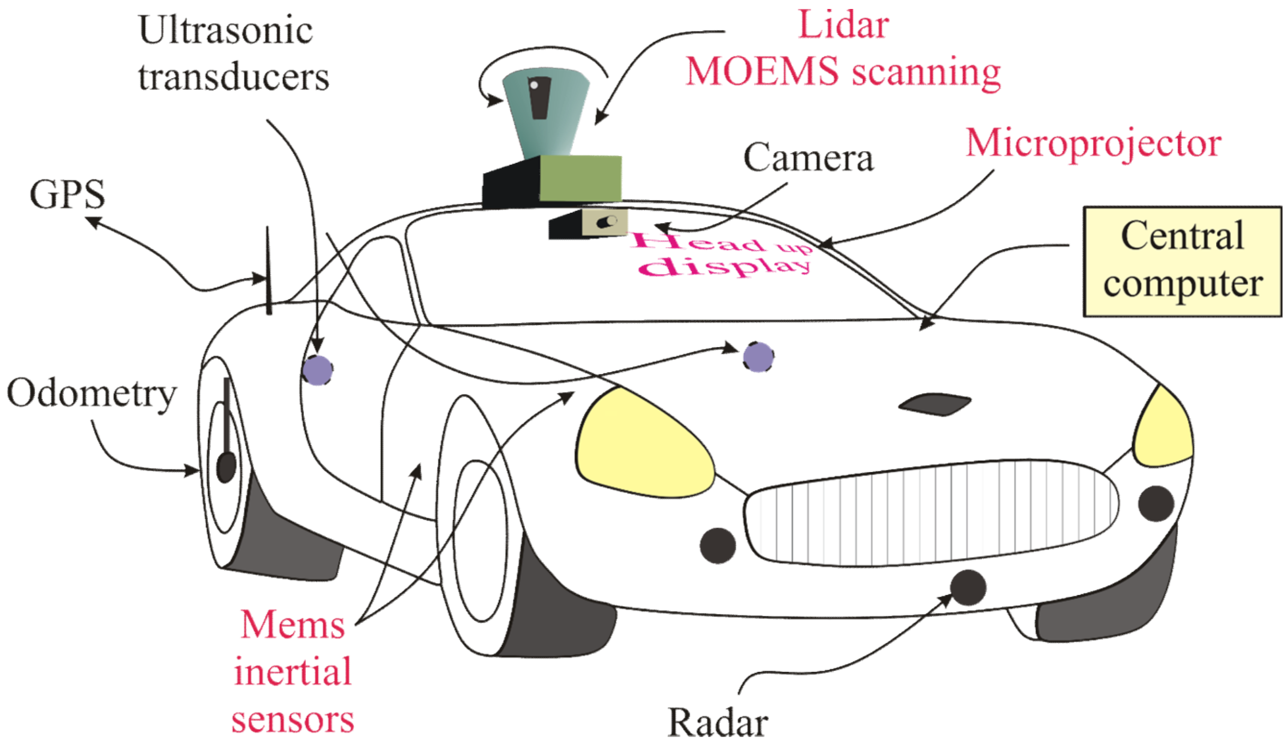
Sensor & measurement systems are KET for

Accurate (cm) & real-time **positioning** and **navigation**

Vehicle **context-awareness** (detect obstacles, avoid collision, planning path)

Driver **assistance** (enhanced vision, fatigue detection)

Sensing & measurement system perspective



What?

obstacle detection

Where?

position and direction of cars and obstacles

When?

car to obstacle relative speed

Measurement system performance

range, **resolution** and **accuracy** of distance, angles & speed?

reliable (**uncertainty, repeatability**) measures in harsh environment ?

secure (**trusted, identified, private**) measures?

ICT companies investing in vehicles&ITS

https://www.google.com/selfdrivingcar/

http://spectrum.ieee.org/cars-that-think/transportation/advanced-cars/nokia-bets-100-million-on-smart-car-tech

Autotalks, ST combine SatNav with V2X | Electronics EETimes

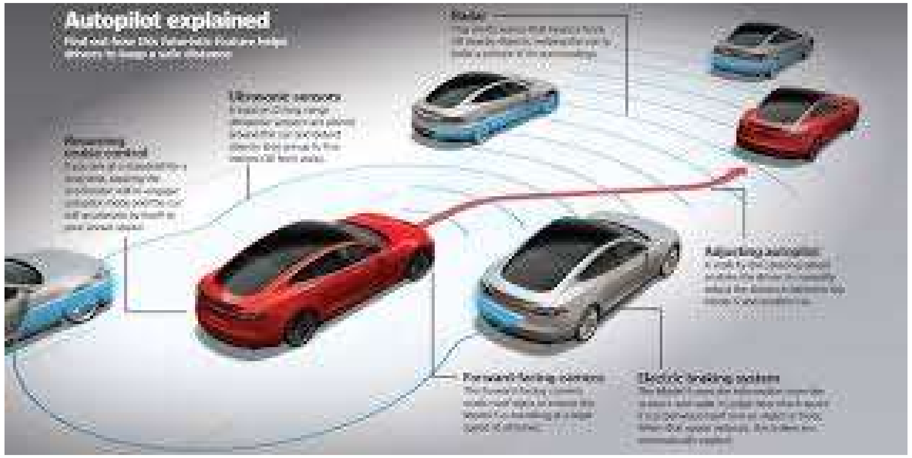
5GAA Automotive Association

Automotive OEM investing in electronics

http://piaggiofastforward.com/, PFF is a new company to promote a revolutionary approach to R&D for innovative mobility

Google and Fiat Chrysler team up for 'first of its kind' self-driving car ...https://www.theguardian.com

Tesla's Autopilot: The smart person's guide - www.techrepublic.com



fortune.com/.../bmw-intel-and-mobileye-are-sending-self-driving-cars-on-the-road

What about in Tuscany?
INTEL acquires YOGITECH in Pisa

OEM

Piaggio Fast Forward, Hitachi Rail Italy

Automotive Components

Magna Closure (smart latch)

Continental (smart injectors)

Pierburg (e-pumps)

AMS

ICT companies

Evidence, Kyunsis, Ingeniars

Pure Power Control, IDS, Intecs .....

Initiatives on vehicles at UNIPISA

MOVET

Association of Universities + Institutions + 15 Industries operating in Tuscany

Post-graduate Master Automotive Engineering

Master Degree in Vehicle Engineering

E-Team

Formula SAE

(Kerub car)

Vehicle as a platform for pervasive electronics

RF Circuits
(mmW Radar, 802.11p V2X & 5G C-V2X, GNSS)

Sensor signal processing
(Image, Radar, Lidar, IMU,..& fusion in real-time)

Power Electronics
(DC/DC converters, inverters, BMS
12V→48V→ 300V)

Low-power Analog & Mixed-signal ICs

Sensors (device & technologies-MEMS/MOEMS)

Predictive-diagnostic
(thermal, EMI/EMC, electrical, ageing, vibrations,..) for functional safety

MCU & memories (multi-core, deep-learning, high SIL in harsh environments)

Outline

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Context-awareness I&M

Radar (Master of Motion Measures)

Active EM sensor. Robust in harsh conditions. Long Range. Limited accuracy

LRR4, range: up to 250 m, ± 5 m/s, accuracy: ±0.1 m, ±0.1 m/s H/V-FOV $30^0/5^0$

Lidar (Master of 3D mapping)

Velodyne

Active Light sensor. Mid Range, good accuracy. 360^0 H-FOV

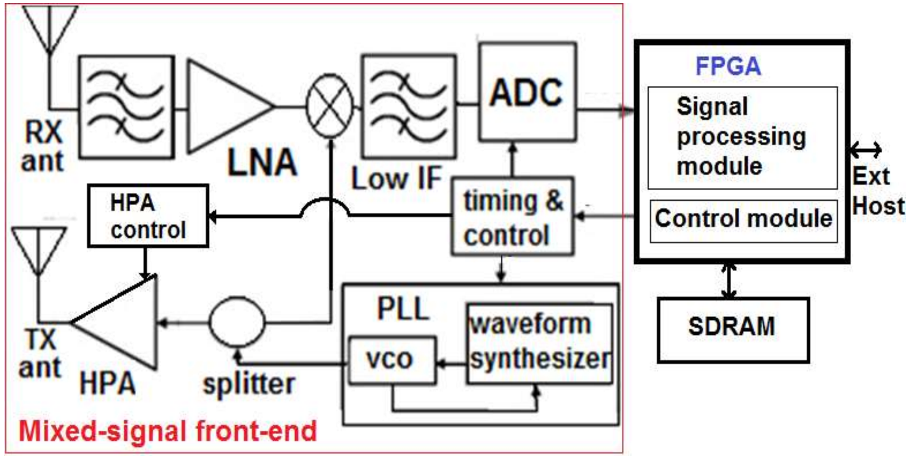
HDL-32/64: up to 100 m, 0.02 m and 0.1^0 accuracy. Limited by cost

Camera (Master of Classification)

Passive. See colors & textures. Cheap. IR sensors needed for night vision

JRTIP2016 640x480 automotive camera & FPGA, recognition at 15 m, <100 ms

CW range-speed radar

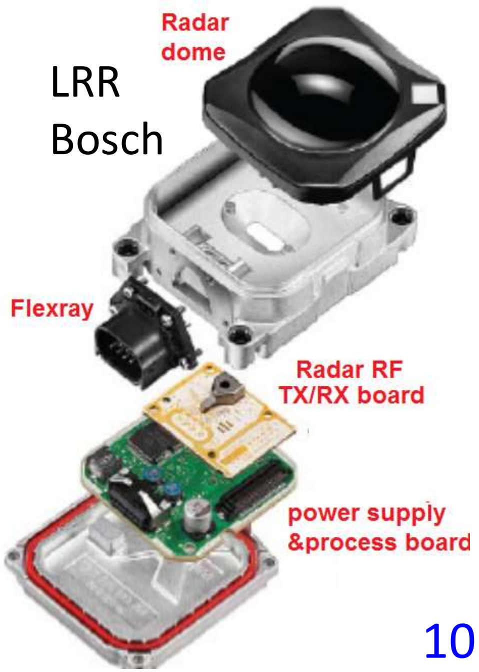


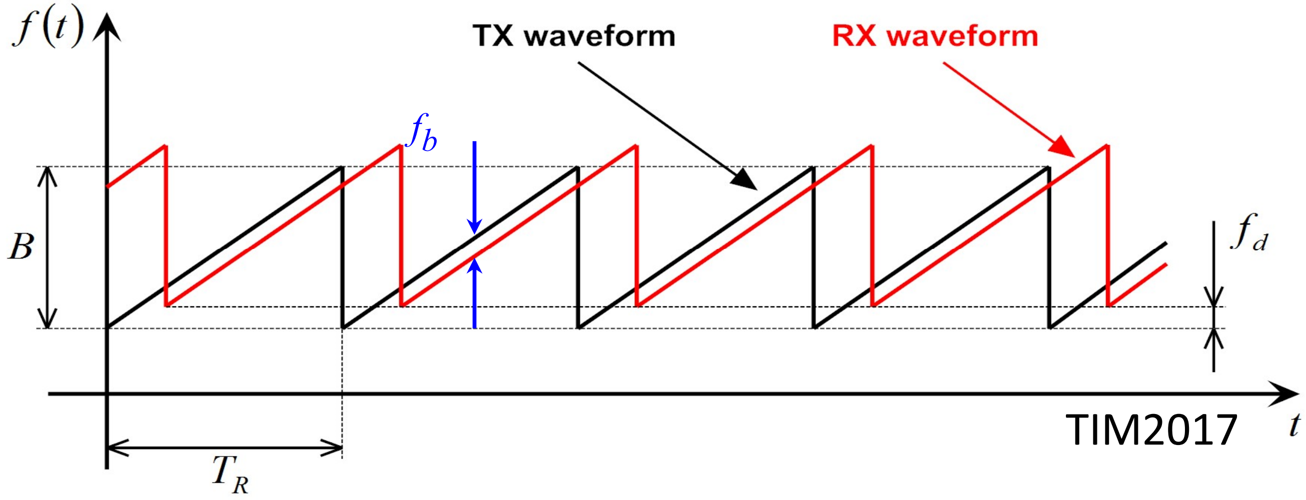
$$f_r = \frac{B}{T_R}\frac{2R_0}{c}$$

$$f_d = -\frac{2v_r}{\lambda_0}$$

$$f_b = f_r + f_d$$

Range-Doppler coupling effect





Multiple channels for DoA estimation

10 GHz surveillance, 24 GHz short-range, 77 GHz long-range radars

CW range-speed radar

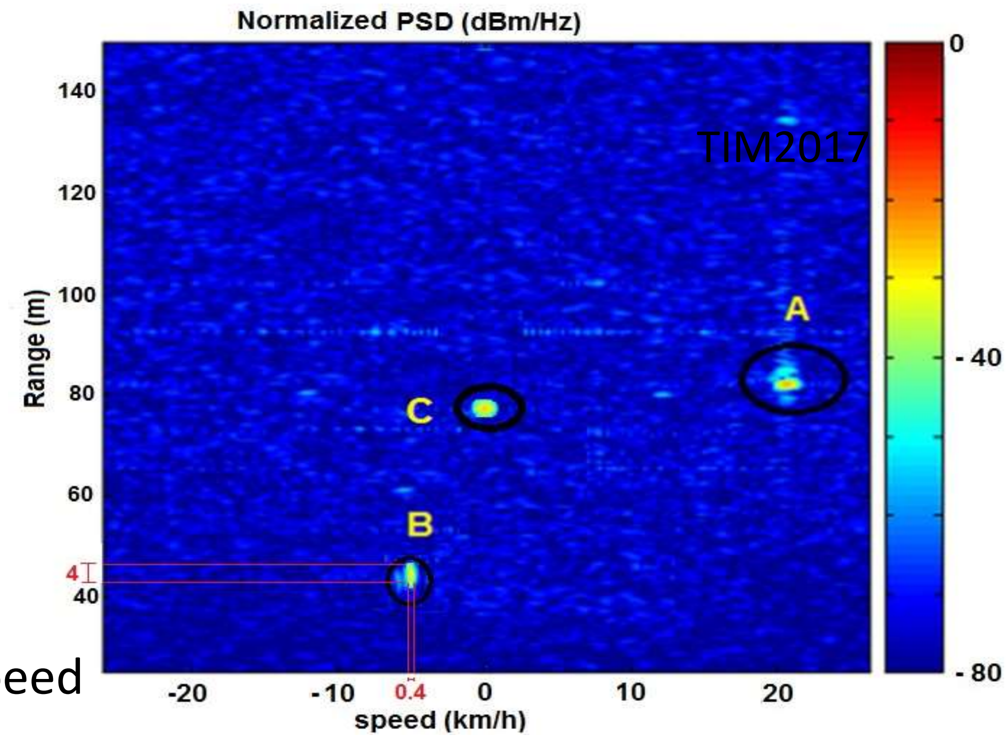
Measurement range R affected by channel impairments, HW performance, target cross-section; resolution d_R depends on sweep band B (4 cm for 77-81 GHz LRR)

$$R = \sqrt[4]{\frac{P_{CW}\lambda^2 G_{ant}^{\;2}}{(4\pi)^3}\frac{1}{L}\frac{\sigma}{SNR_{dig}}\frac{1}{k_B T N_F \Delta f}}$$

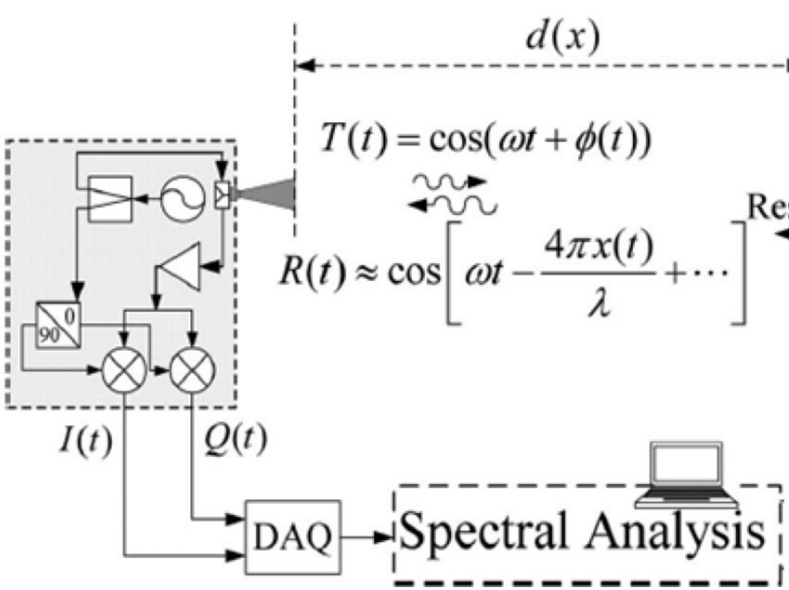
$$d_R = {c}/{2B}$$

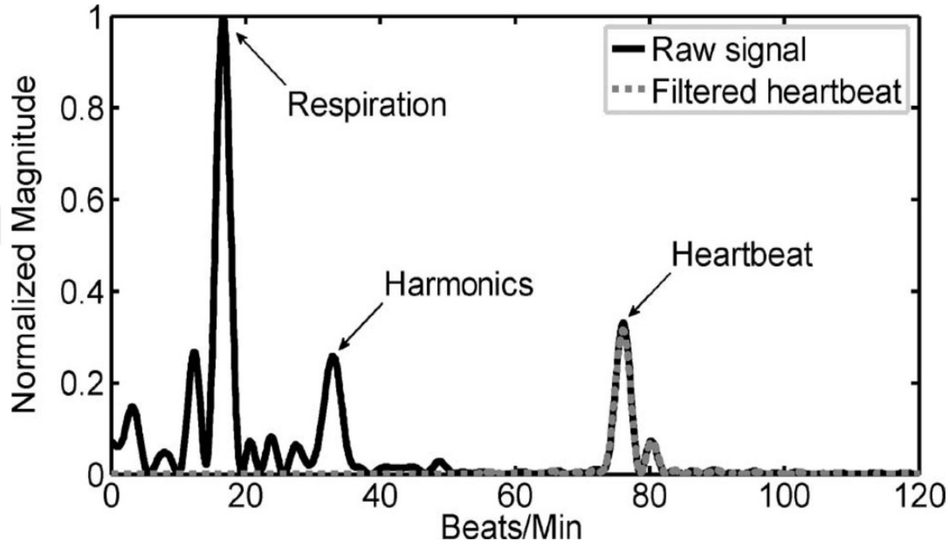
A: moving vehicle
B: biker
C: still vehicle

Detected targets appear like an oval due to their physical size and to the Radar resolution limits in distance and speed



Biometric measures



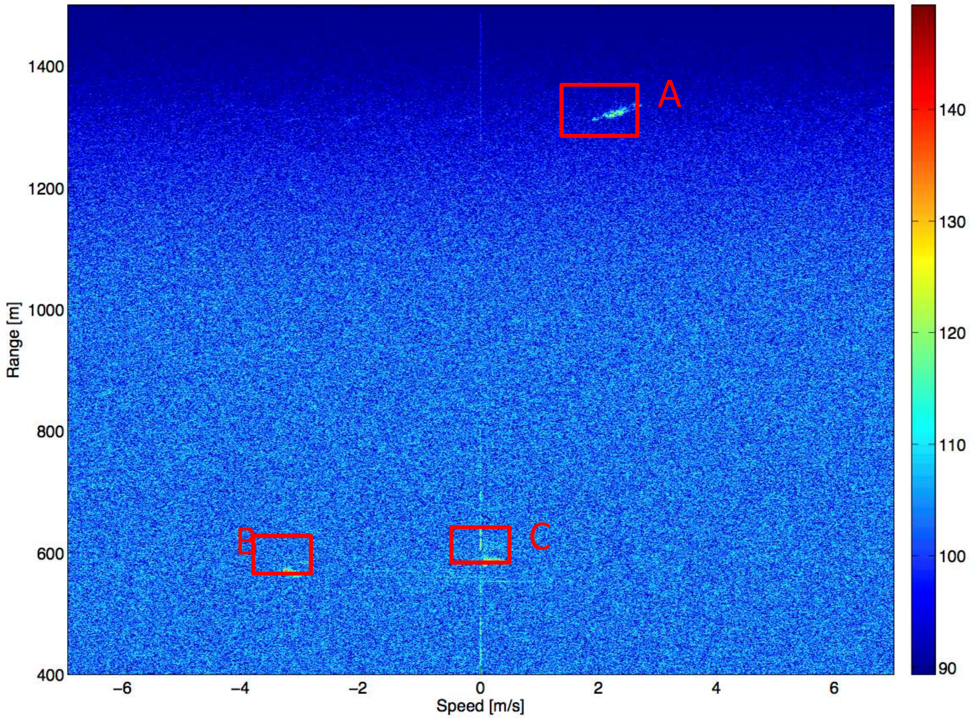


TIM2010, TIM2016

Driver drowsiness check by HR variability (radar) and eye opening level monitoring (camera)

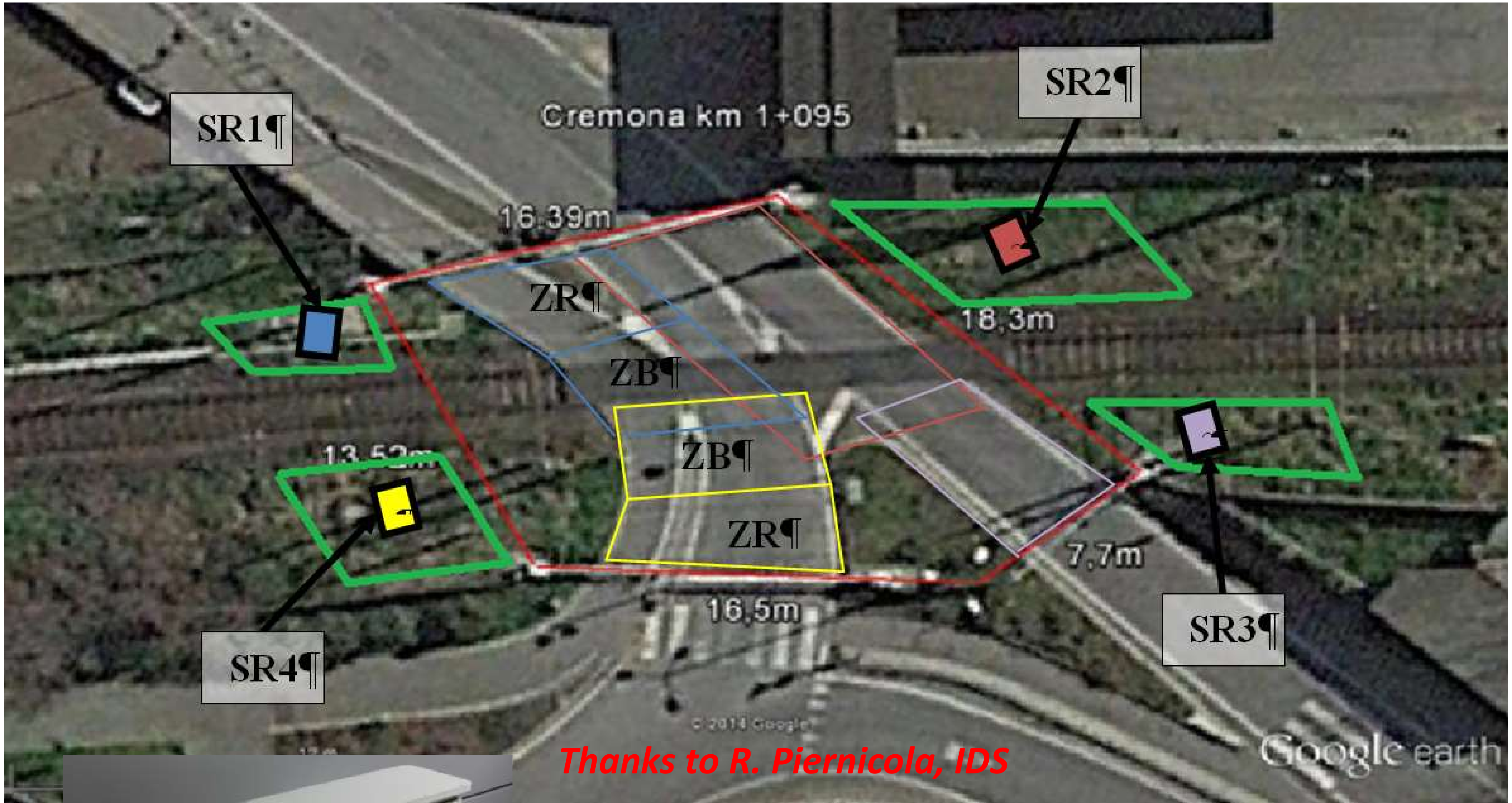
Radar for harbour surveillance

		
A. Length: 33,25 m, Width: 6,47 m • Material: wood and iron	B. Length: 8.5 m, Width: 2.3 m • Material: fiberglass and iron	C. Length: 13.20 m, Height: 13 m • Material: wood



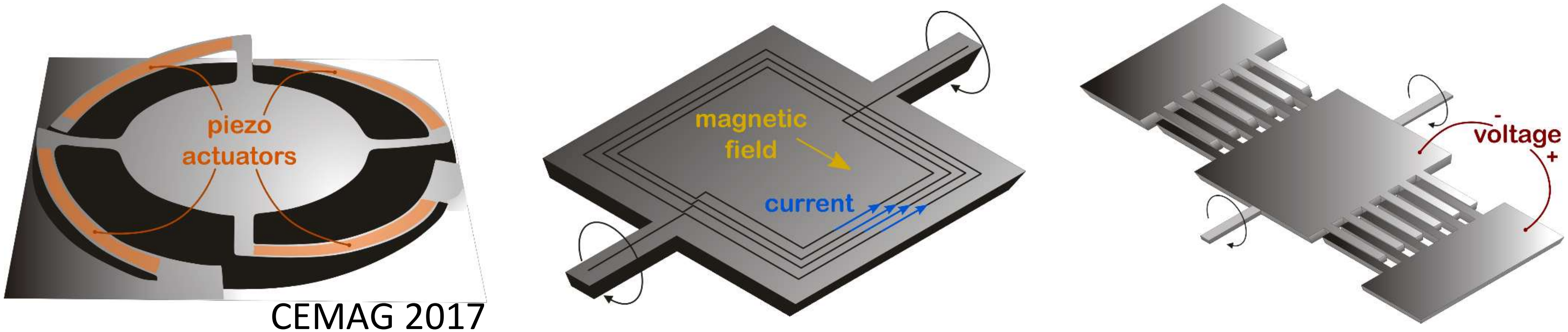
- $P_T = 33\ dBm$
- $B = 300\ MHz$
- $PRF = 1\ kHz$
- $CPI = 1\ s$

Radar installation for crossing safety



Research on low-cost Lidar

Supplier	Type	HFOV in deg	VFOV in deg	Scanning Freq.	Cost	Range
Osram/Infineon/ Innoluce	Scanning, MEMS	120, (res. 0.1)	20 (res. 0.5)	<2kHz	40 USD	200m
Quanergy	Scanning, OPA	120	120	N/A	250 USD	150m
Velodyne (VLP-16)	Scanning mechanical	360 (res 0.1-0.4)	30 (res. 2)	5-20Hz	7999 USD	300m
LeddarTech (LeddarVu)	Solid-state	100	0.3-3	N/A	750 USD	60m
ASC (Peregrine)	Solid-state	up to 60 (res. 0.5)	up to 15 (res. 0.5)	20 Hz	N/A	N/A
Microvision(PSE-0400Li-101)	Scanning MEMS	90 (res. 0.18)	30 (res. 0.08)	30Hz	N/A	15m



CEMAG 2017

3D scanning Lidar using MOEMS micro-mirrors: scanning micro-mirrors with three different actuations schemes: (right) electrostatic, (center) magnetic, (left) piezoelectric

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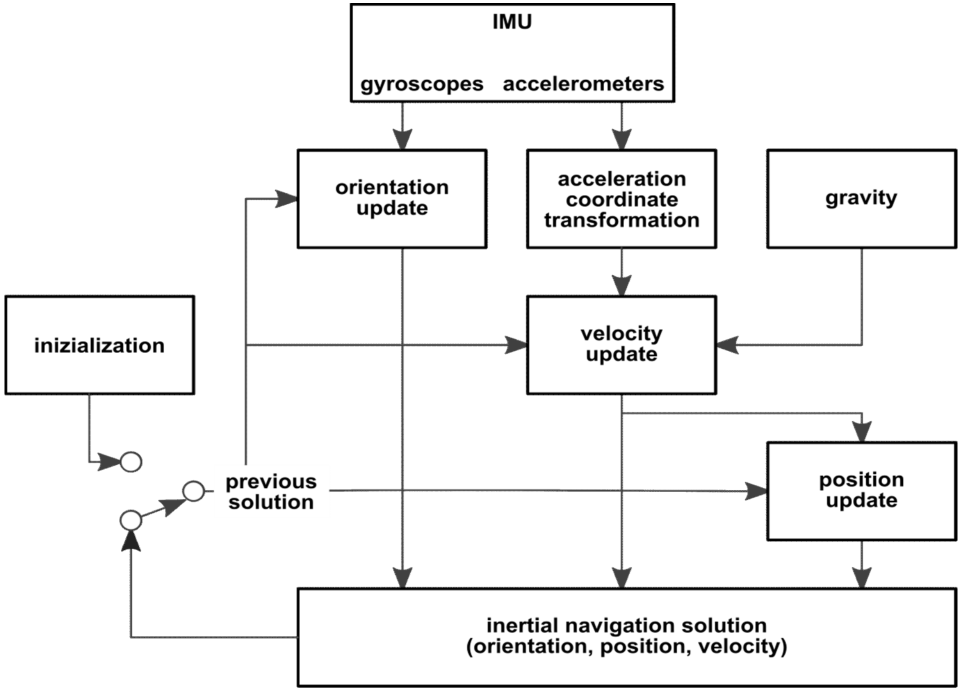
Inertial Navigation System

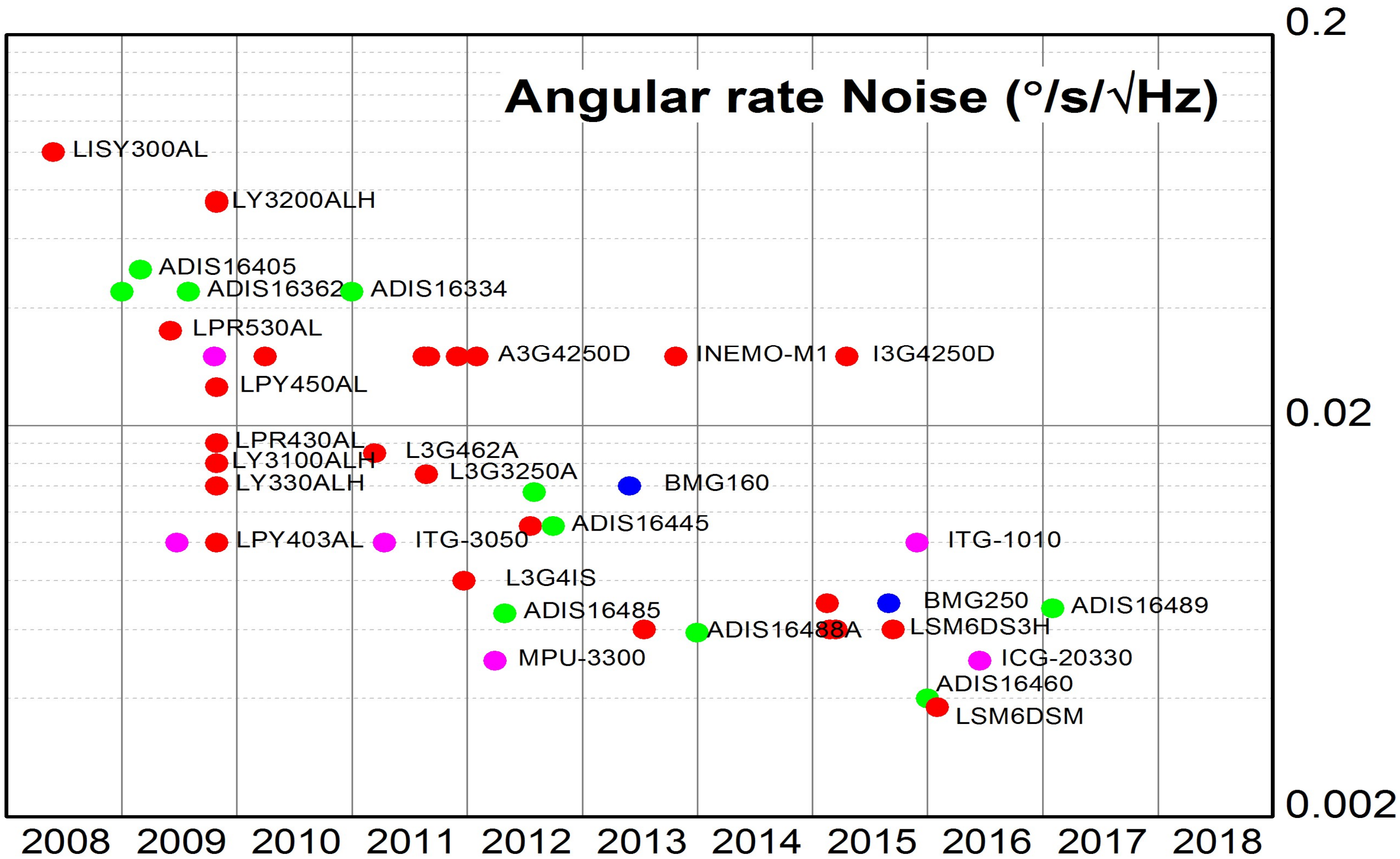
Bias as a limit of navigation & positioning accuracy



IMU grades by bias values

IMU grade	Acceleration bias (mg)	Angular rate bias (deg/hr)
Strategic	$10^{-3} – 10^{-2}$	$10^{-4} – 10^{-3}$
Navigation	$10^{-2} – 1$	$10^{-3} – 0.1$
Tactical	1 – 30	0.1 – 30
Consumer	>30	>30

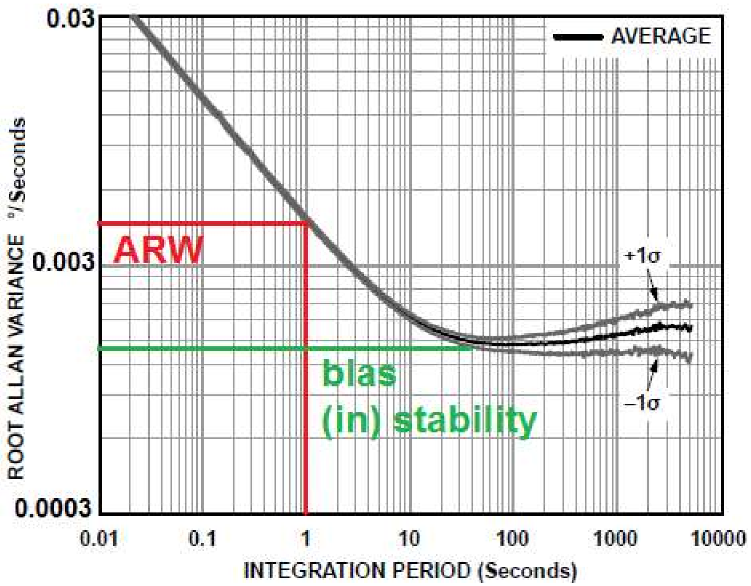
Inertial Navigation System



Noise spectral density of several recent different commercial gyroscopes, by year
Color marks the supplier *Thanks to F. Pieri*

ST, AD, Bosch, InvenSense

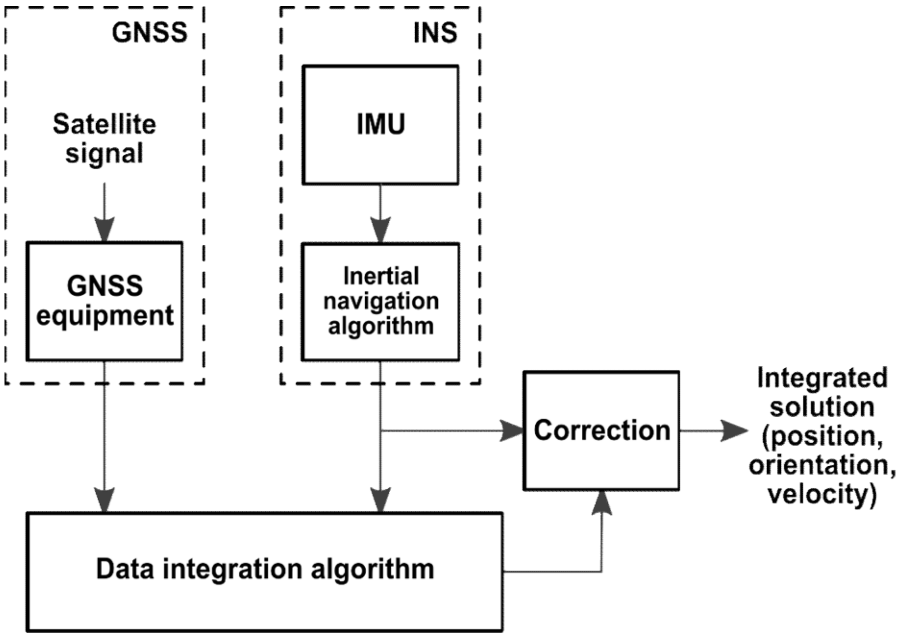
Inertial Navigation System



Ten-second position errors due to sensor bias

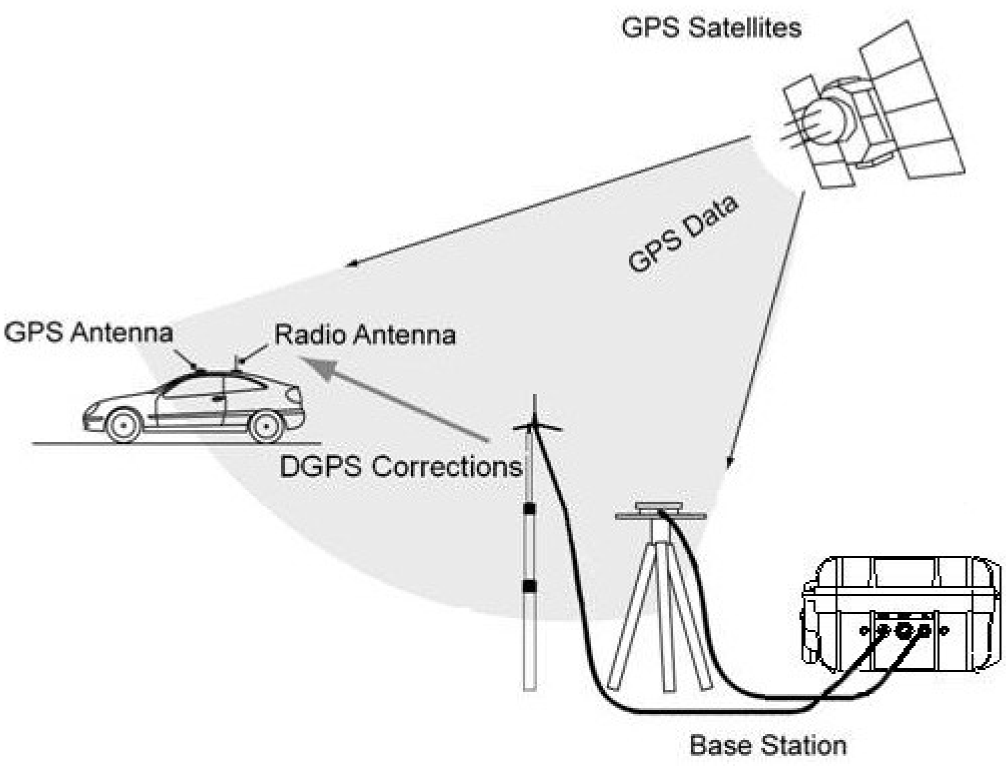
IMU grade	Due to acceleration bias (m)	Due to angular rate bias (m)
Strategic	$< 0.5\times10^{-3}$	$< 8\times10^{-6}$
Navigation	0.5×10^{-3}-0.5	8×10^{-6}-0.8×10^{-3}
Tactical	0.5-15	0.8×10^{-3} - 0.25
Consumer	> 15	> 0.25

Fusion of GNSS & IMU needed



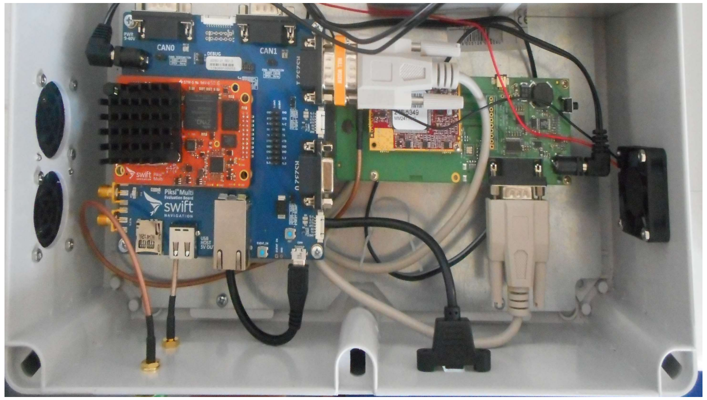
Still not–enough for cm accuracy in positioning/navigation

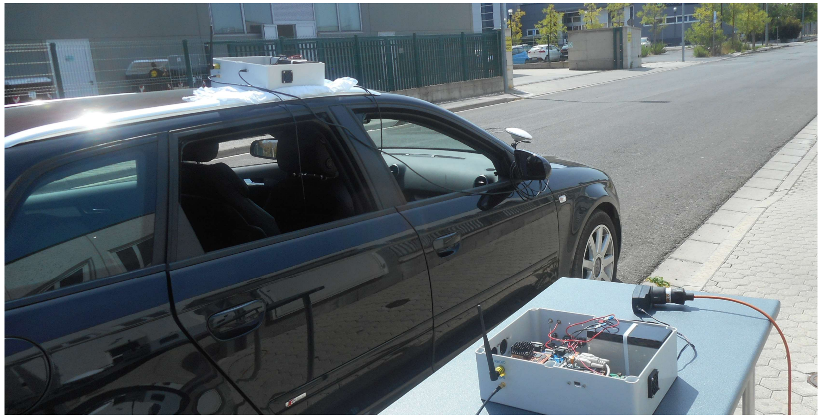
RTK: Fusion of Multiple-GNSS & IMU



The vehicle receives its GPS signal plus the GPS signal of a reference point through a vehicle to infrastructure communication link

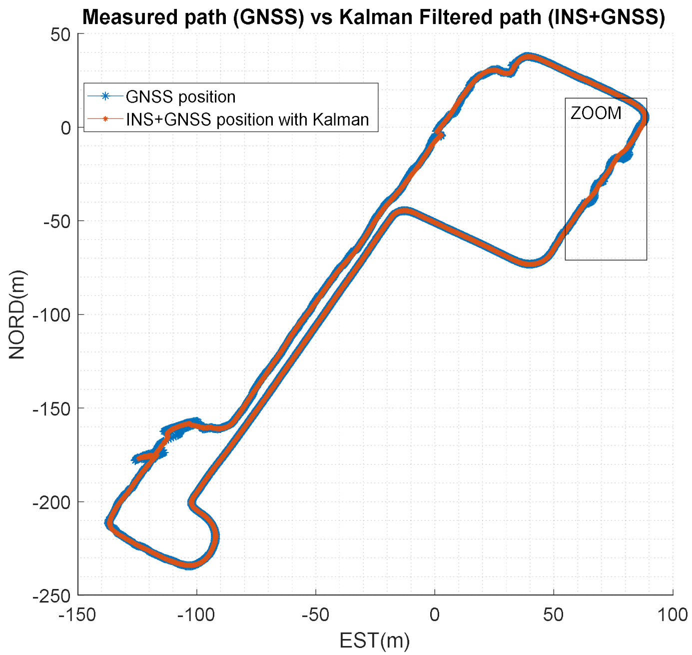
RTK: Fusion of Multiple-GNSS & IMU

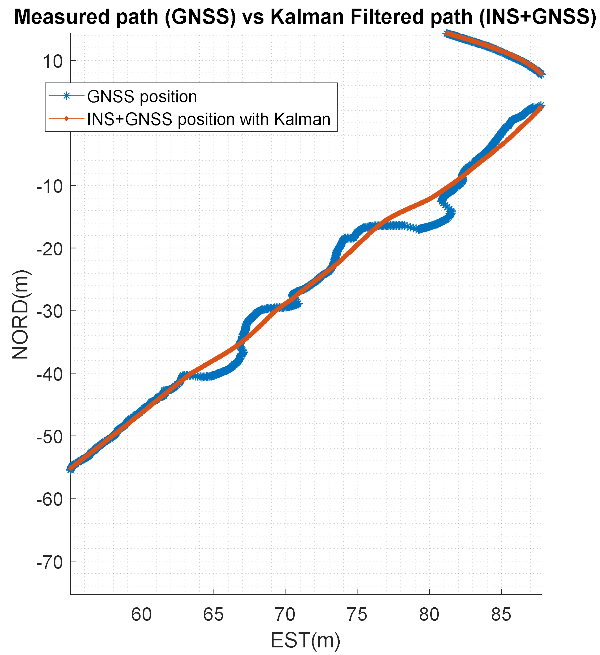




A prototype realized using COTS components (embedded signal using Kalman filter & fusion of 2 GPS data & on-board accelerometer and gyroscope) achieves an accuracy of 10 cm.
Fully integrated system under development

RTK: Fusion of Multiple-GNSS & IMU





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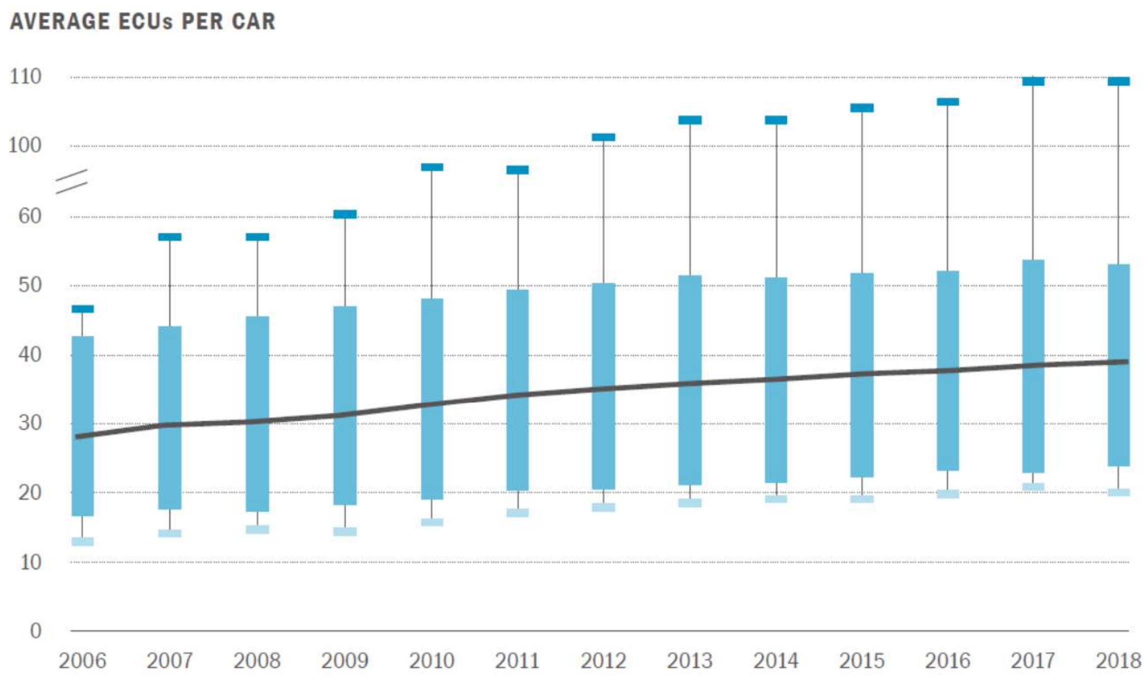
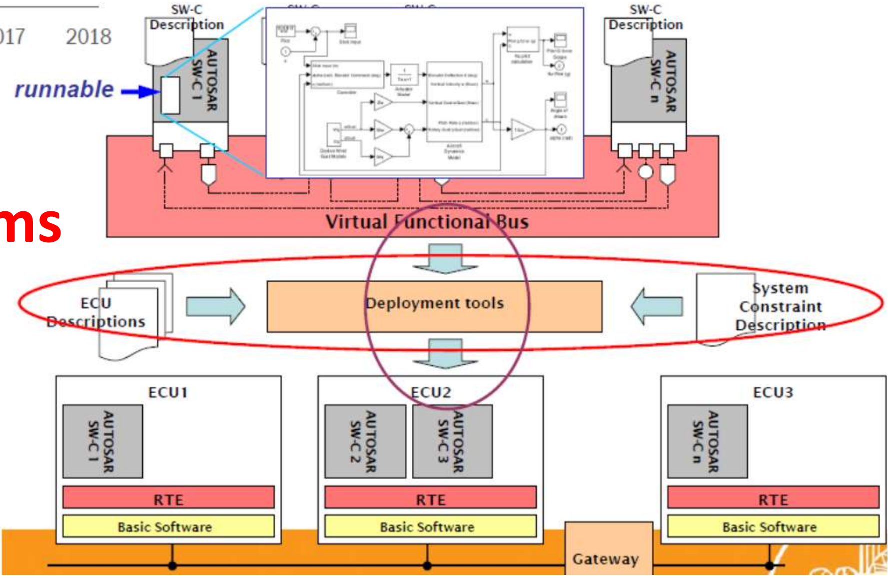
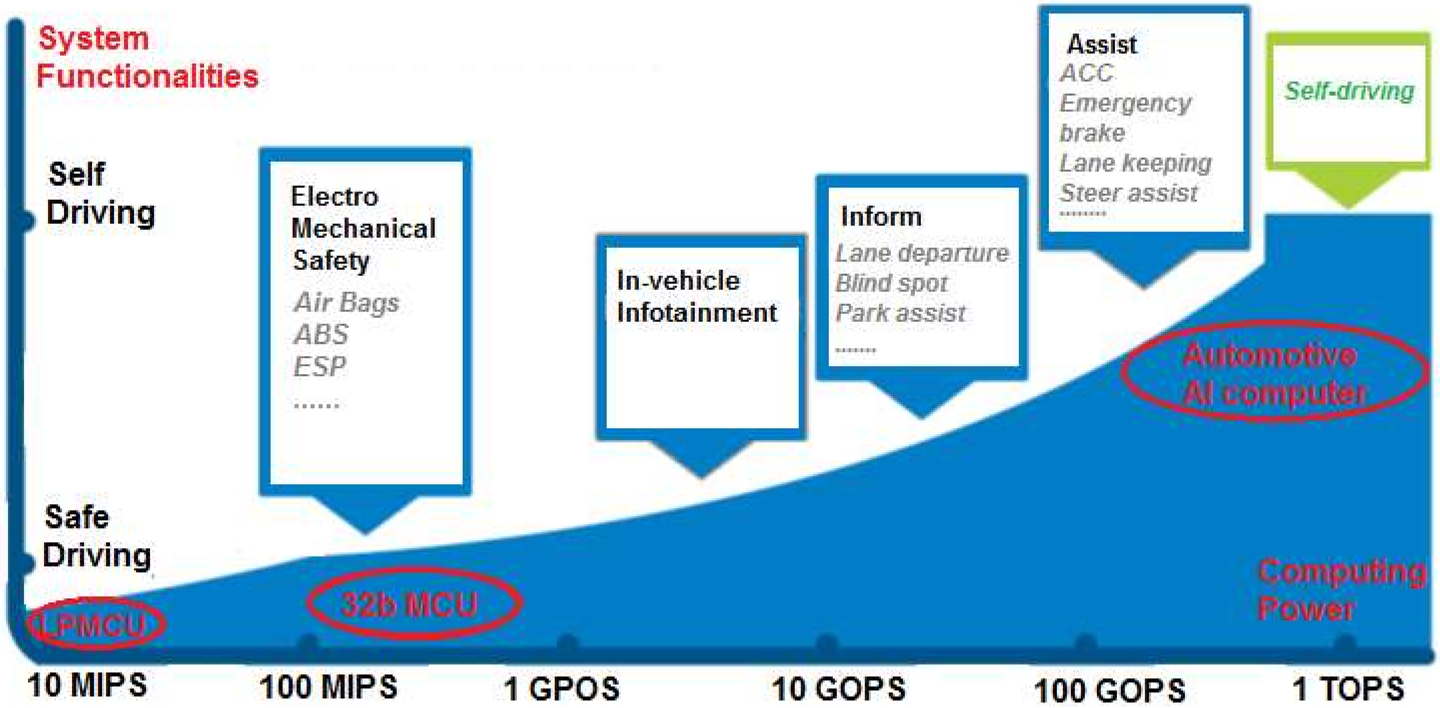
ECU and sensor DSP computing





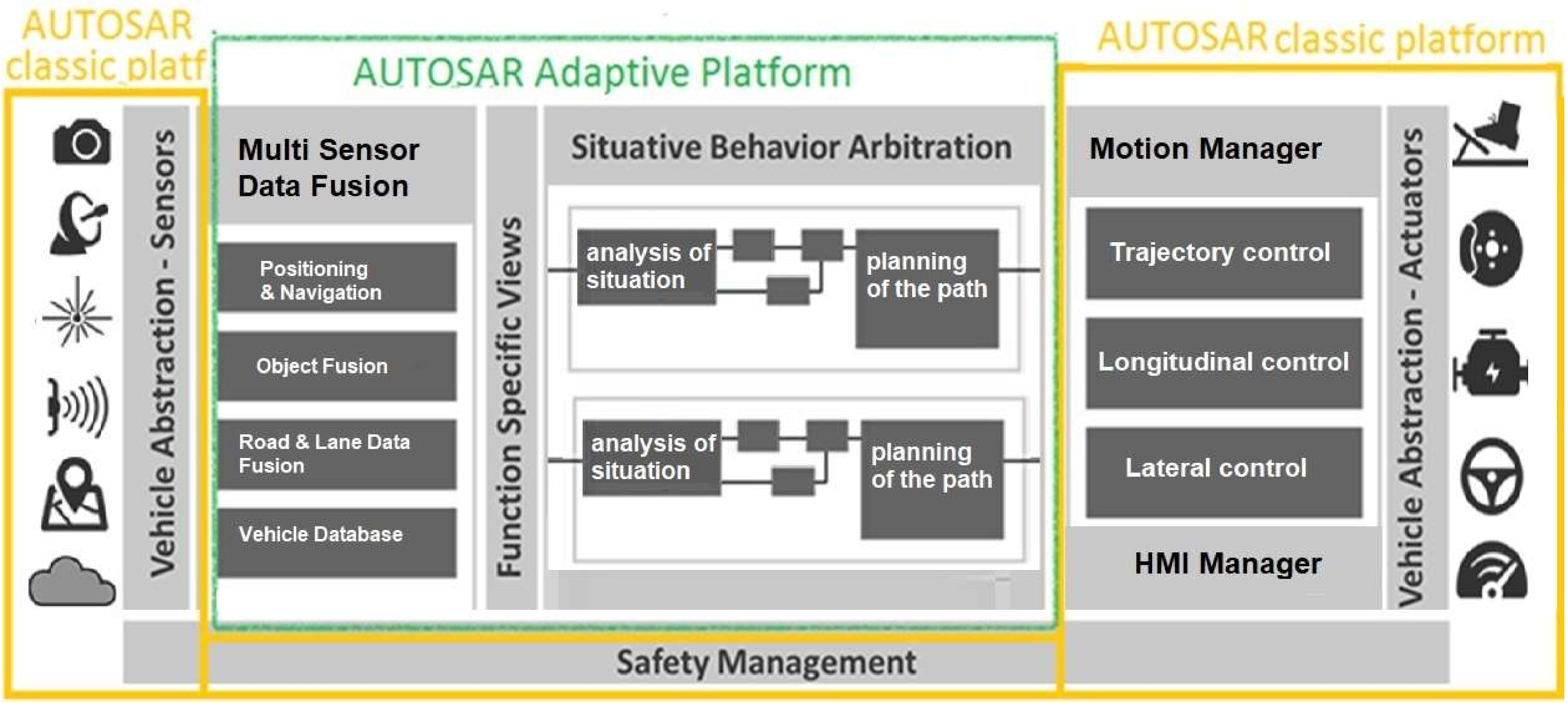
HW-SW co-design & embedded systems for computing intensive applications

ECU and sensor DSP computing

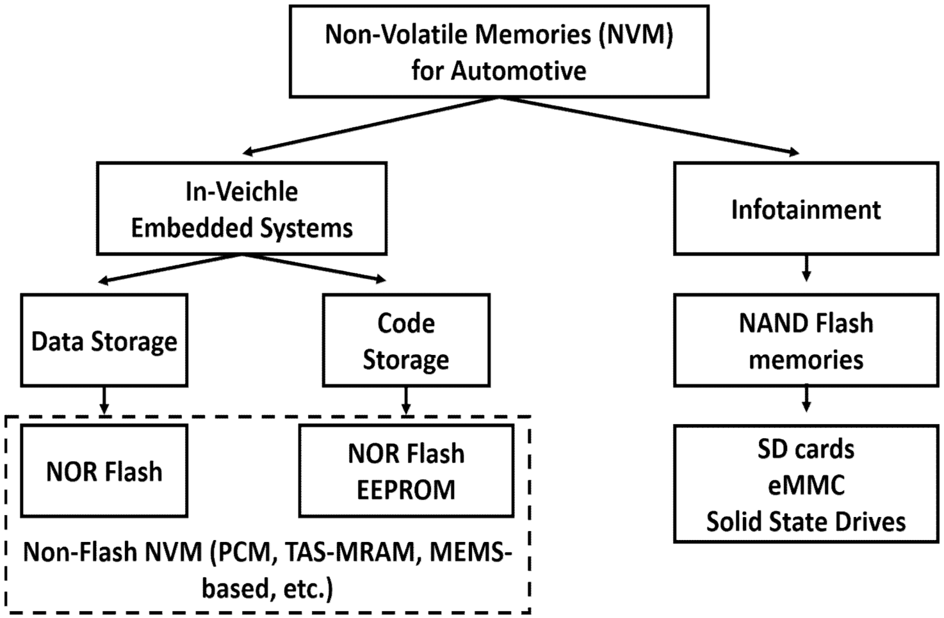


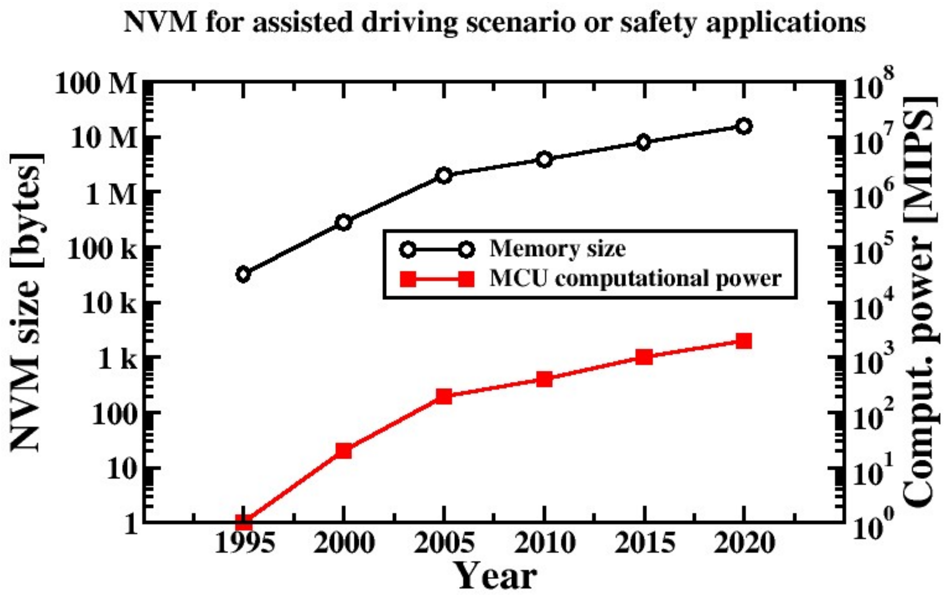
State-of-art is 32b MCU with high-SIL Increase in system but functionalities towards autonomous driving will require multi-core platforms with up to TOPS capability

ECU and AUTOSAR



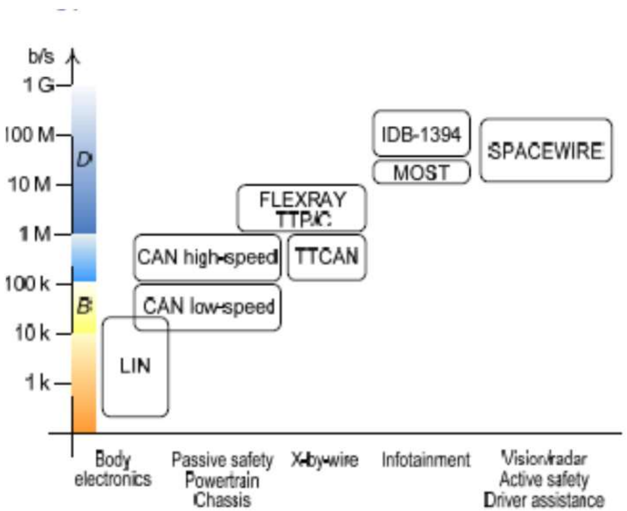
Memory needs

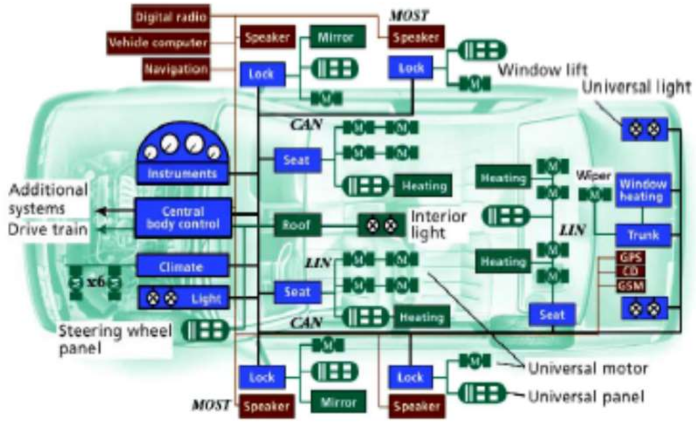




Parameter	EEPROM	NOR Flash Code Storage	NOR Flash Data Storage	PCM	MEMS-based	RRAM CBRAM	TAS-MRAM
Endurance	500k	10k – 100k	500k – 1M	>1M	>1M	100k	>1M
Data Retention	>10 yrs/125 °C	10 yrs/125 °C	>10 yrs/125 °C	10 yrs/85 °C	>10 yrs/125°C	10 yrs/85 °C	>10 yrs/125 °C
Power consumption	Low	Low	Low	High (Write)	Low	Low	High
Read Latency	20 – 50 ns	< 20 ns	< 20 ns	> 20 ns	> 100 ns	> 20 ns	50 – 100 ns
Cost per bit	Medium/High	Medium	Medium	Low	High	Low	High

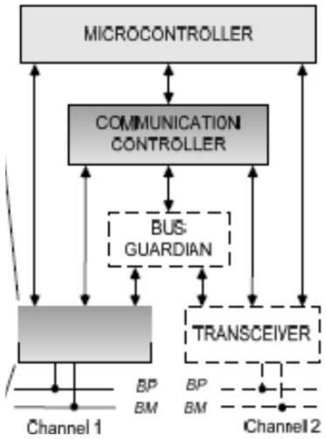
On-board vehicle networking

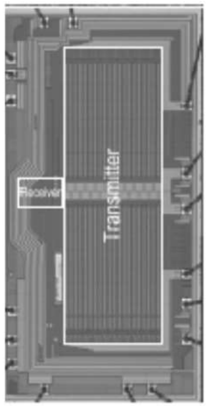




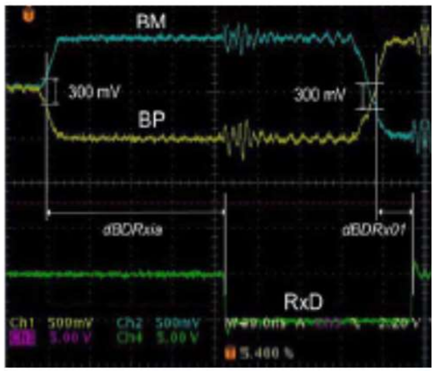
- **FlexRay** nuovo standard event/time-triggered a **10 Mb/s** per **X-by-wire** (su BMW X6)
- **CAN**
- **ISB-1394/MOST per infortainment**
- **LIN per interconnesioni locali a basso bitrate (pochi Kbps)**

On-board diagnostic/control measurements & networking

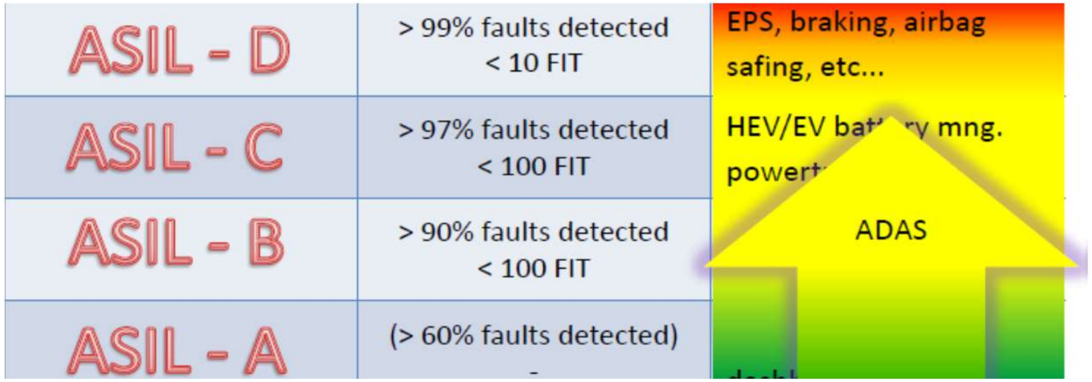




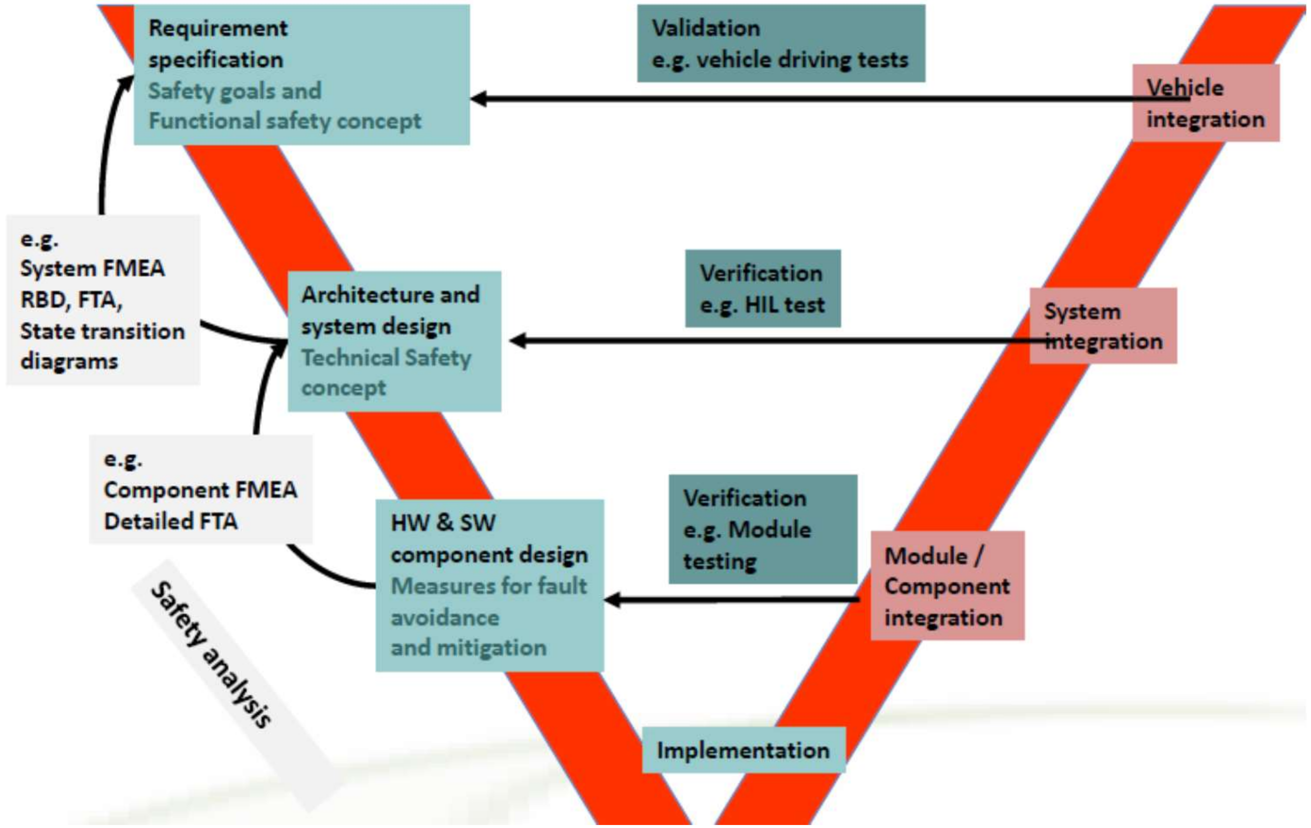
	min	max
Battery	-0.3 V	+58 V
Bus DC Voltage	-58 V	+58 V
Junction Temp. (TJ)	-40°C	+150°C
ESD (HBM)	-4 kV	+4 kV
Latchup immunity	-100 mA	100 mA



Functional safety



ADAS is a multi-disciplinary research field



Functional safety ISO26262 & Verification

Outline

- Innovation and trends of circuits & systems for smart vehicles and int. transport systems (ITS)
- Remote sensing (Radar) for smart vehicle & ITS
- Sensing technology for navigation
- Computing & memory needs
- Mixed-signal ICs for smart vehicles
- Image processing for smart vehicles and ITS
- Conclusions

Intelligent Generic Sensor Interface (I-GSI)

Sensors needs signal conditioning in both analog and digital domains for continuous compensation (bias, temperature, …)

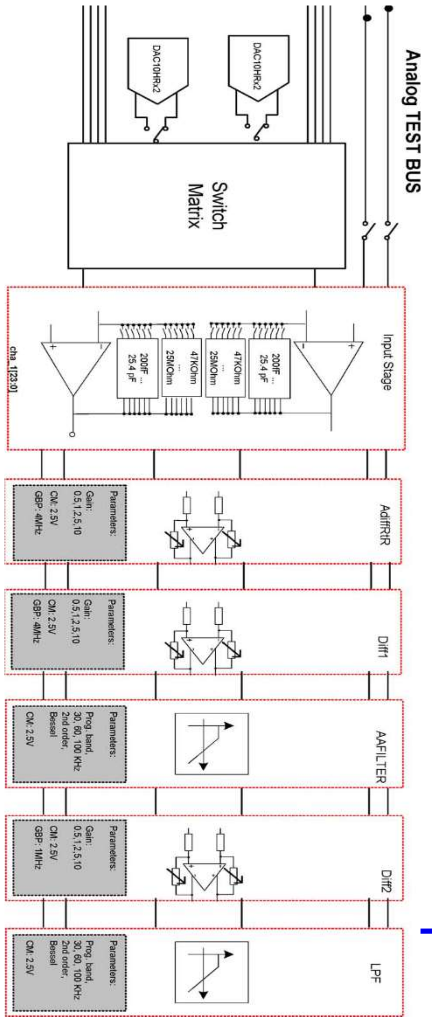
Smart vehicles need lots of different sensors (accelerometers, gyroscopes, temperature., speed, gas leaks, pressure,…)

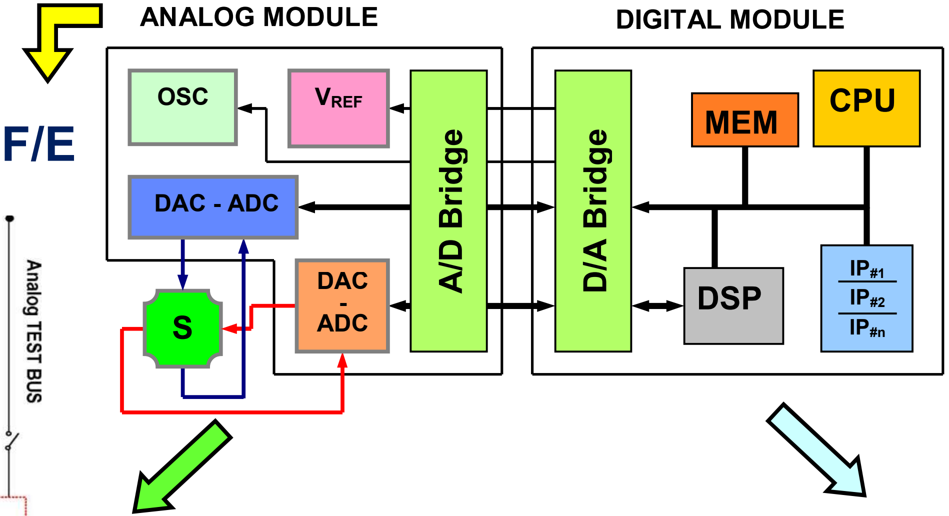
Automotive industry needs low-cost but configurable solutions

Intelligent Generic Sensor Interface

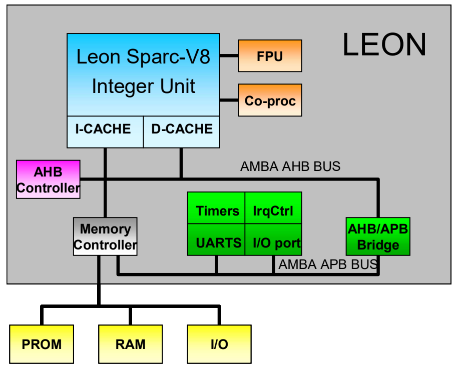
Intelligent Generic Sensor Interface (I-GSI)

Multi-channel config. analog F/E





Processor



Generic Sensor

temperature

speed

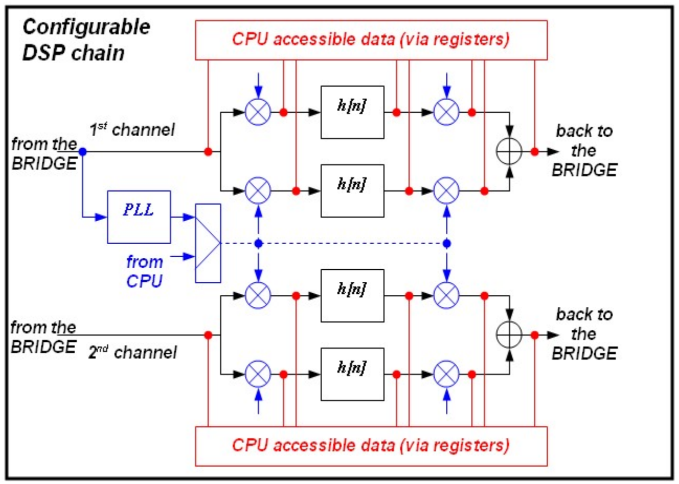
pressure

acceleration

angular speed

gas ......

Digital Signal Processing

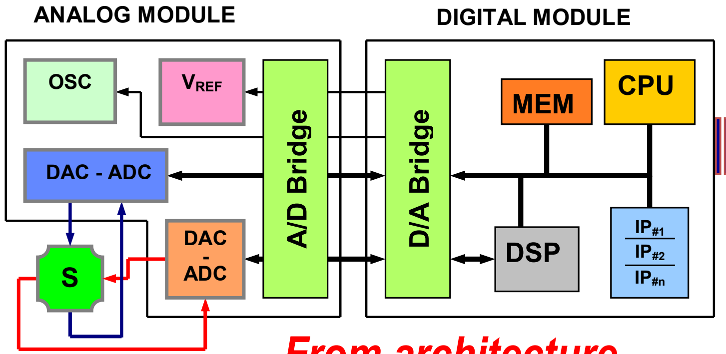


Automotive, Space, Industrial

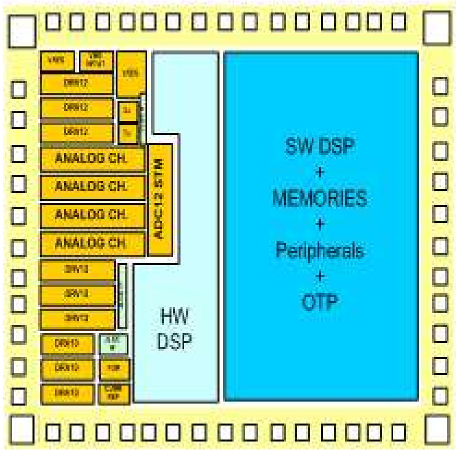
2 IEEE TIM in 2011, IEEE TIM16

TRIUMF, Vancouver, Canada, 7th Dec. 2017

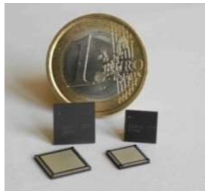
I-GSI platform & specific ICs spin-off



From architecture

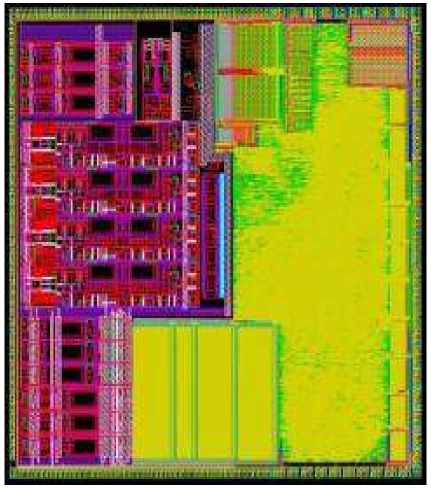


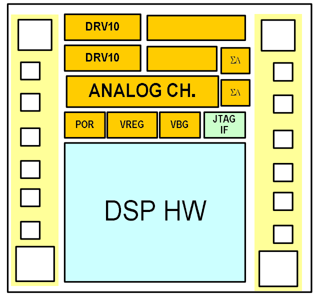
Proven in real-products (SD41x)



sensordynamics

..to configurable GSI





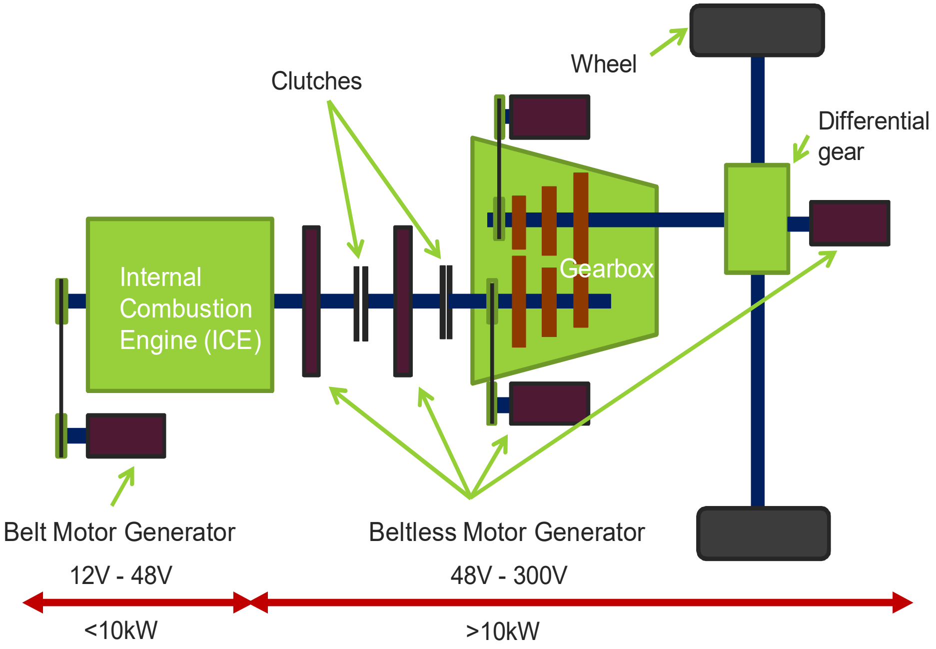
esa

..to testing

..to silicon (tens of mm2, in 0.25/0.35 μm)

..spin-off of sensor specific ICs low design effort (few mm2)

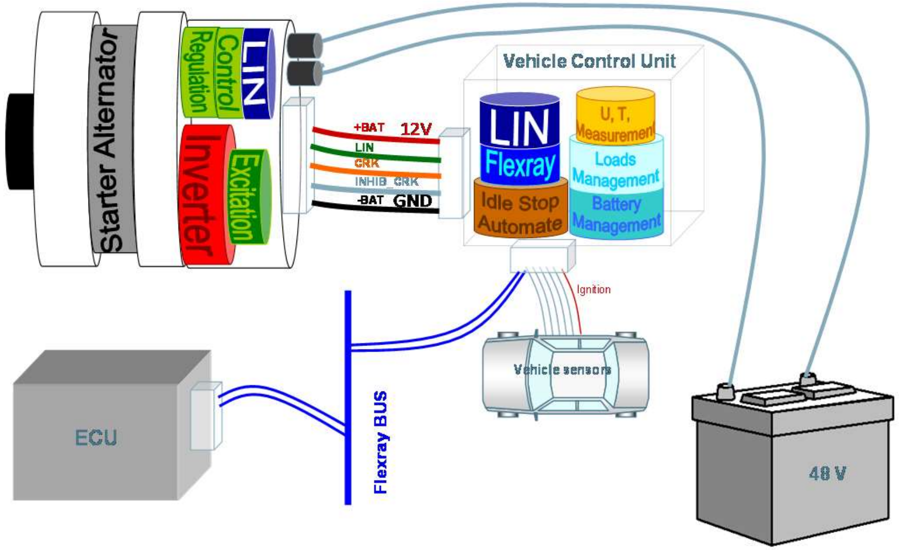
Integrated Power Converters for 48 V micro/mild-hybrid vehicles

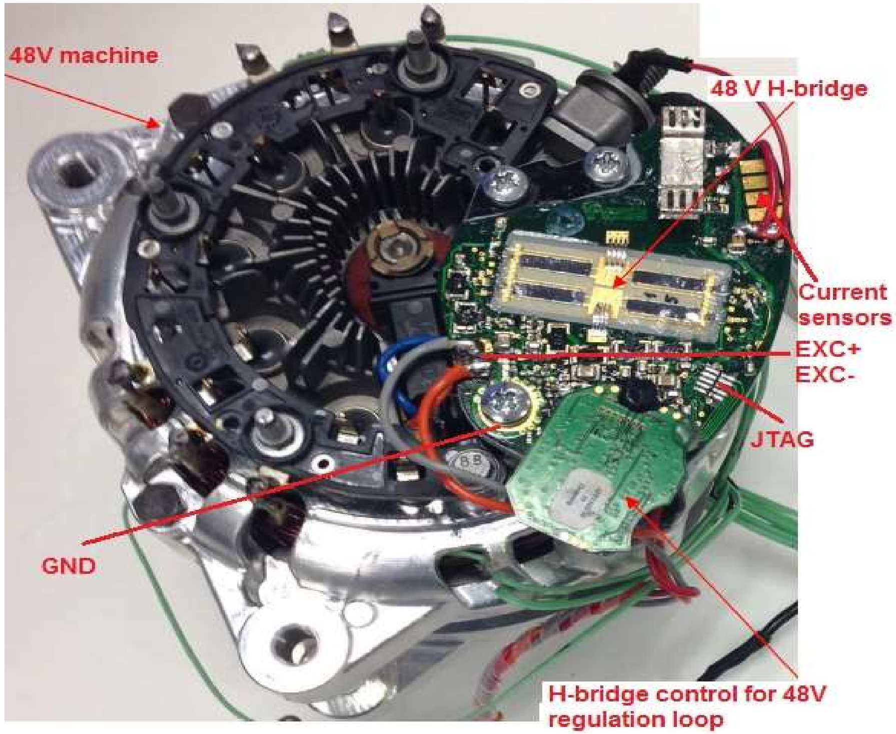


In 48 V micro/mild-hybrid vehicles a integrated starter/generator up to 10 kW, provides starting torque & low-speed torque assistance to the downsized ICE & regenerative braking

Below 70 V schock protection is NOT needed

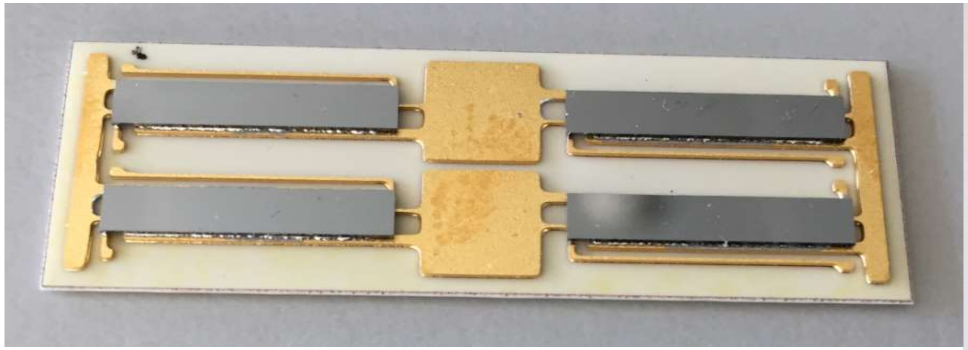
Integrated Power Converters for 48 V micro/mild-hybrid vehicles

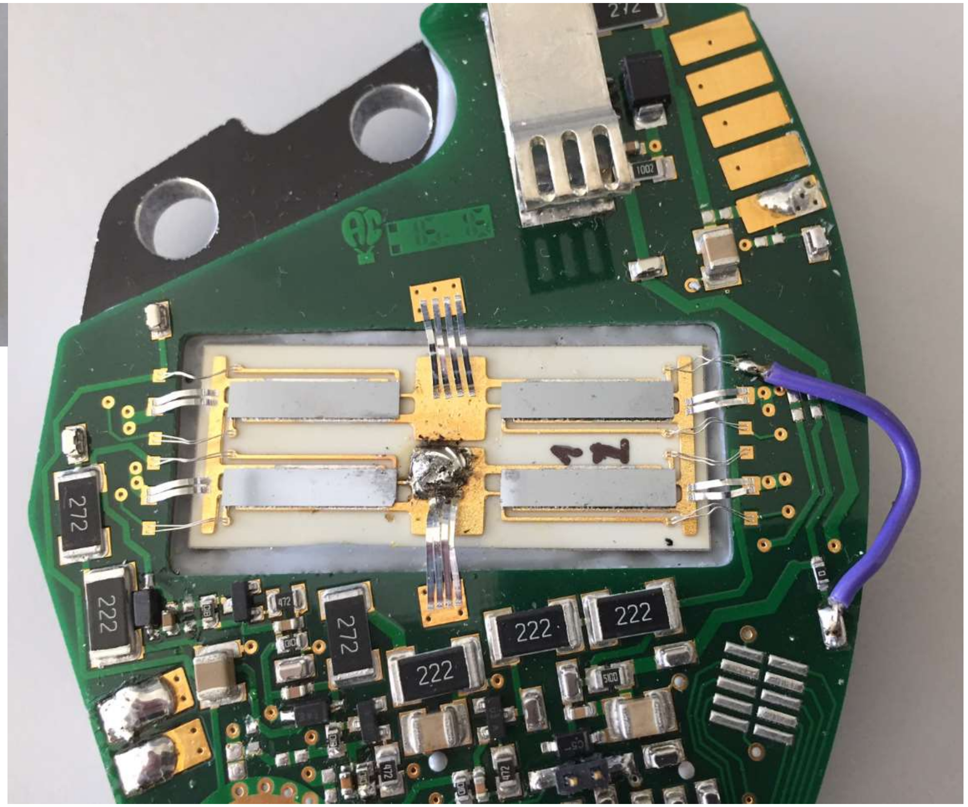




48 V power bridge provides AC excitation to the electrical machine

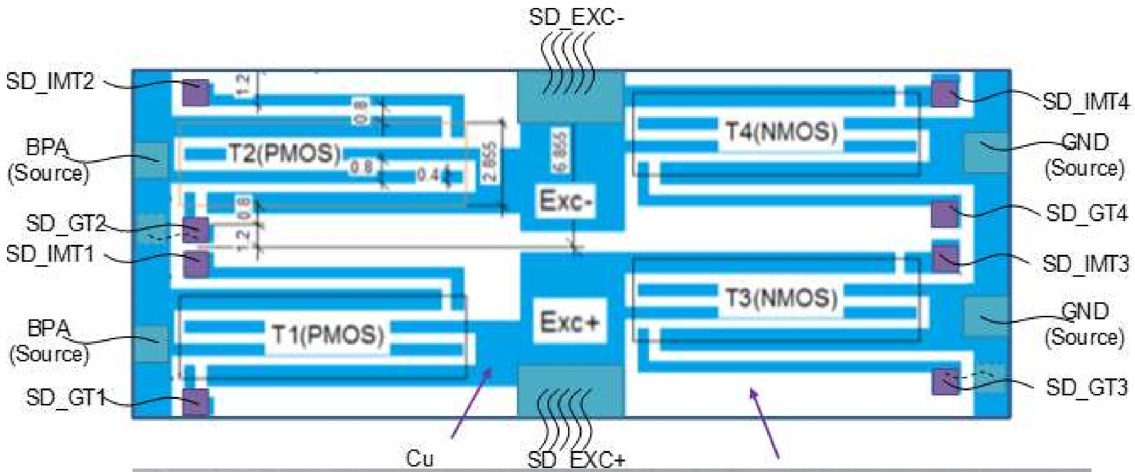
48 V power bridge in 0.18 um HVMOS

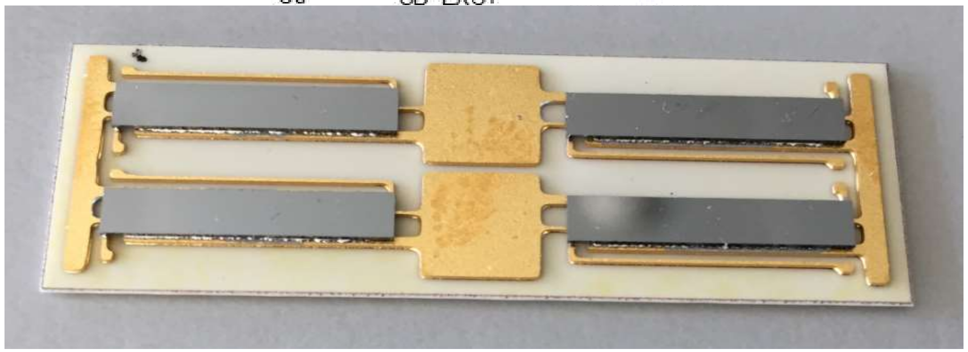


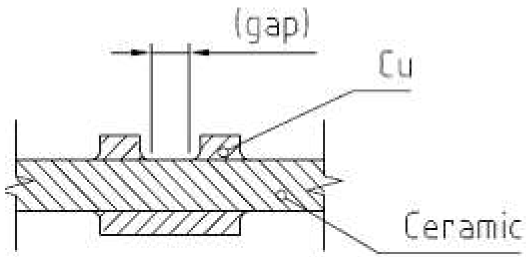


48 V Power bridge embedded within the electrical machine (Ron limited at about 10 mOhm)

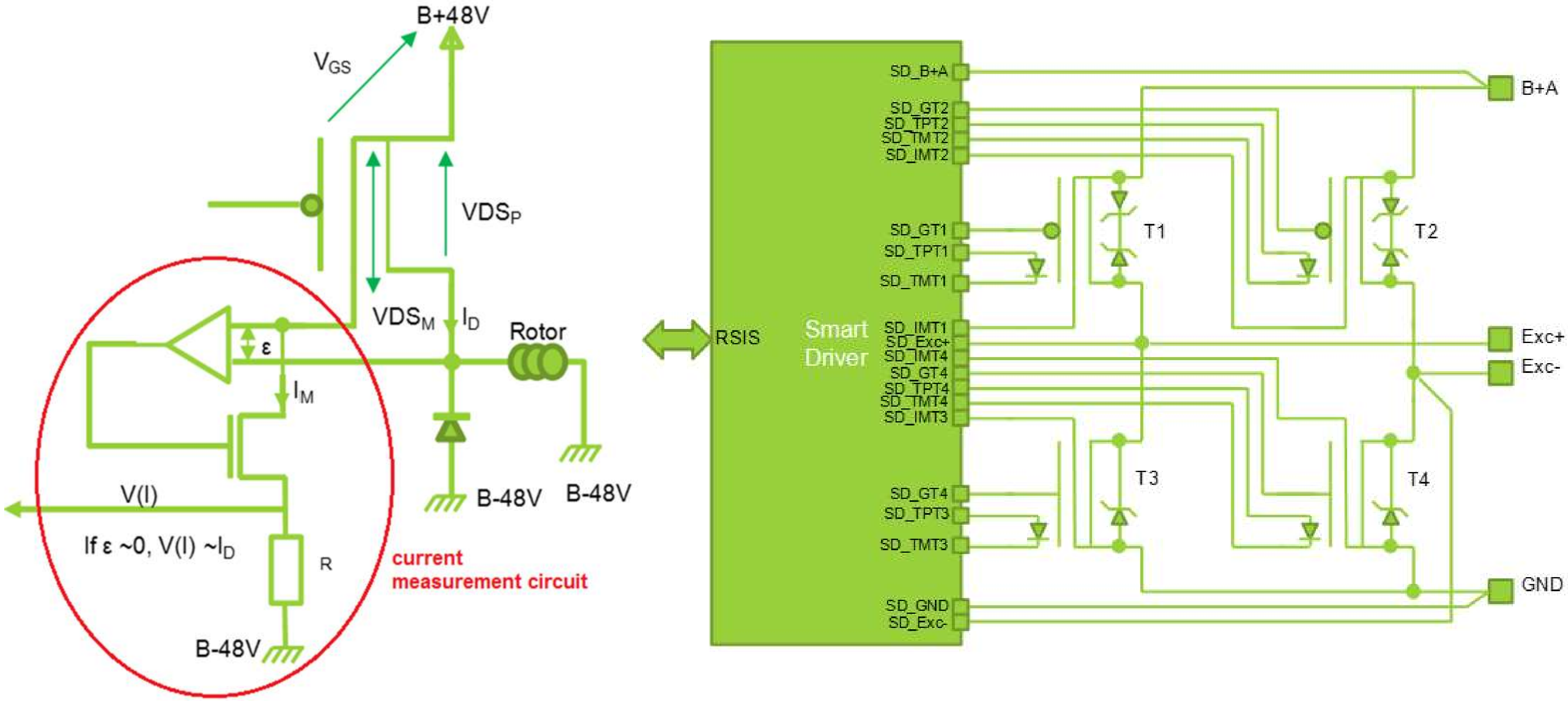
Direct bonded copper to reduce on-resistance







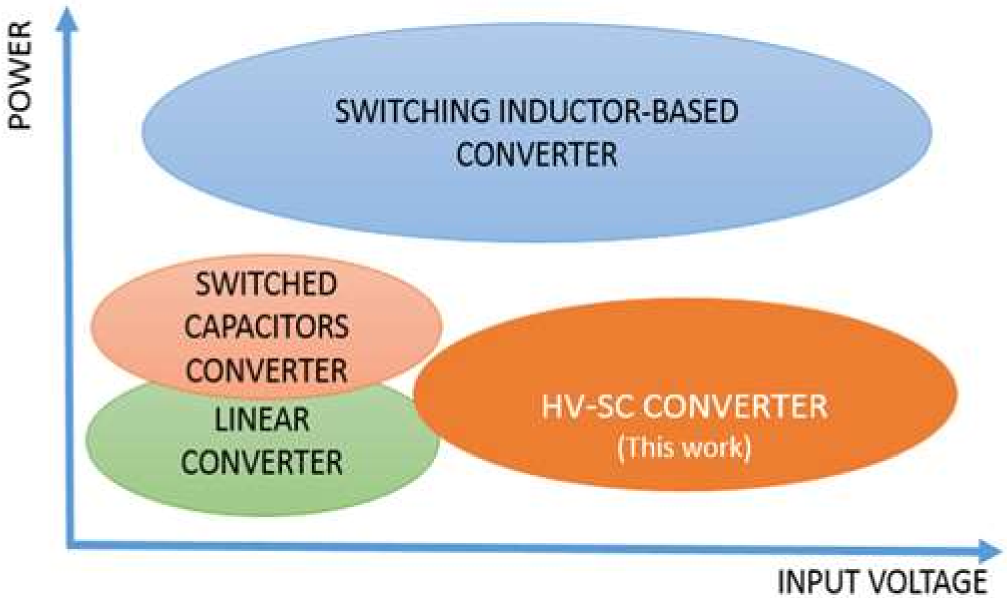
Integrated current measurement



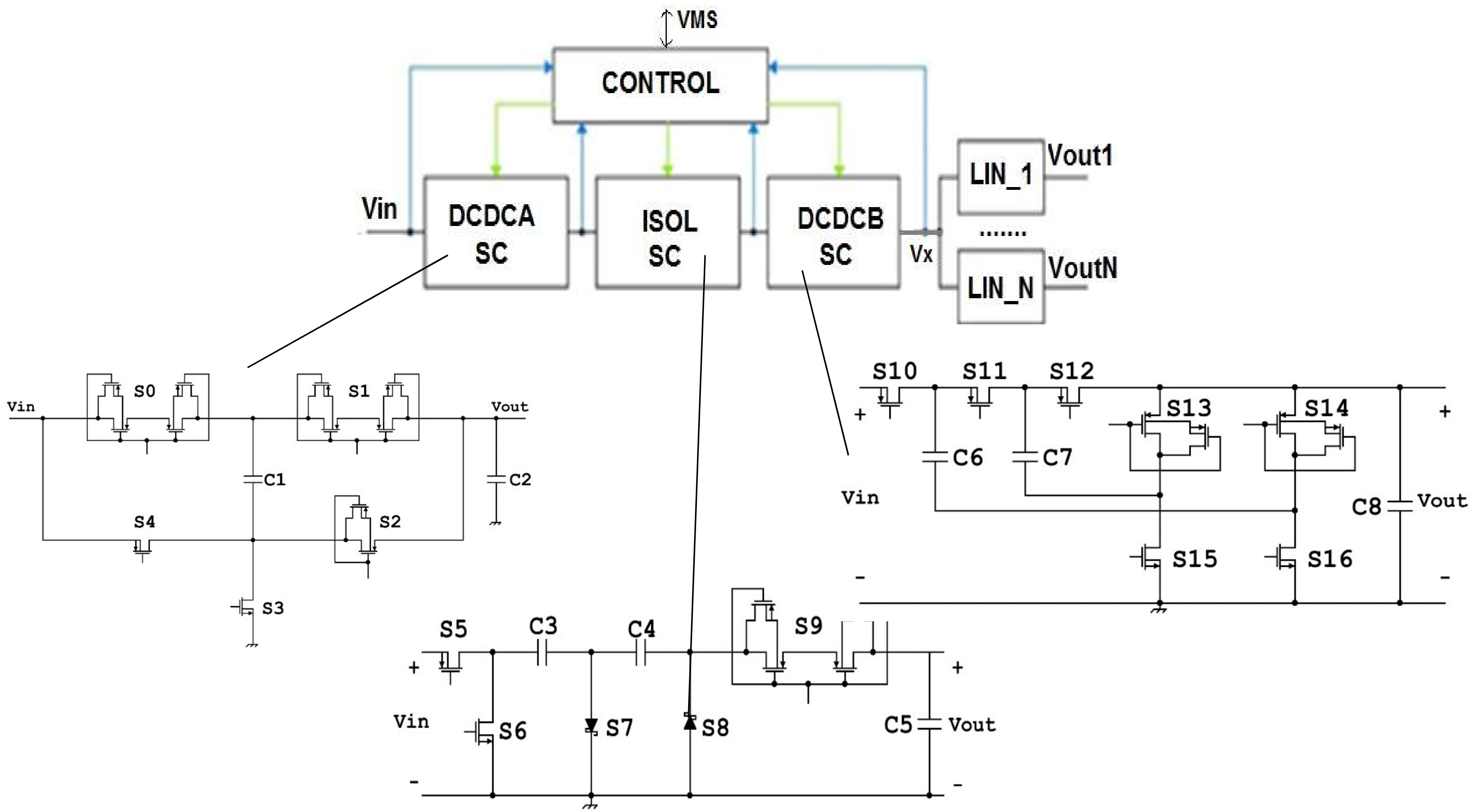
48 V DC/DC converter

In 48 V vehicle systems a DC/DC converter is needed for direct supply of low-voltage loads (processors, sensor, memories)

The proposed DC/DC converter covers a gap in state of art (switched cap inductorless converter for high voltage input and low power loads)

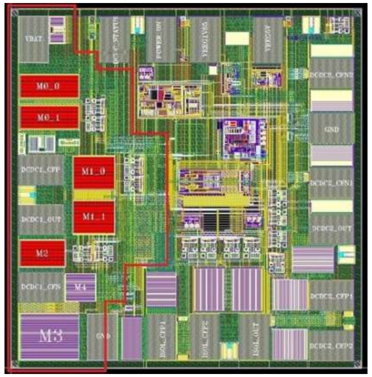


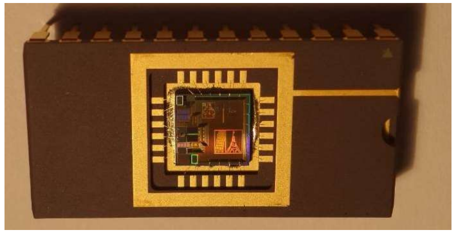
48 V Switched-Cap (SC) architecture



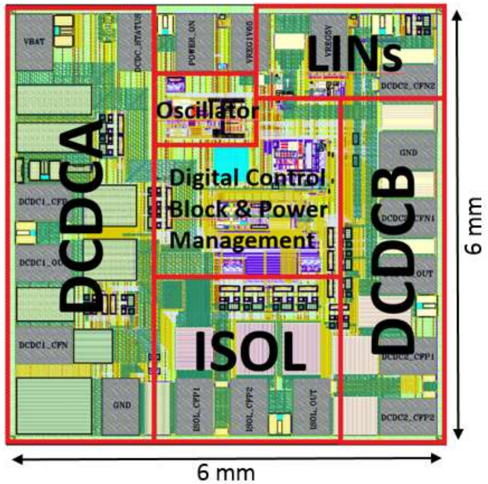
48 V chip layout and test PCB

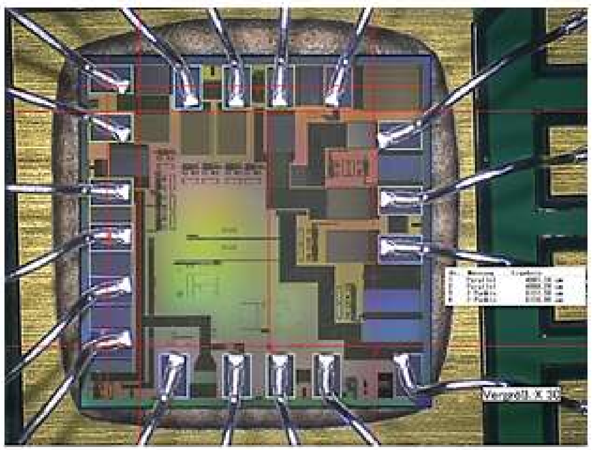
V1

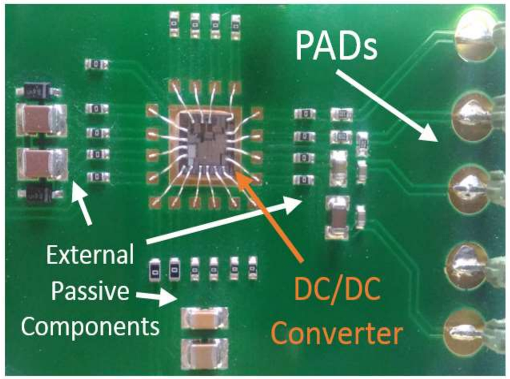




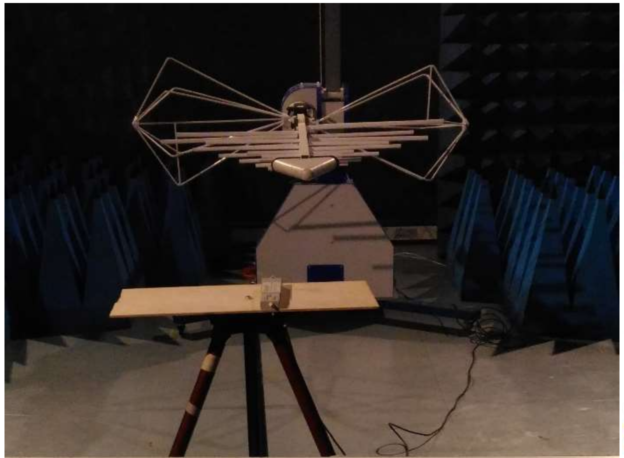
V2

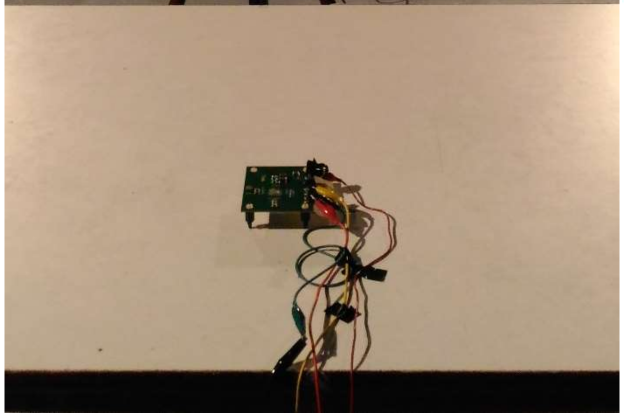


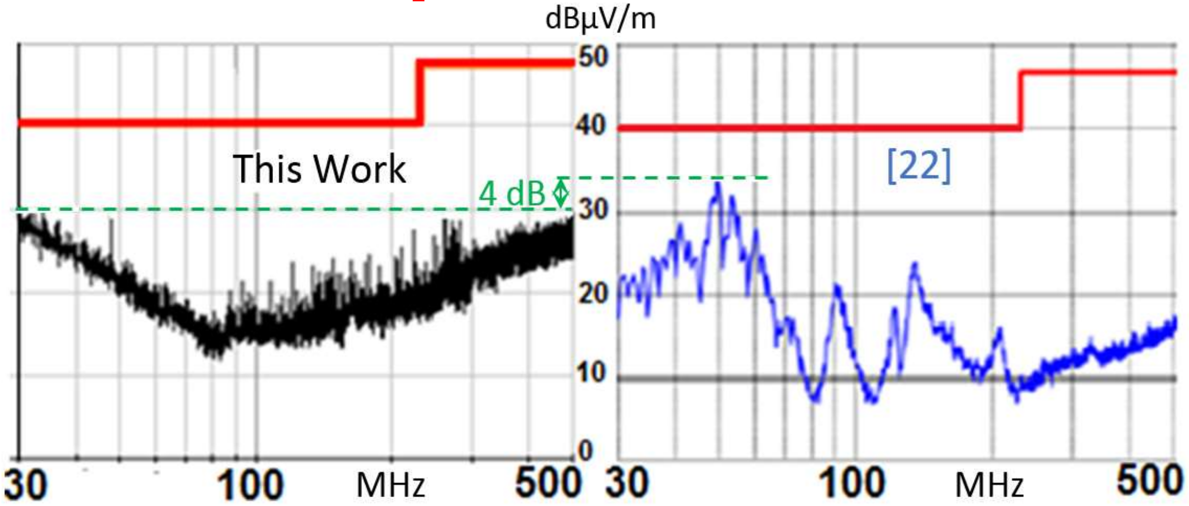


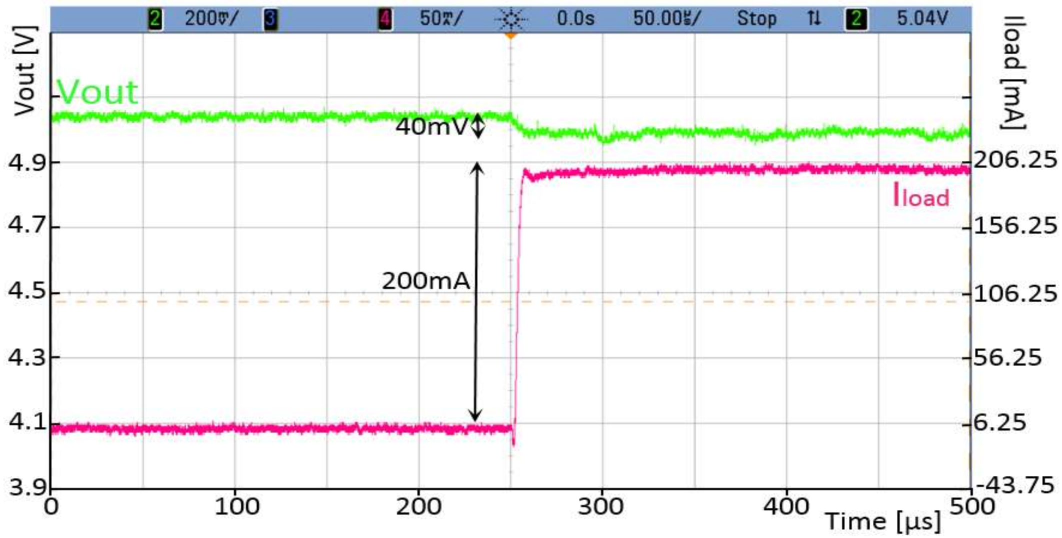


Regulation and EMC performance



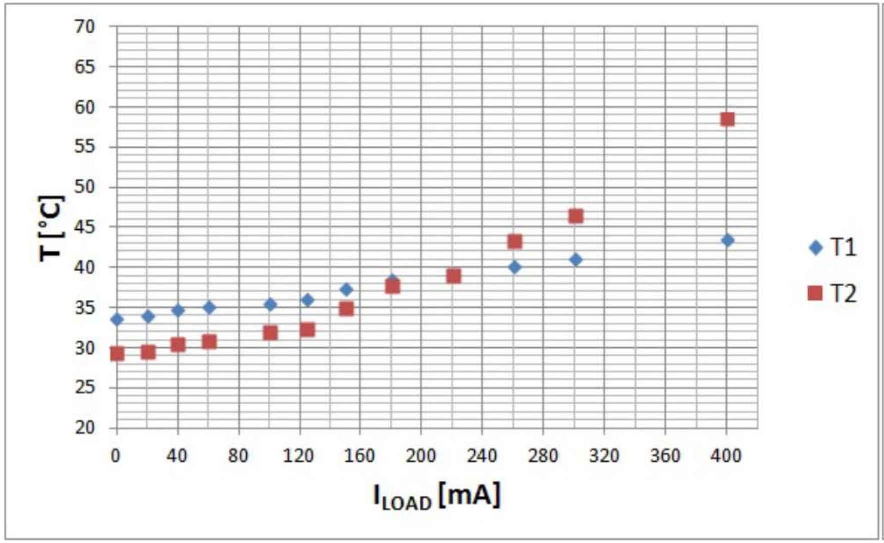






Low radiated EMI

Temperature tests and state-of-art review

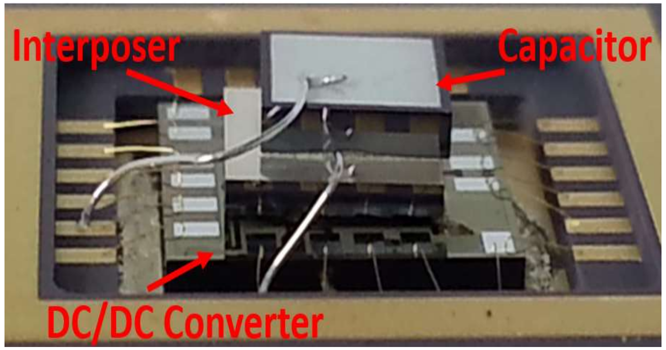


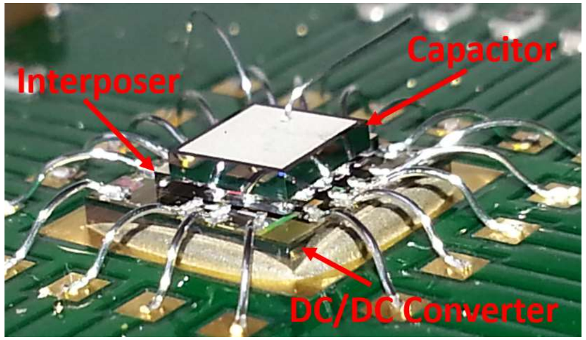
Low over-temperature (can work also without cooling system)

Integrated LDO, I/O insulation and wide input range vs. state-of-art

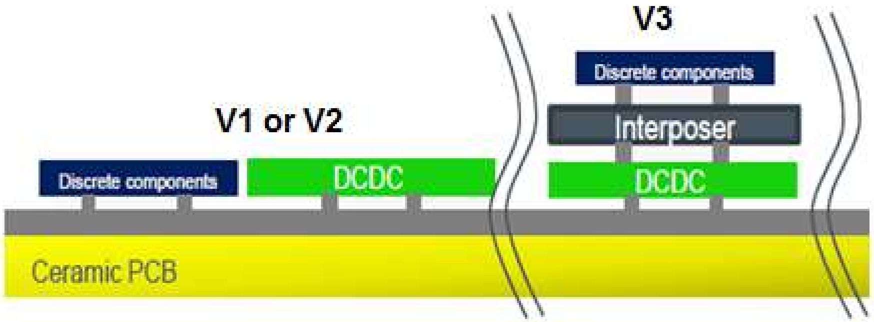
	This Work	PT4660	LT3245	LM5170
Type	SC+linear	Inductive	SC	Inductive
In-Out insulation	Yes	Yes	No	No
Input range [V]	57*	39	35	79
PSRR [dB]	-60	Off-chip LDO needed		
Output voltage [V]	1.65 / 5	3.3 / 5	5	12 / 48
Max load current [A]	0.4	30	0.25	5
Efficiency peak [%]	63	86	81	N/A
Stand-by current [μA]	5	5000	4	10

V3 with capacitors stacked on top





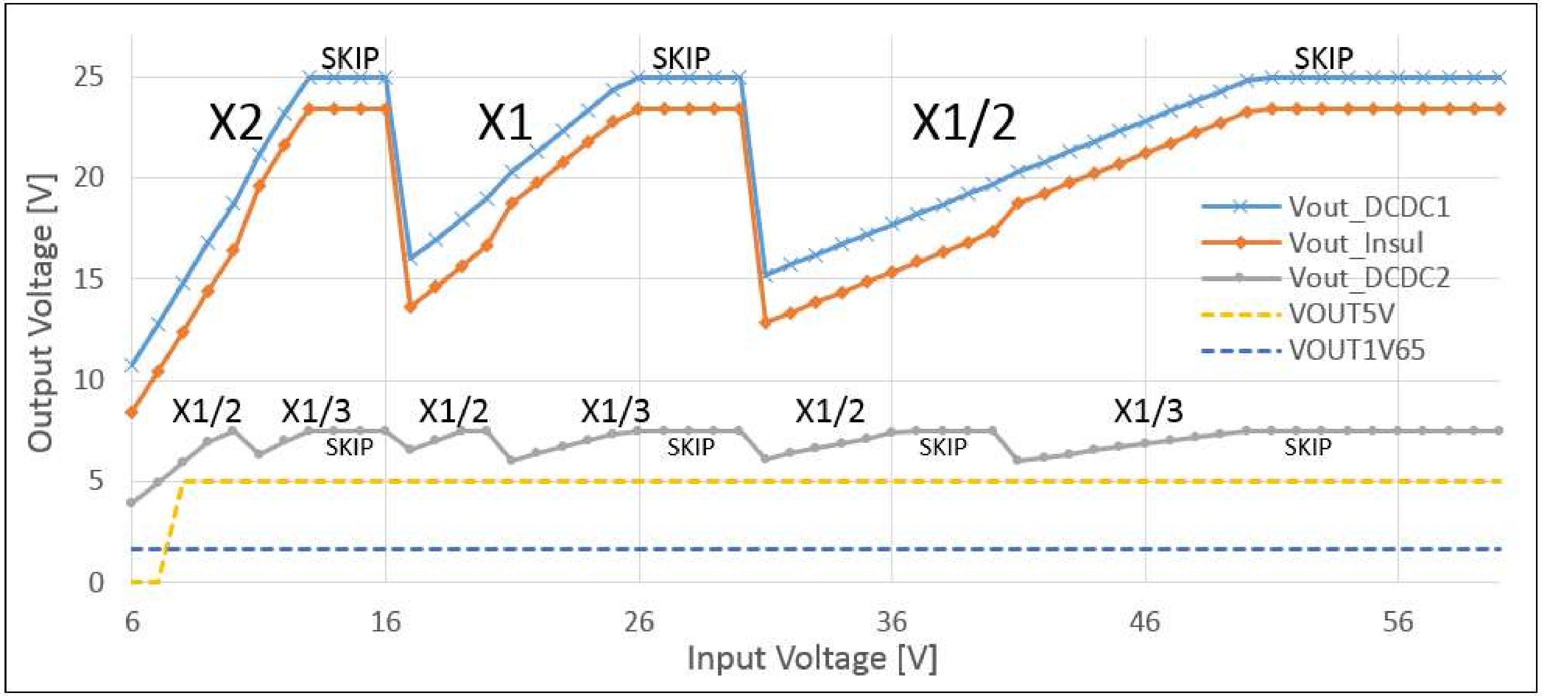
Unaltered performance of V3 vs. V2 but much lower area



Advanced control techniques: Topology reconfiguration

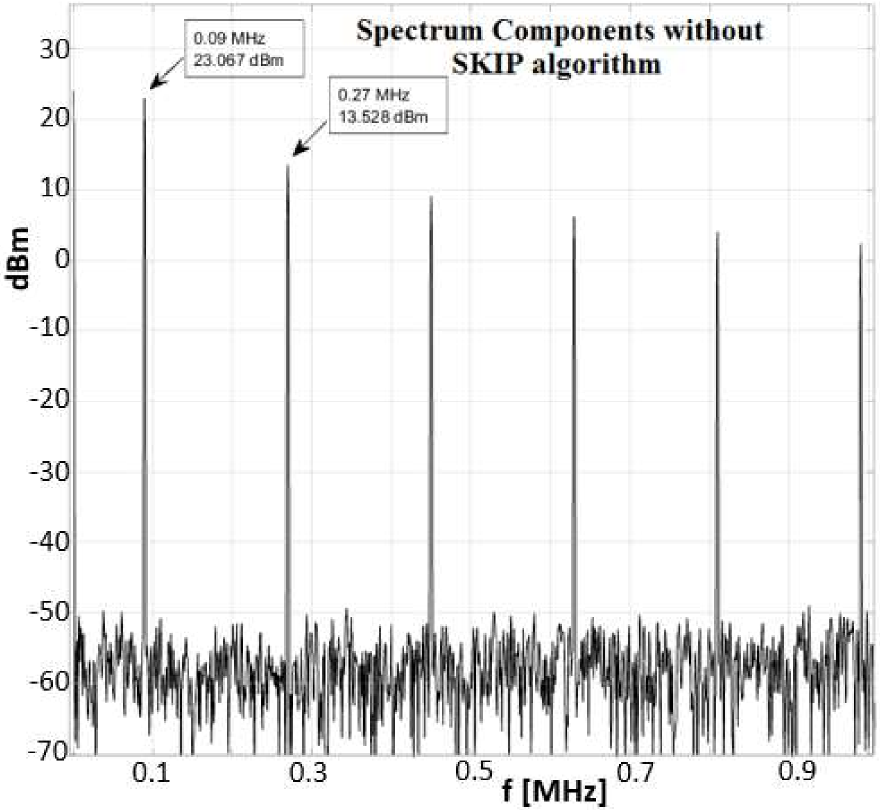
Stage	Input Voltage [V]	VCR	Output Voltage [V]
DCDCA	6 < Vin < 15	2	12 < Vout < 30
	15 < Vin < 29	1	15 < Vout < 29
	29 < Vin < 60	1/2	14.5 < Vout < 30
ISOL	12 < Vin < 30	1	12 < Vout < 30
DCDCB	12 < Vin < 18	1/2	6 < Vout < 9
	18 < Vin < 30	1/3	6 < Vout < 10
LIN_1	V_X > 6	-	5
LIN_2	V_X > 3	-	1.65

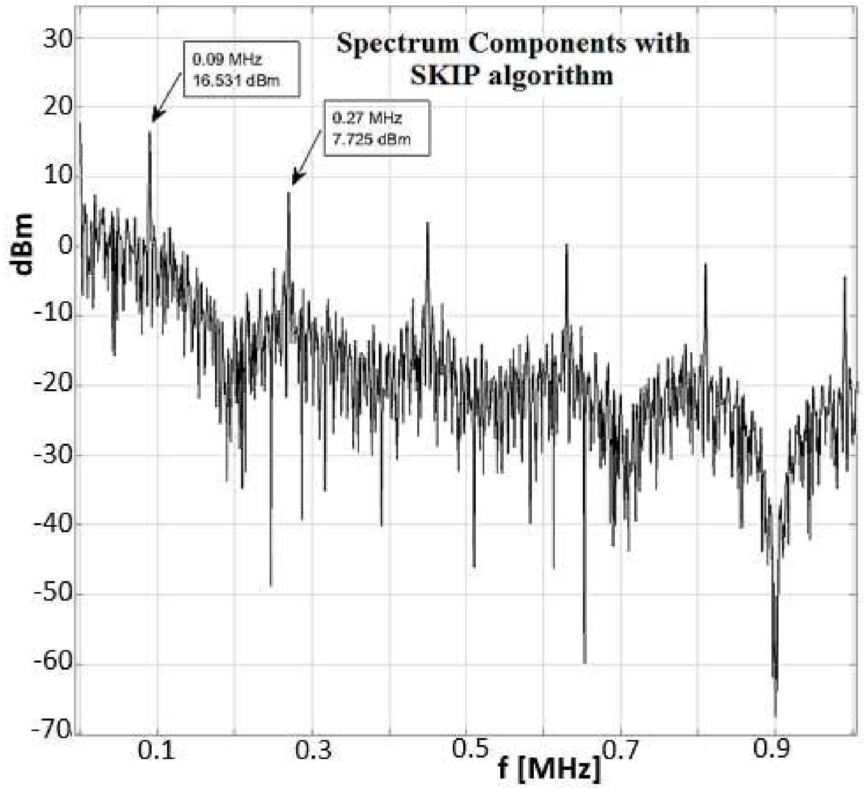
Effects of the control techniques (topology reconfiguration and SKIP-mode on the voltage regulation in the multi-stage DC/DC architecture)



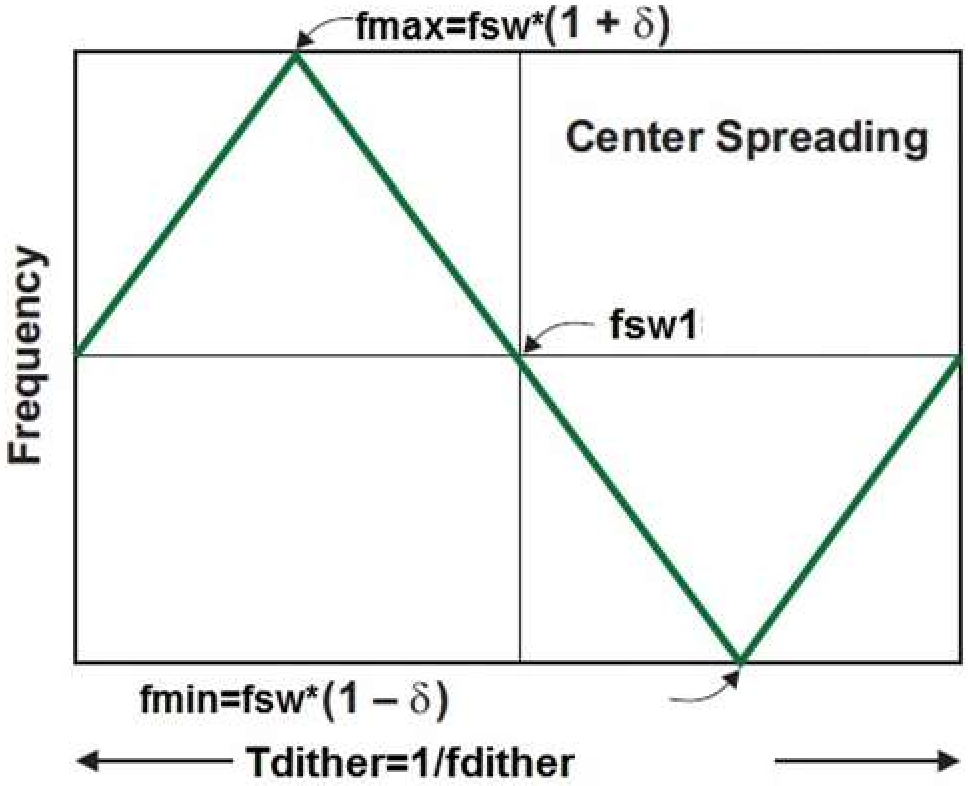
Advanced control techniques: Skip Mode

More than 6 dB reduction of the EM Interference power emission thanks to SKIP-mode. Fixed frequency, like a PWM with duty-cycle hopping between 0.5 and 0



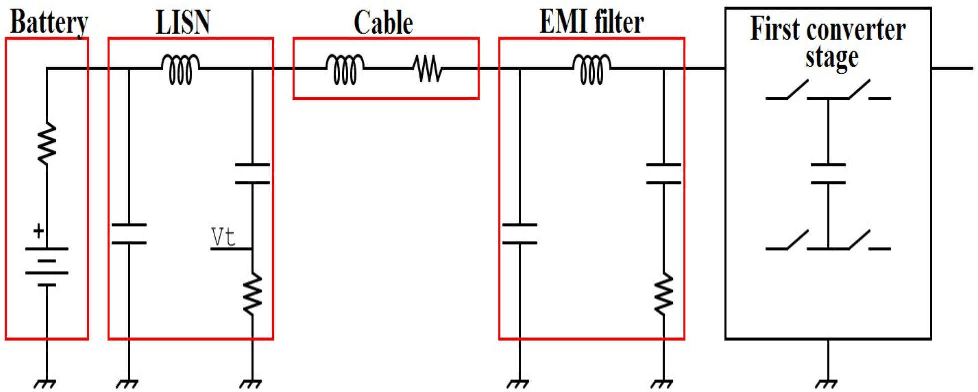


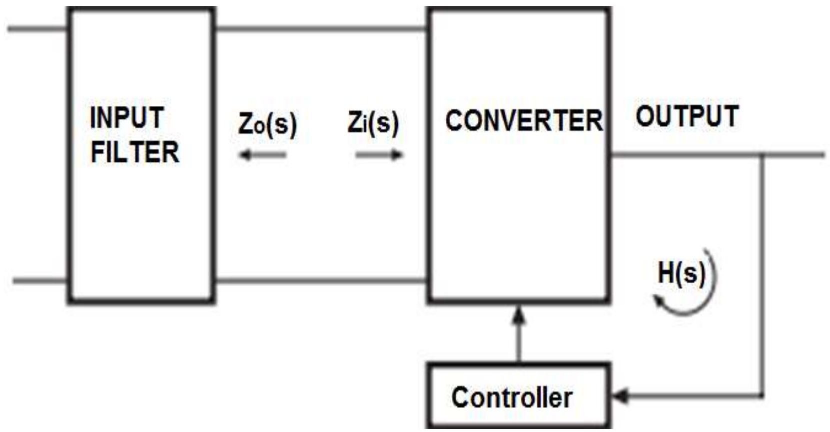
Advanced control techniques: Switching frequency spreading



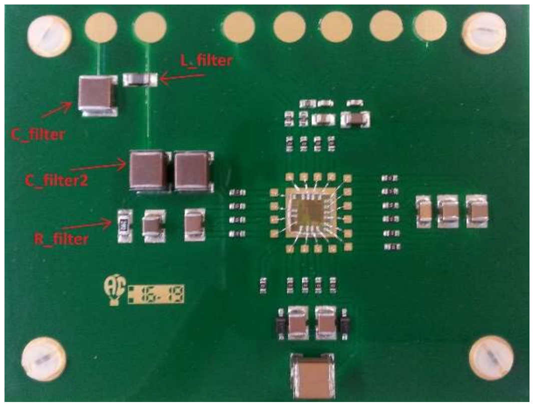
$$Extra\ spectral\ attenuation\ (dB) = 10 * log[(f_{SW} * \delta)/(f_{DITHER}/n)]$$

Advanced control techniques: Anti-EMI filter





The design of anti-EMI filter aware of input converter impedance allows reducing x 3 the size of the filter components and avoids instability

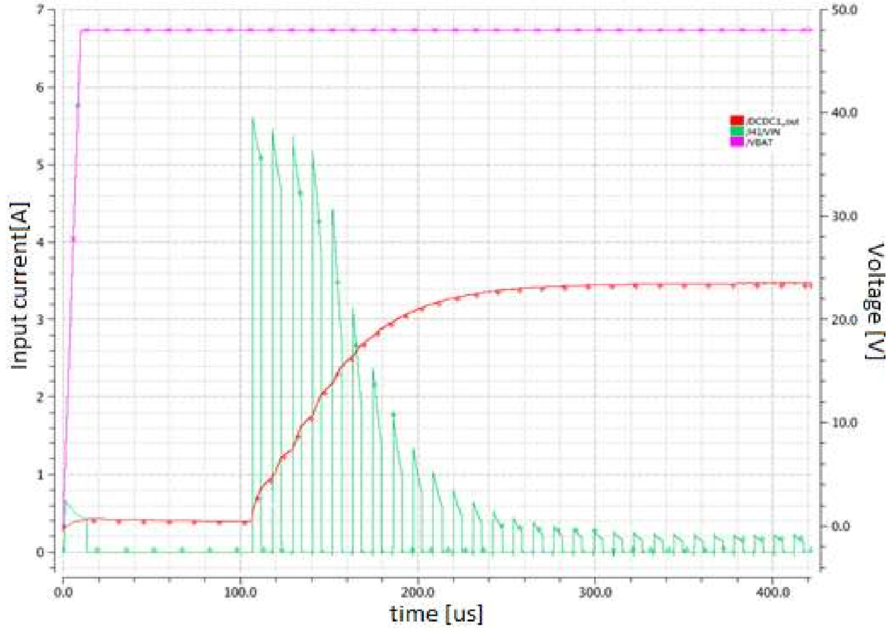


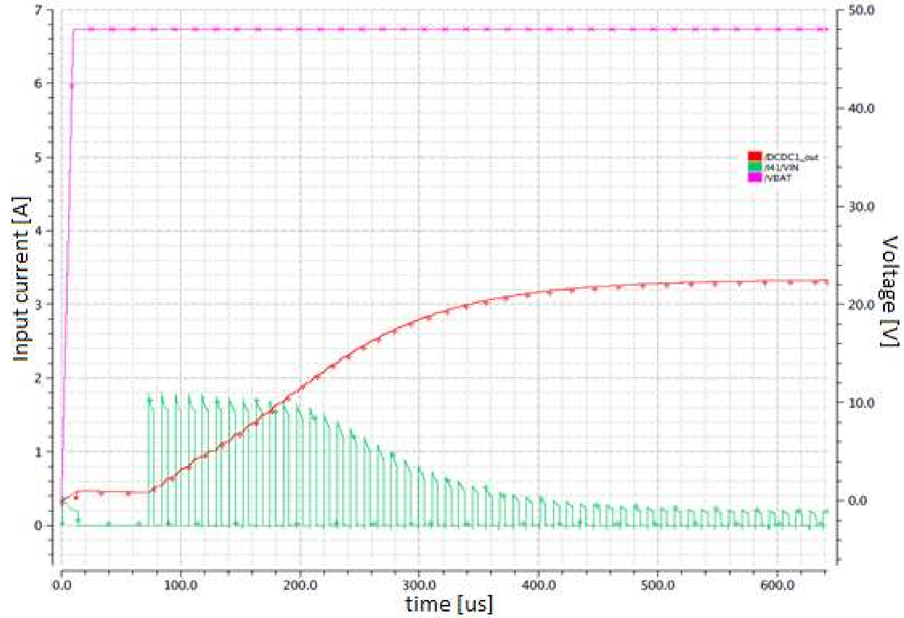
	Set-up		EMI measurement results	
	$V_{battery,}$[V]	I_{load}, [mA]	Freq.peak., [kHz]	Amplitude, [dBV]
This work	8	0-300	180	-84, -74.8, -65.4
	12	0-300	180	-87.2, -77.4, -69.8
	24	0-300	180	-77.8, -77.2, -75.4
	48	0-300	160	-74.4, -76.4, -71.4
	60	0-300	100	-71.4, -63, -57.8
[TI]	30	1600	10	-47.5

Advanced control techniques: Soft-start

Input current without/with soft-start modality (the current peaks, represented from green signal, are reduced by 3 times).

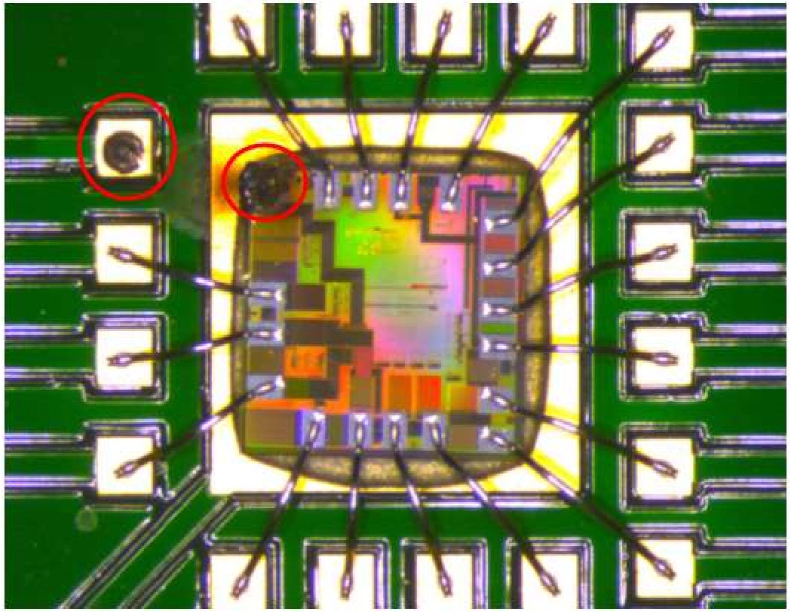
HV-MOS are realized as multiple parallel devices, activated according to a proper sequence when starting to avoid high in-rush currents





Advanced control techniques: Soft-start

Without soft-start chip can be damaged by high current peaks at device start



	Conducted EMI reduction	Radiated EMI reduction	Could be integrated	Low design effort	Low cost
EMI filter	+ + +	-	- -	- -	- -
SKIP control	+ +	+ +	+ + +	+	+ +
Soft-Start technique	+	+	+ + +	-	+

Outline

- Innovation and trends of circuits & systems for smart vehicles and int. transport systems (ITS)
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ADAS signal processing computation levels

Low-level operations characterized by computing intensive algorithms, applied at pixel level, such as filtering. For them custom and parallelized architectures can be an efficient solution

Medium-level operations apply tasks such as feature extraction, segmentation, classification to selected ROIs

High-level operations consist in decision-making algorithms, for which the flow of data and operations is irregular and a sequential flow on a programmable core is more suited

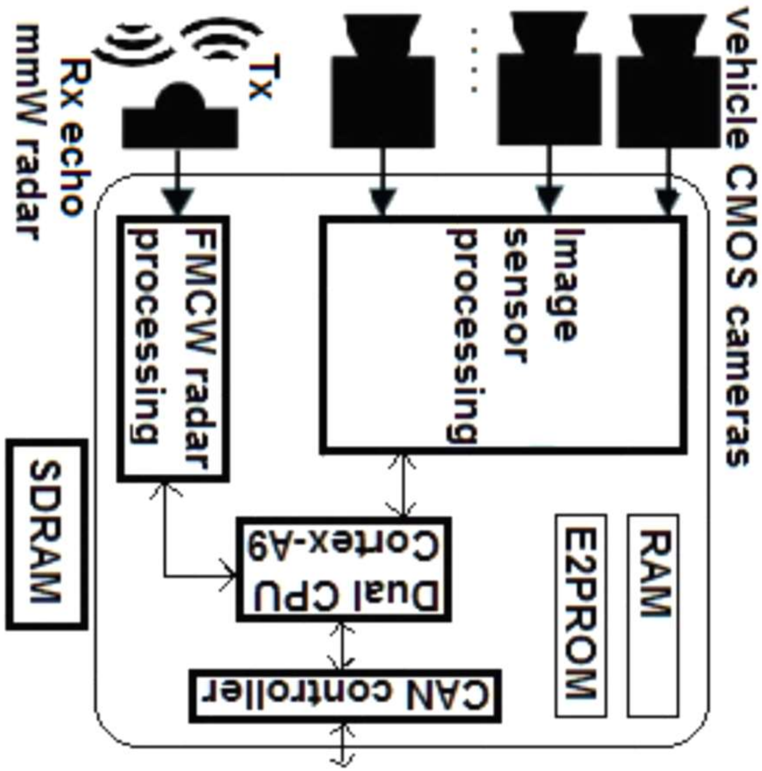
Due to constraints in terms of low power consumption, and real-time computing capability, the best-suited ADAS architecture in the state-of-the-art is an heterogeneous one mixing software-programmable core and configurable hardware co-processors

Reference HW-SW architecture for ADAS

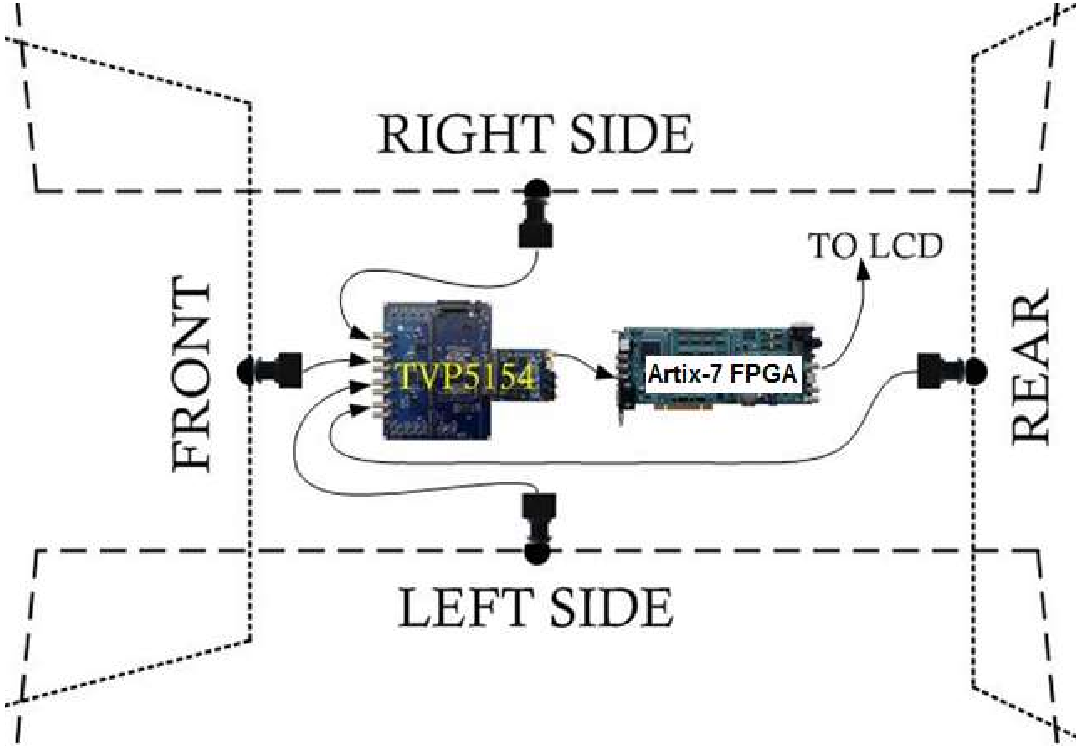
Fusion of multiple sensors: FMCW Radar and Video CMOS cameras

Multi-core Cortex-A9 (x2, x4) SW programmable processor enhanced by HW image processing accelerators and on-chip/off-chip memories CAN/FlexRay networking

Design of configurable HW accelerators for key ADAS functions



ADAS platform with 4 fish-eye cameras for all-around view



TI TVP5154 Video Mux + Artix-7 Automotive grade FPGA for real-time fish-eye correction and video mosaicking

Fish-eye lens distortion correction

Backward mapping Lookup Table (LUT)-based correction

The LUT stores the positions of the source pixels calculated initially, and then is used to rearrange the pixels of each video frame
The resulting frames can be re-assembled in a video stream
In the Backward Mapping mode, for a generic pixel far R_P from the focal axis the correct source position R_{source} is calculated according to Eq. A where the apparent focal length λ is calculated according to Eq. B and f is calculated according to Eq. C

$$R_{source} = 2 * f * \sin[\lambda /2] \quad \text{(A)}$$

$$\lambda = \tan^{-1}(R_P/f) \quad \text{(B)}$$

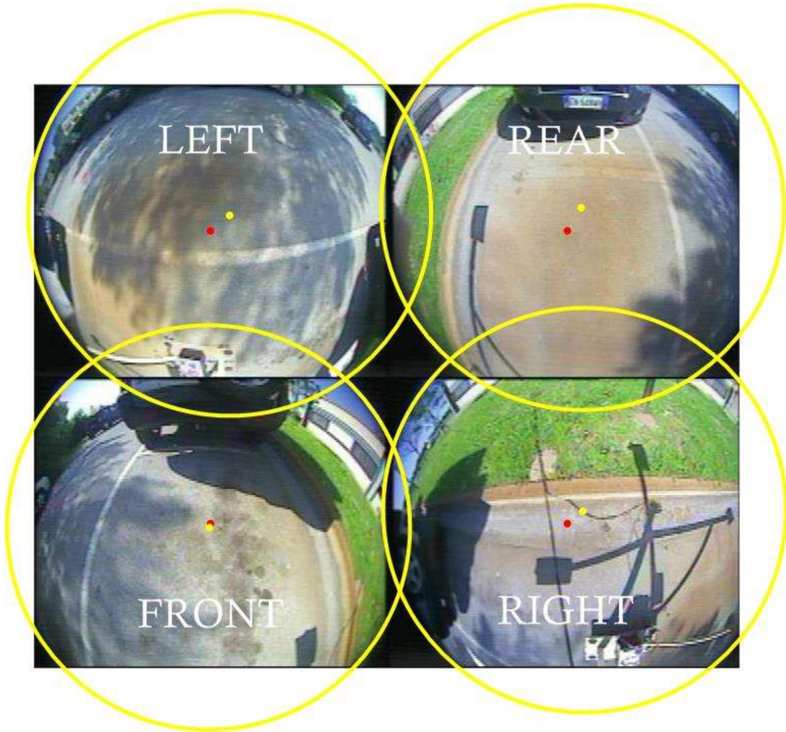
$$f = W/[4*\sin(FOV_{hor}/2)] \quad \text{(C)}$$

Lens manufacturing distortion correction

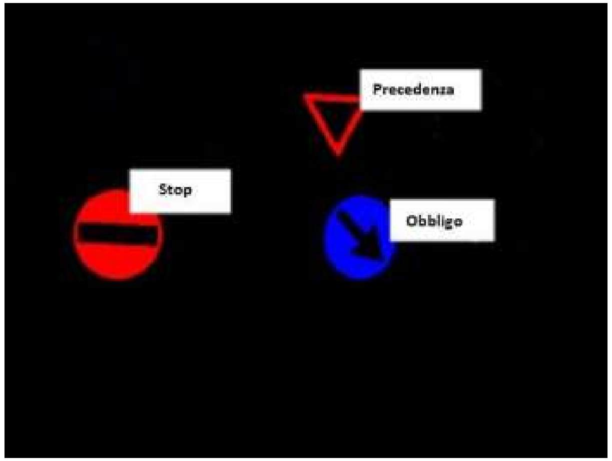
Different misalignment for each camera. The red point is the sensor center, yellow one is the center of distortion

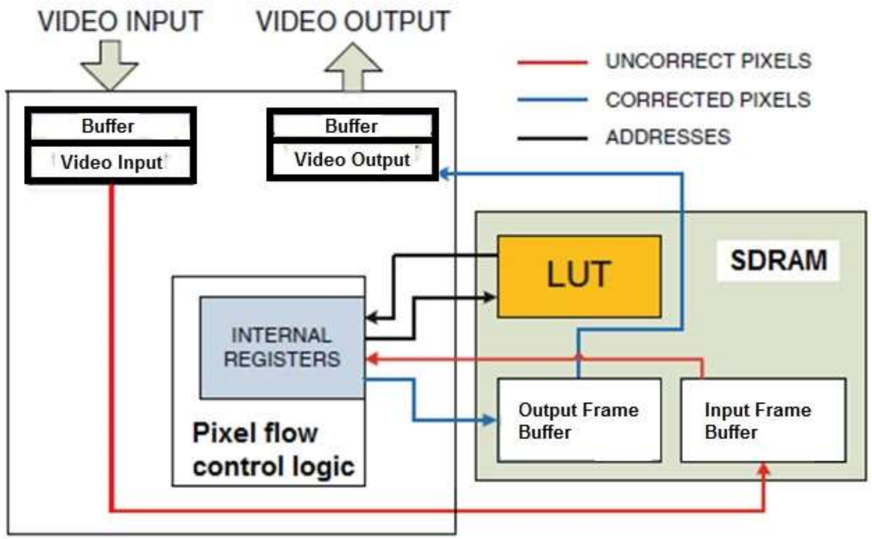
We apply the radial correction algorithm by the Center of Distortion. The corrected images need to be re-centered on this point. The correction of this manufacturing imperfection is done in a calibration phase of the ADAS system.

Our algorithm allows to specify vertical and horizontal offsets, to indicate the misalignment of the center of distortion



Fish-eye correction & surrounding view





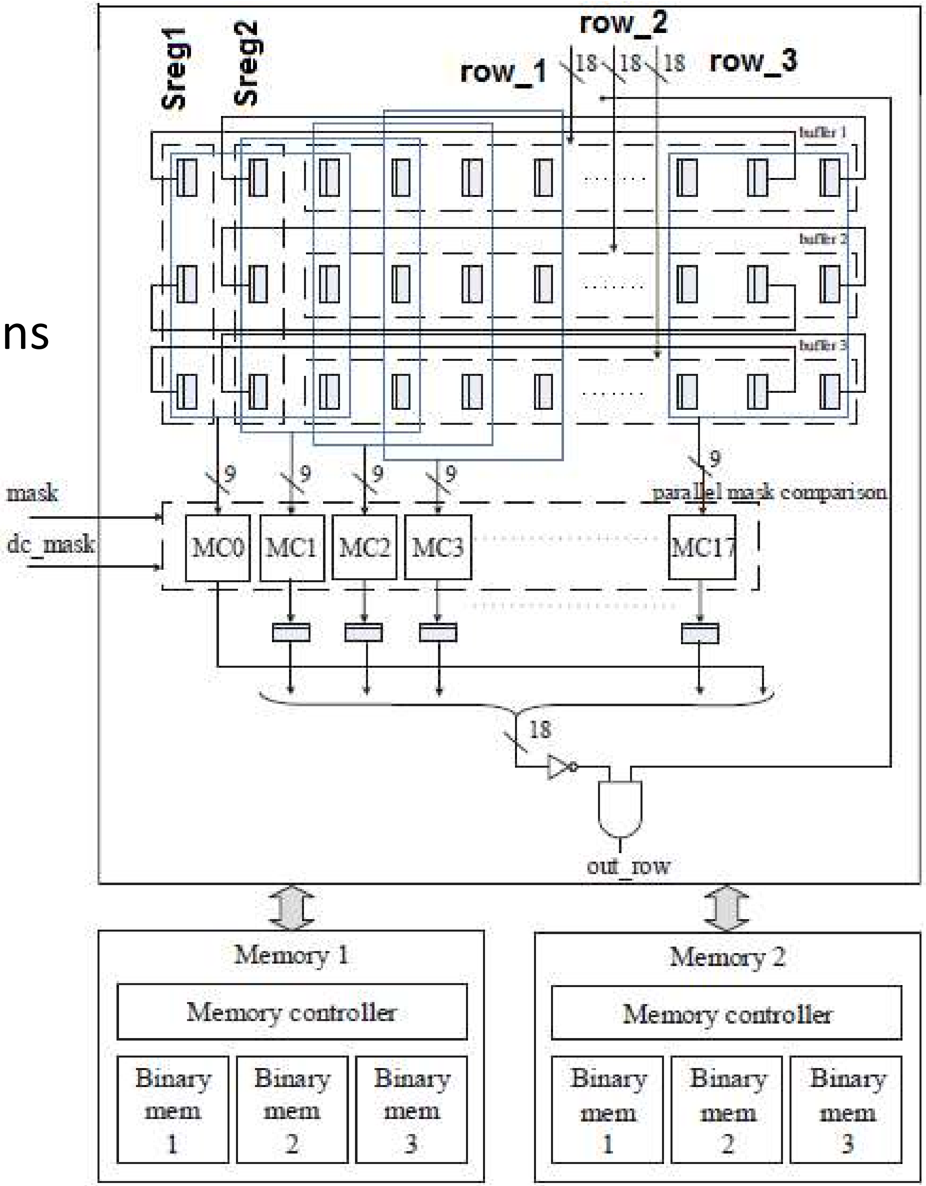
Results and comparison to state-of-art

Implementation on XA7A100T FPGA device:
10% of the reconfigurable logic + 2 MB of total memory for LUTs
56 Mb of input and output frame buffers to store 24 b VGA images (external SDRAM)
Correction and fusion of 4 VGA cameras in real-time at 30 fps
100 mW power consumption

2 main benefits vs. state-of-art Zhang2014, Turturici 2014:
A- HW implementation compliant with harsh automotive specs
B- better power efficiency vs. Turturici 2014 (having similar power cost for fish eye correction, but which does not implement image fusion) or the dual C66x DSP in Zhang2014, whose power cost is above 1W

Parallelized architecture for pixel level filtering

2D-filtering applied at pixel level,
e.g. with 3x3 masks, around each pixel
Different masks (R) and multiple-iterations (I) can be used → different algorithms
R and I are configurable parameters



Example application to image thinning for ADAS

Architecture configuration for image thinning applied to object segmentation in traffic sign recognition

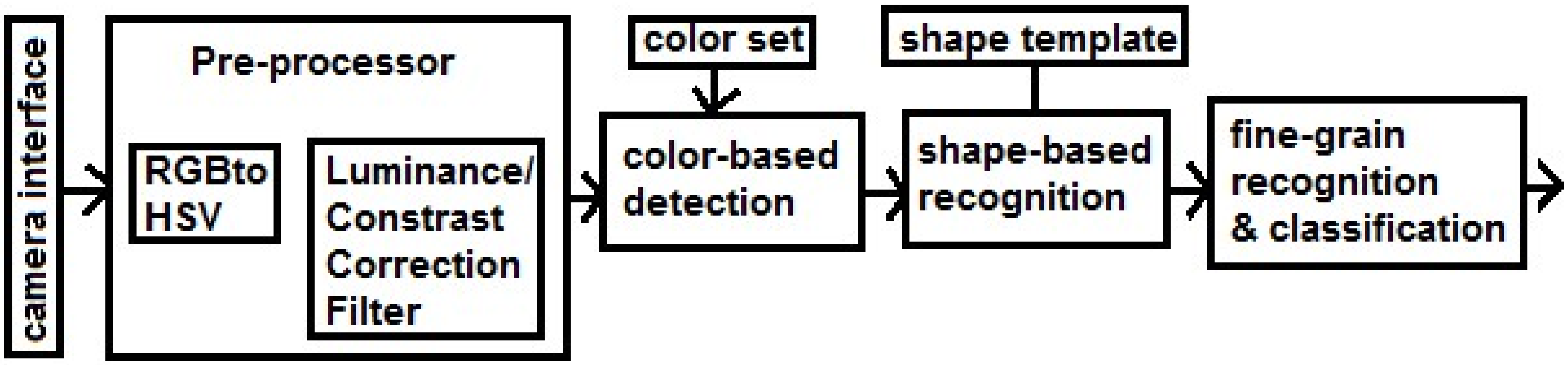
Synthesis on Artix-7 FPGA (automotive-grade XA7A100T FPGA) requires just 1 % of the configurable logic and 12.5% of on-chip RAM

The max clock frequency is 200 MHz → real time 67 fps VGA videos

Synthesis in 45 nm CMOS standard-cells: 5 gates plus 600 kbits of SRAM; 350 MHz max. speed (160 fps VGA video in real-time).

With respect to state-of-the-art, the parallel architecture achieves a speed up factor of roughly 4 times vs. Hsiao et al. ISCAS

TSR macrocell architecture



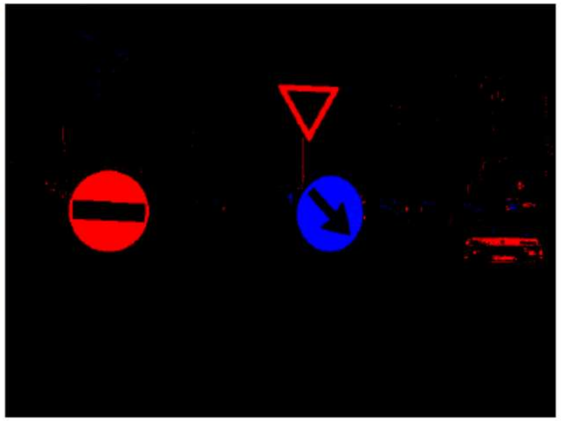
According to a ping-pong buffering scheme, this macrocell relies on 2 frame buffers: when the pre-processor is working on the first frame memory on the successive image acquired from the input camera, the other processing blocks are working on an image stored in the second frame memory

The two memories are periodically swapped

For automotive 24b VGA (640x480) cameras, the buffer frame size is 14 Mbits (stored in external SDRAM since this value exceeds the on-chip memory size of the considered automotive grade FPGA)

Color-based image decomposition

This step changes the color space of the loaded image from RGB to HSV and filter the obtained image, leaving only parts of interest



Extraction of key characteristics

For the regions remained after segmentation and noise removal steps, the following characteristics are extracted: color, area, perimeter, object center, radius, distances from border to center, area under and above the center of the figure, ratio between its area and the area of the rectangle inscribing it

According to these characteristics, the shape and color of the traffic/road sign is evaluated and the type can be recognized

Traffic sign classification (1/2)

First discriminant characteristic is the color

Second, we must consider the ratio between the square of the perimeter and its area; this ratio has different and specific values for the different classes of signs

Third, we must perform a roundness control and this can be done comparing distances from the center of the figure in the points we have sampled before with the radius of the sign (in case all values are almost the same, apart a predefined tolerance, the shape is a circle)

Fourth, the ratio between the area of the region and the area of the rectangle in which it is inscribed assumes specific values useful when recognizing triangles and octagons

If the sign is a triangle, is important to know its orientation: if the area above the center is larger than the area below the center, it means that the triangle basis is on the top and vice versa

Traffic sign classification (2/2)

the detected traffic sign is recognized as one of the signs in the set reported below:

Speed Limit sign, Prohibition sign, Stop sign, Priority sign, Warning sign, Obligation sign, Roundabout sign, Direction sign

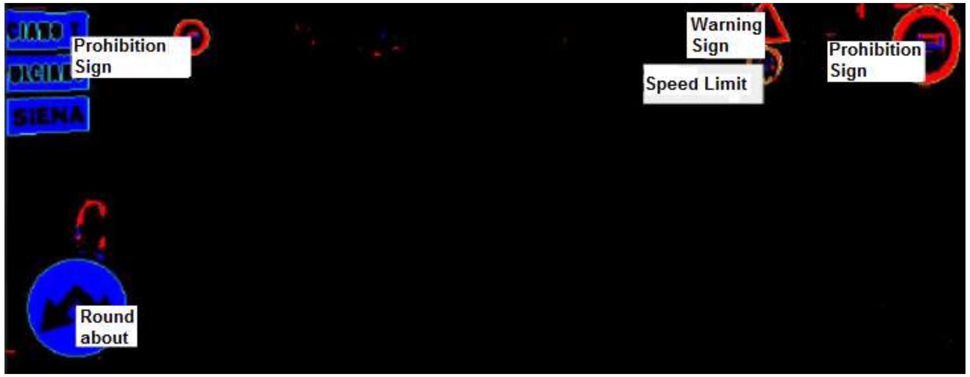
In case of the classified speed limit sign, the specific limit is recognized from a correlation analysis of the specific pattern (30, 50, 60, 70, 80, 90, 100, 110, 130 in Italy)

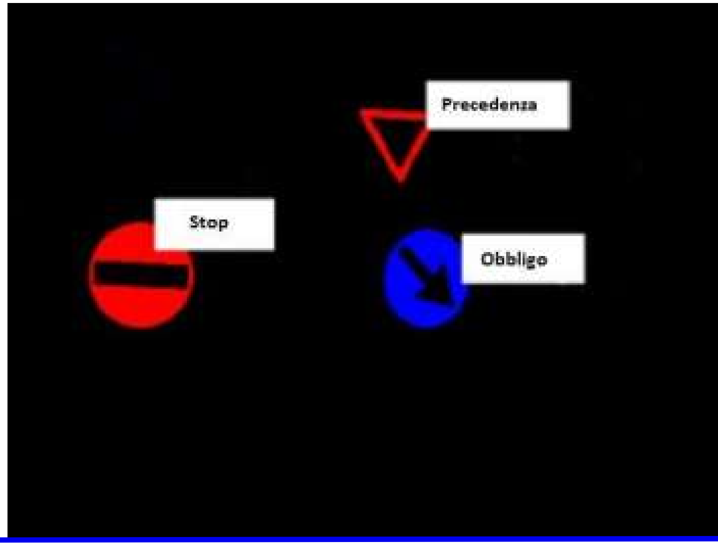
The same concept is repeated for the road signs allowing for a recognition within the set reported below:

Parking signs (with/without payment, reserved or not), Carriage limit (with/without overtaking prohibition), Stop sign, Priority sign, Direction sign

Performance results (1/2)

Aptina CMOS camera with 640x480 resolution
typical recognized images are no bigger than 200 x 200 pixel
signs recognized at an average distance of about 15 meters from
the car worst-case computation time less than 100 ms





Performance results (2/2)

Test campaign of about 2000 traffic/road signs
Missed recognition < 6%
False positive recognitions < 3 %

Real-time on a 200 MHz artix-7 FPGA

Device	FF	DSPslice	LUTs	Mem block	Power
XA7A100T	95.6%	100 %	91.2%	100%	950 mW

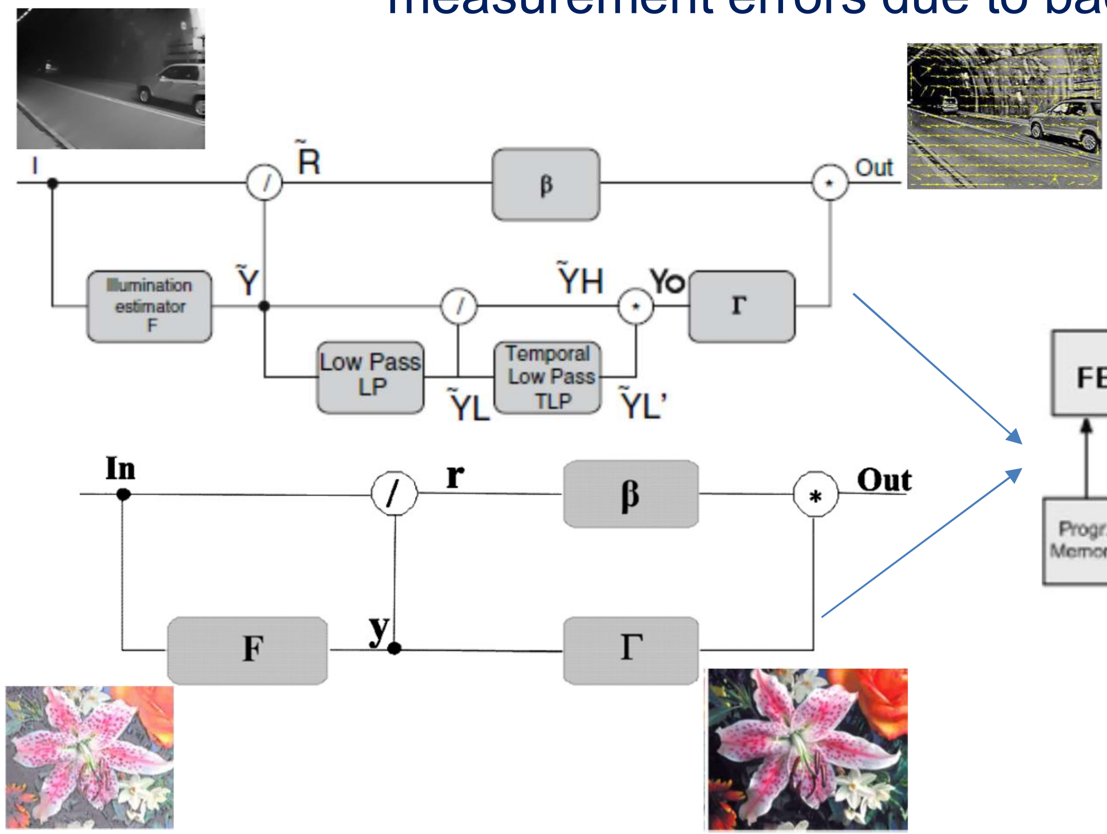
Our solution can sustain large image formats, VGA, while most of state-of-art works are limited to small 320x240 or 256x256 formats

The % of missed detection/false alarms is comparable to the best at SoA

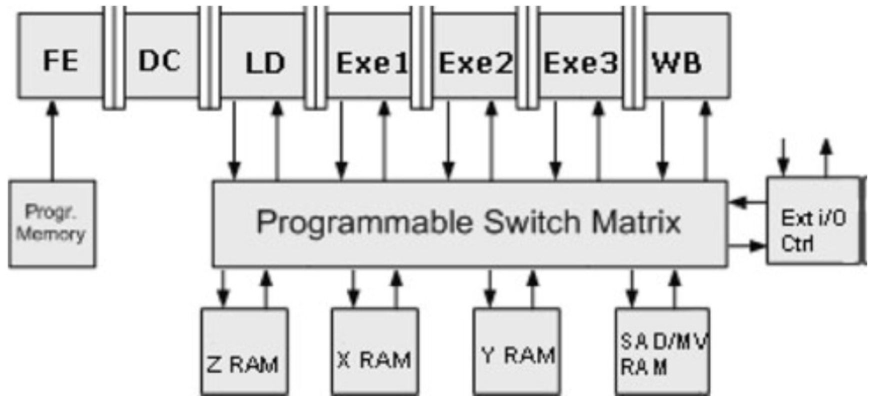
ASIPs for Retinex image pre-processing

Processors with custom instruction set: similar energy–efficiency to HW designs but with SW flexibility (nJ/pixel in 0.18 um→ X10 power saving vs. DSP)

Illumination estimation & correction, contrast enhancement, allows reducing measurement errors due to bad light conditions



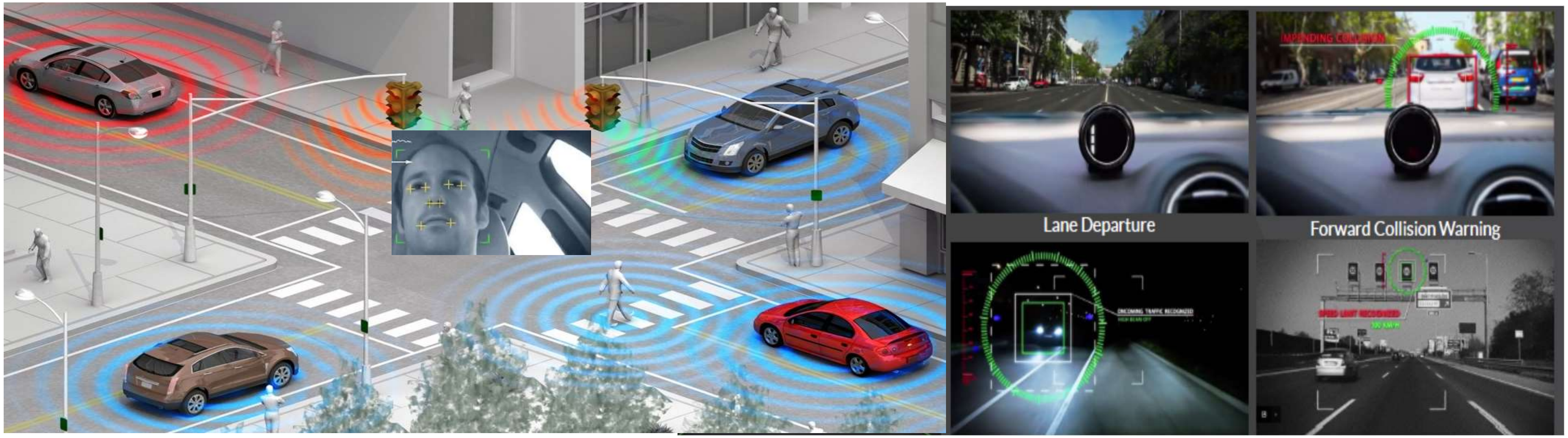
Multiple algorithms → 1 ASIP



Outline

- Innovation and trends of circuits & systems for smart vehicles and int. transport systems (ITS)
- Remote sensing (Radar) for smart vehicle & ITS
- Sensing technology for navigation
- Computing & memory needs
- Mixed-signal ICs for smart vehicles
- Image processing for smart vehicles and ITS
- Conclusions

Conclusions & on-going activities



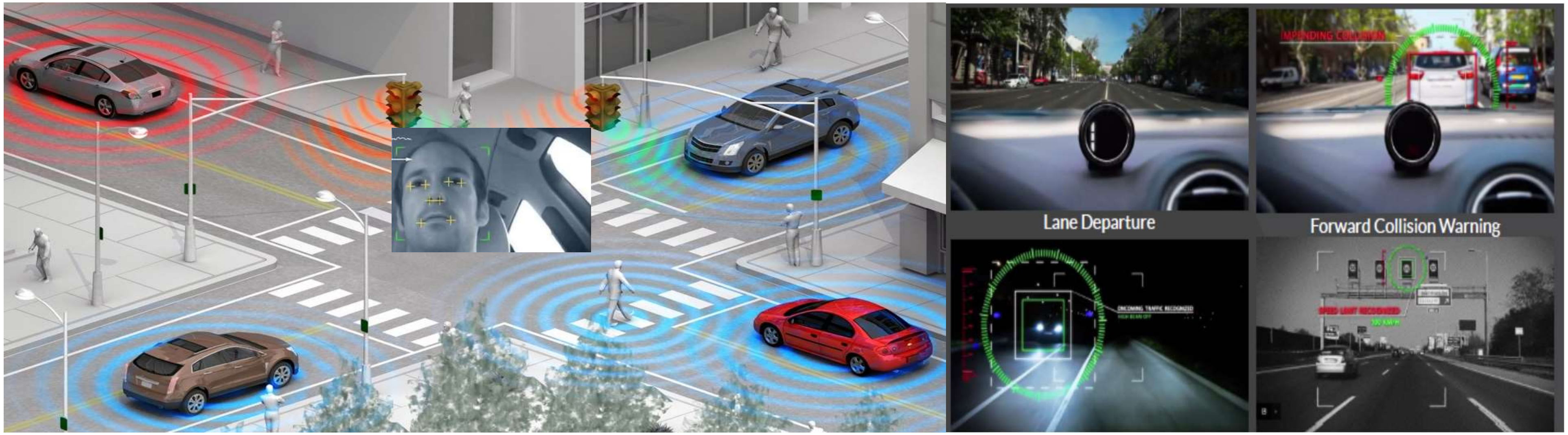
Smart vehicles and ITS are a huge R&D field for I&M

Minimizing bias and random errors in intertial sensors

Fusion of Radar, cameras, Lidar & intertial sensors for ADAS
New fusion algorithms, compact and low-cost radar/lidar, secure in-vehicle networks, on-board MPSoCs in harsh environments, high SIL, HMI & MMI

Sensing technologies for natural Human Machine Interfacing & contactless biometric measurements for fatigue/attention detection

Conclusions & on-going activities



V2X (802.11p) and Cellular-V2X (4GLTE/5G) wireless transceivers

robust and secure links, guaranteed QoS --> integrated security, TSCH/FH, MIMO transceivers, high RX sensitivity, high TX efficiency, beamforming, opportunities at mm-waves, convergence with 5G (www.5gaa.org)

Innovative acquisition, control and actuations units

for BMS, power converters, distributed sensors/actuators,
3D integration opportunities, EMC/thermal/electrical measurements

Thanks for your attention

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