isep
École d'ingénieurs du numérique

Connected Vehicle

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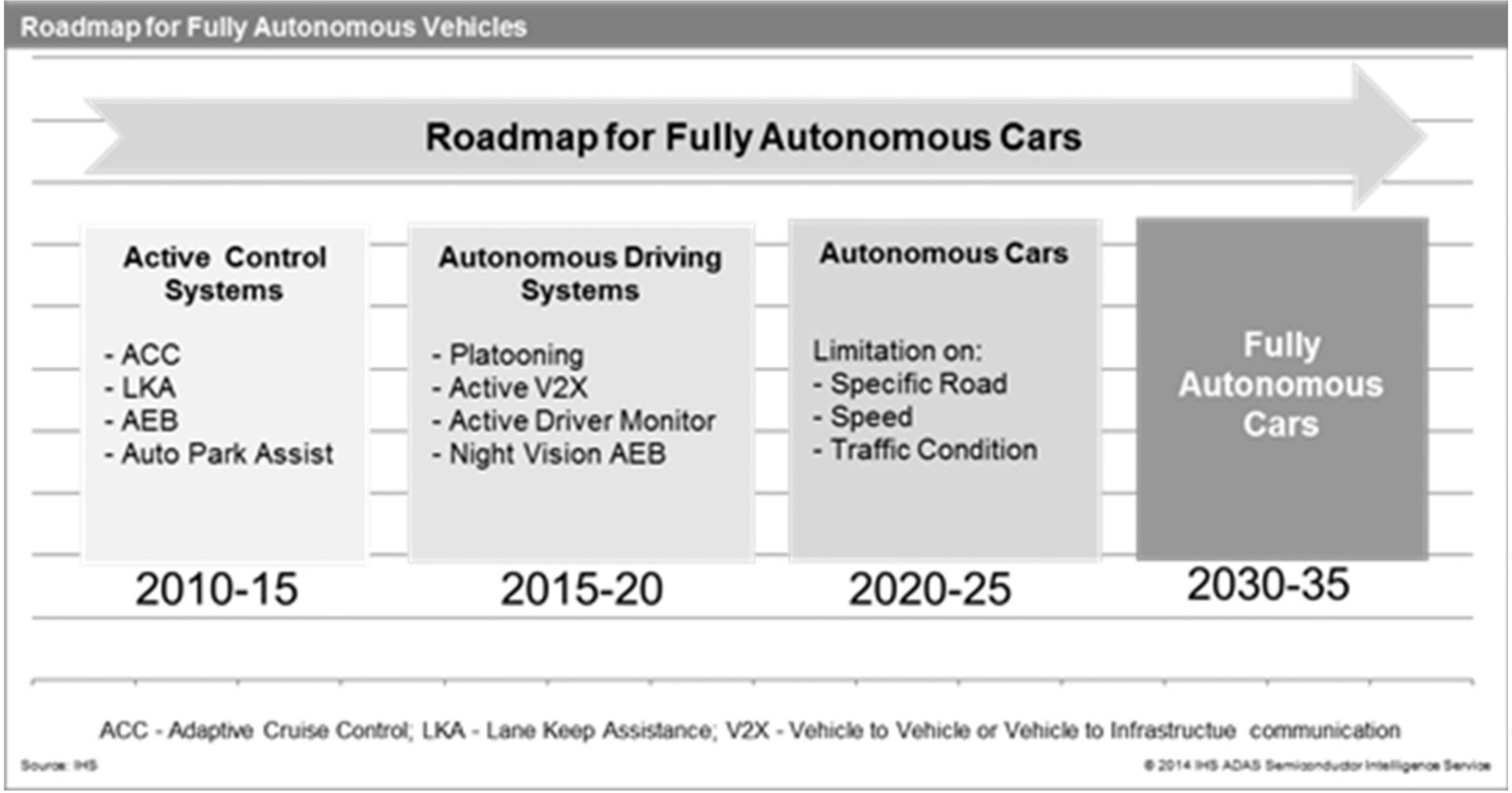
Disruptive innovation

Agenda



- ✓ Connected vehicle car – Key Points
- ✓ Functional Roadmap
- ✓ Data computing
- ✓ Communication & standards
- ✓ Technologies
- ✓ Security issues

Autonomous vhcl

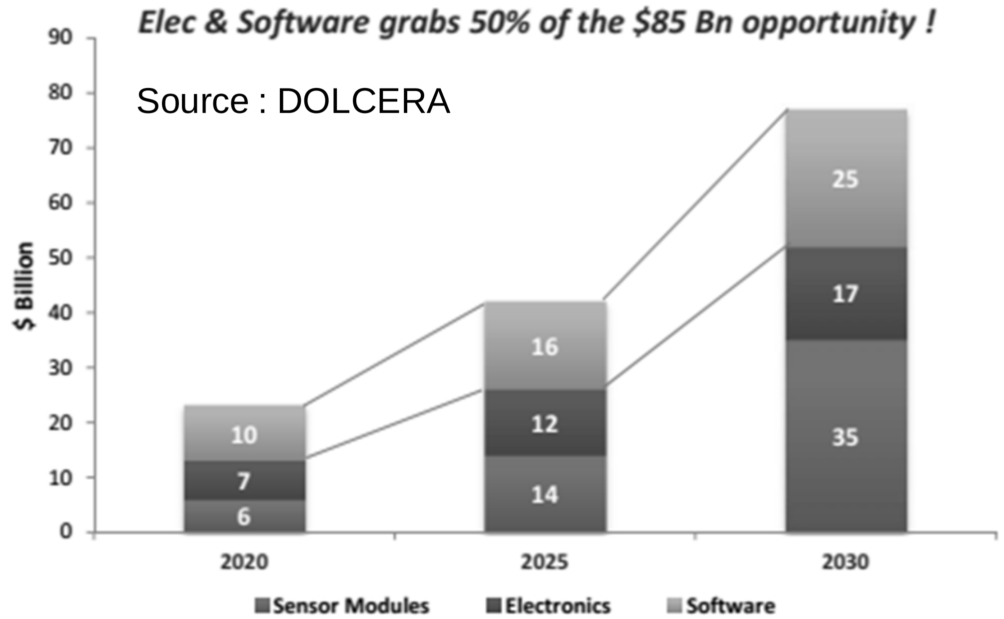
Introduction

Autonomous Vehicle : Intelligent system, capable of perceiving and estimate its (chaotic) environment to assure a safe, efficient and cooperative travel.

This autonomy involves several capabilities : Measure & detection, analyzes & computing and real time decision.

Environment ➔ Nearby vehicles & pedestrians
Grounded infrastructures

Road traffic - Context



Heavy traffic
- Travel time increasing,
- Bad health consequences
- energy cost (waste)

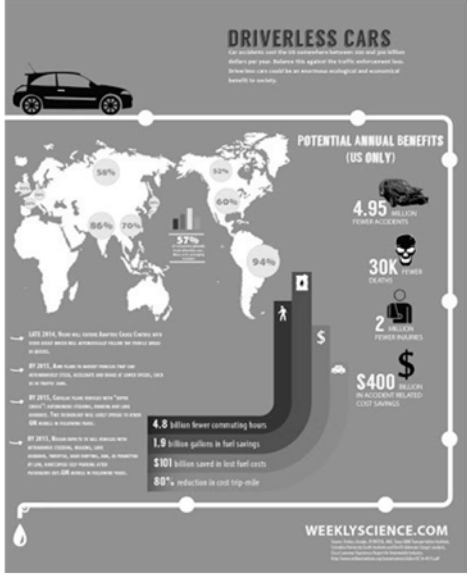
Strong willingness to control traffic flow.

Connectivity
- Vehicle more & more connected,
- Use Time travel for convenience.

Road injuries
- Population ageing,
- Chaotic Environment,
- Flow

2030 predictions forecast a « massive » spreading of the connected vehicles and (+/-) autonomous... And probably unconnected vehicle **banning** to get in congested big city !

Human errors – Few figures & Hints

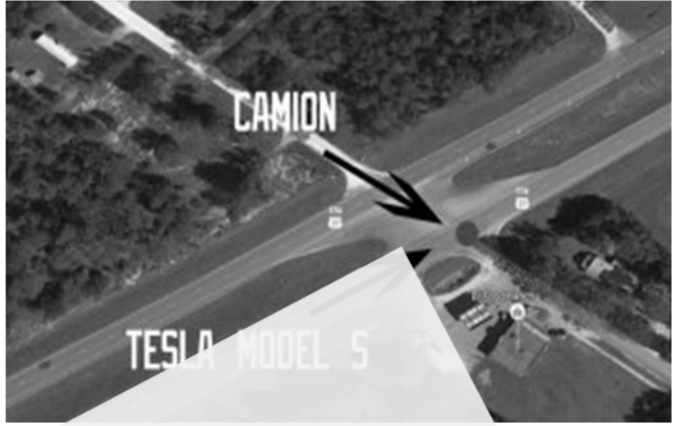


- World Health Organization : 1.3 millions of fatalities / year in the world,
- Human errors lead to 90% of road accidents,
  - Expected 90% crash reduction

- Health impact,
- Energy print foot (Oil !)
  - Expected ~15% (best case)
- Stringent regulators will

=> Smart & connected vehicles to deal with chaotic traffic

Regulation



Accidents Tesla

This accident occurs in **2016** of May, in U.S (Florida), the vehicle strokes a truck which was on perpendicular road, the truck runs across the Tesla one.
Survey has been given to NHTSA. Who is responsible for ?

Following market state of the art, we don't cope with level 4 or 5 . Nevertheless, issue comes up about to establish a regulation to avoid legal holes.

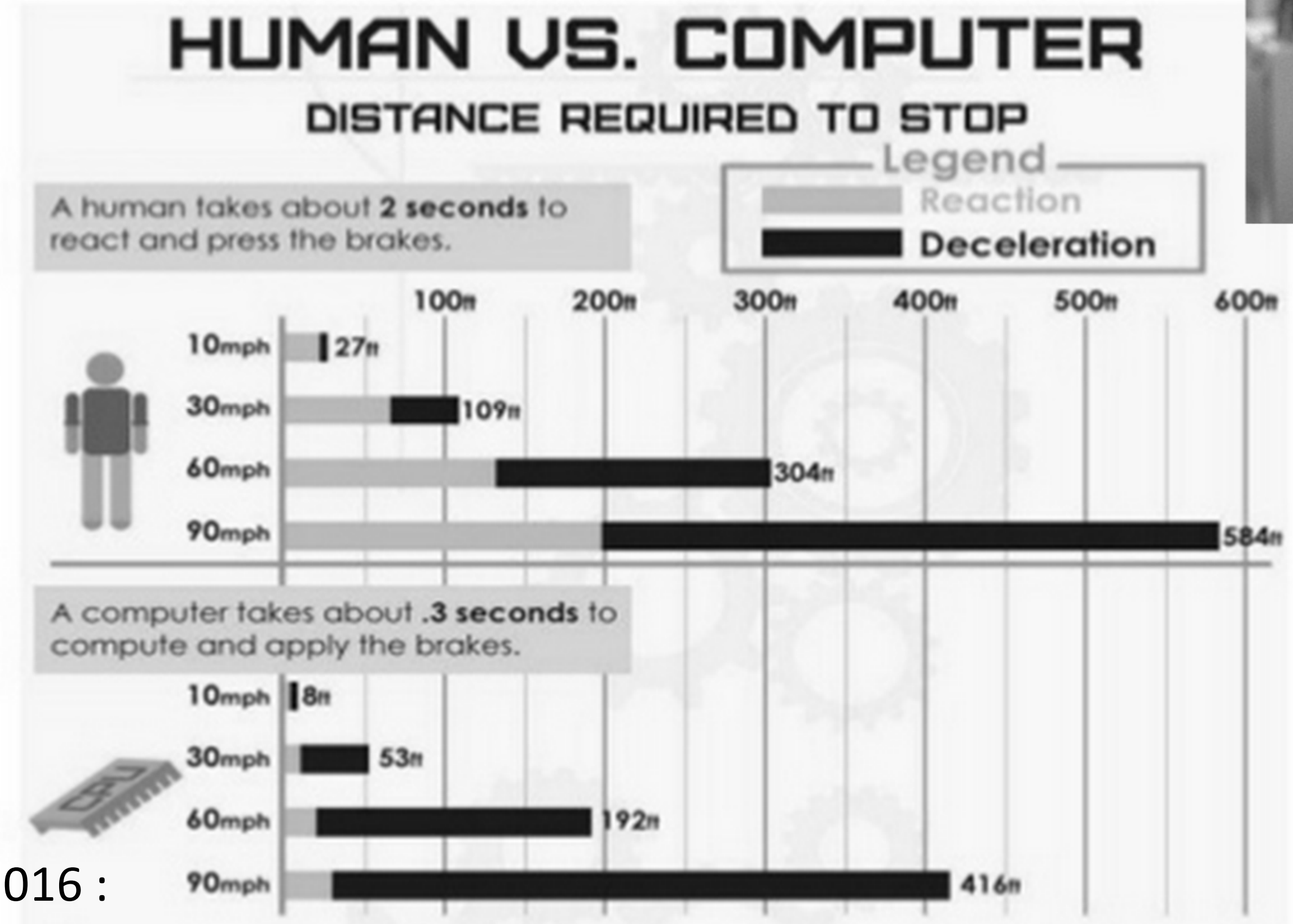
Arizona, march **2018** : According to Tempe police, the test driver in the car that struck pedestrian was watching TV on her phone until just moments before the fatal collision. A preliminary report by the National Transportation Safety Board found that the car's sensors had detected Herzberg six seconds before the crash, but had trouble classifying her as a pedestrian and were delayed in deciding on a course of action.

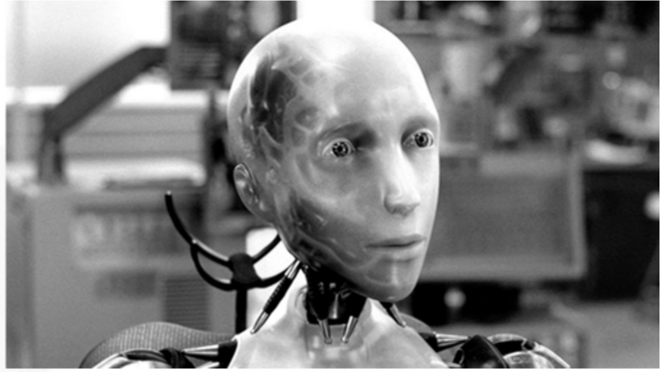
And what to say about flying drones ?

Beyond the purely technical aspects (which remain numerous), there are a lot of "political" obstacle as well as scenario of migration (cohabitation between the autonomous and the "others") to establish.

Since the start of 2023, Waymo & Cruise have completed a total of 8 millions driverless miles in San Francisco and… a total of 102 crashes !

Enabler – Silicon performances



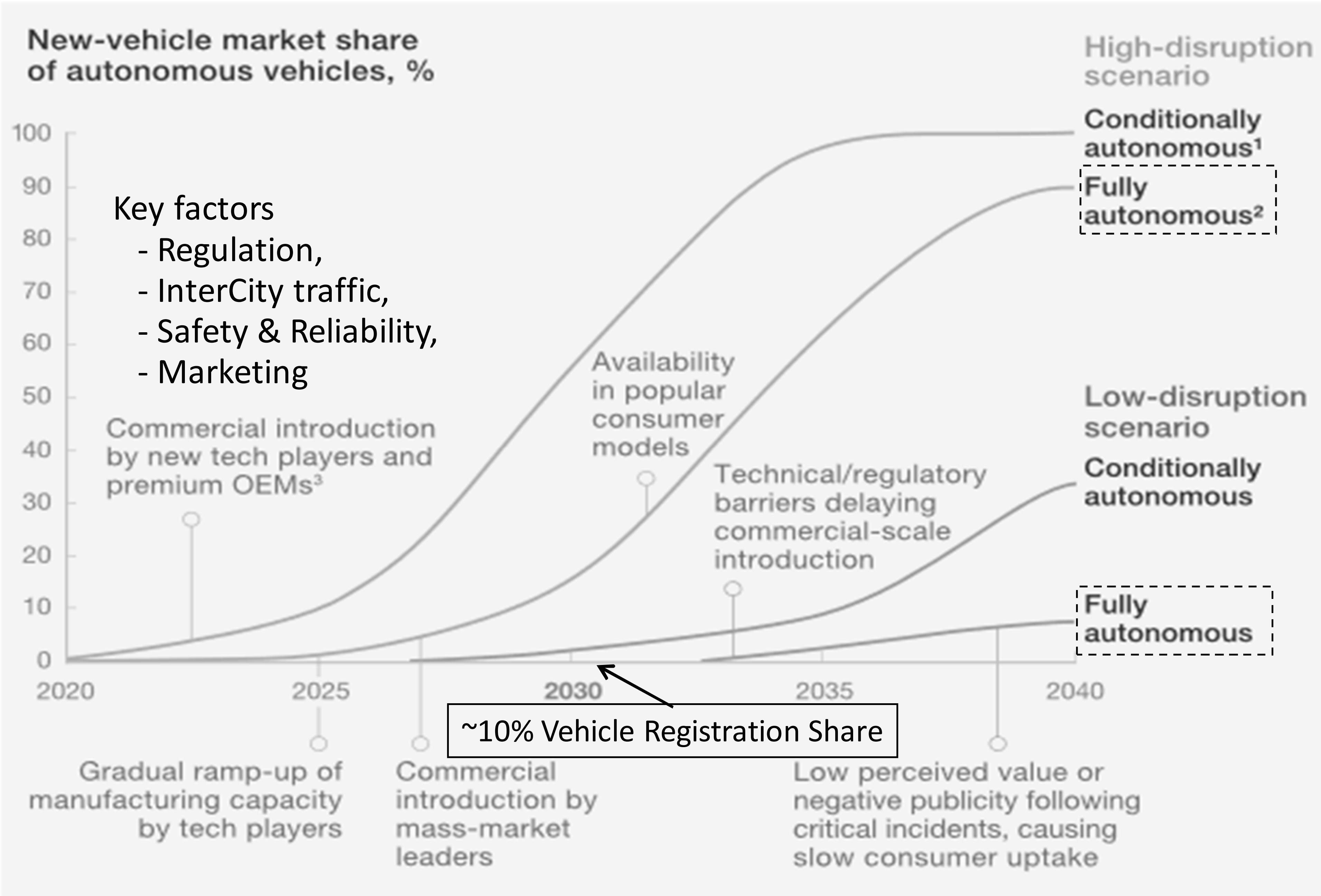


2016 :

Google-owned artificial intelligence company DeepMind shocked the world by defeating S
four matches to one with its AlphaGo AI system.

Researchers from Google's DeepMind & the University of Oxford developed a deep learnin
system that outperformed a professional lip reader. Using a TITAN X GPU, AI system annota
about 50% of the words without any errors, compared to the professional who annotated
12.4%.

Market Trends

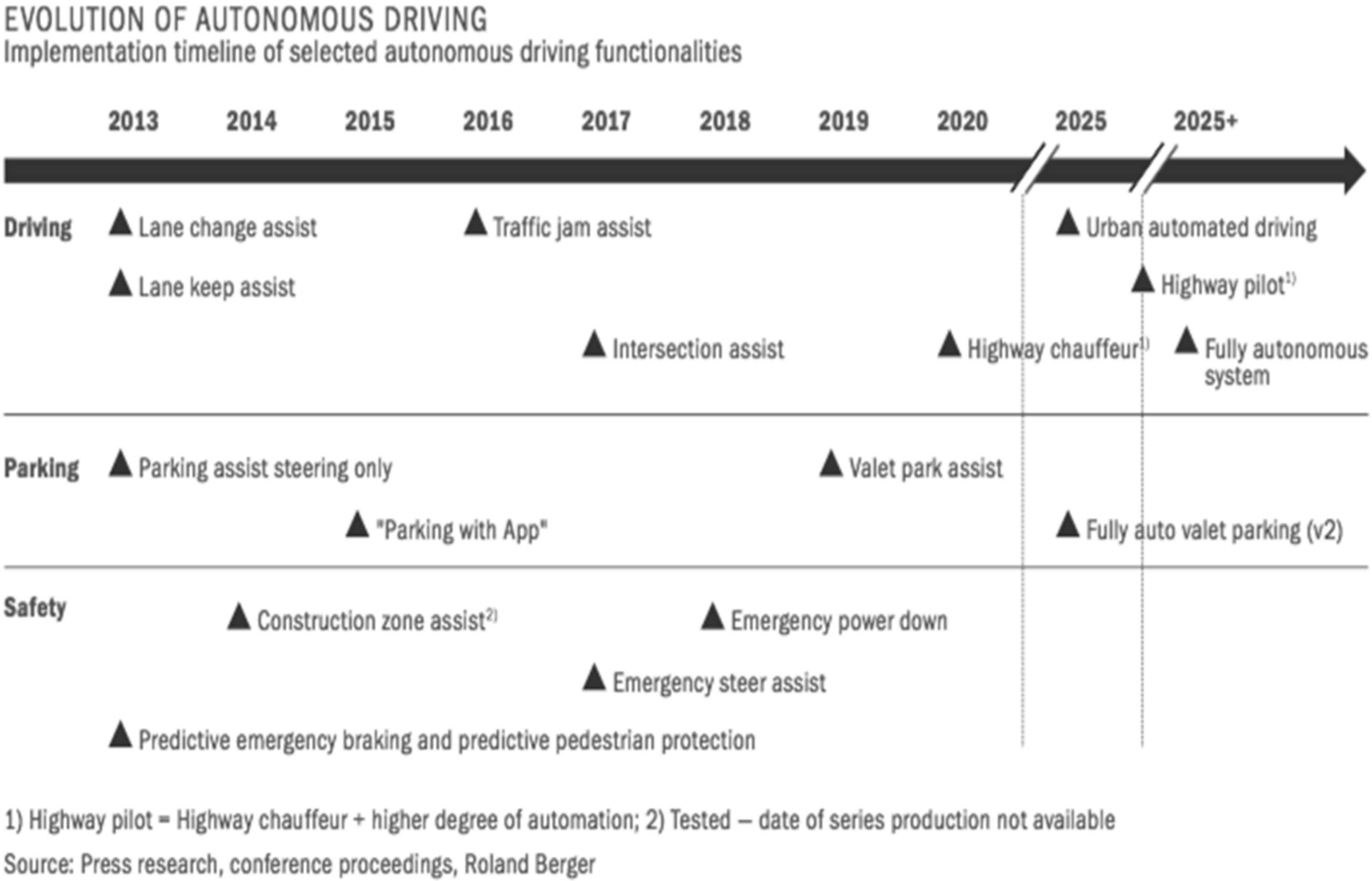


Key factors

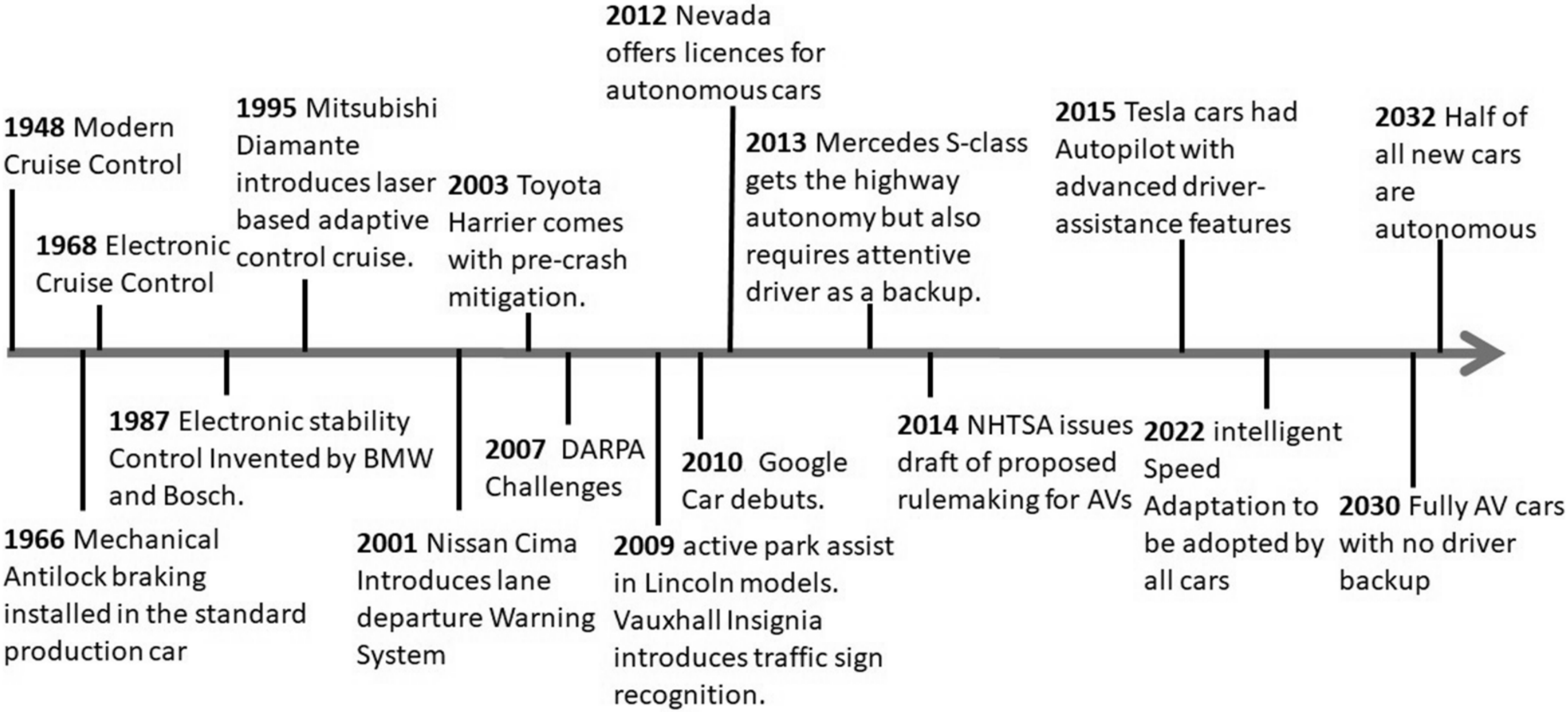
- Regulation,
- InterCity traffic,
- Safety & Reliability,
- Marketing

~10% Vehicle Registration Share

Autonomous Vehicle - Roadmap



Autonomous Vehicle - Roadmap



Recent

Tesla

- 2019 : 6 billi
- 2021 : FSD (

Keolis :

- 2018 (CES in
Autonom Cab,

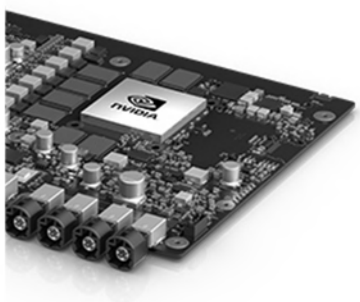
Google :

In December 2 … iving-car project, officia … of Phoenix

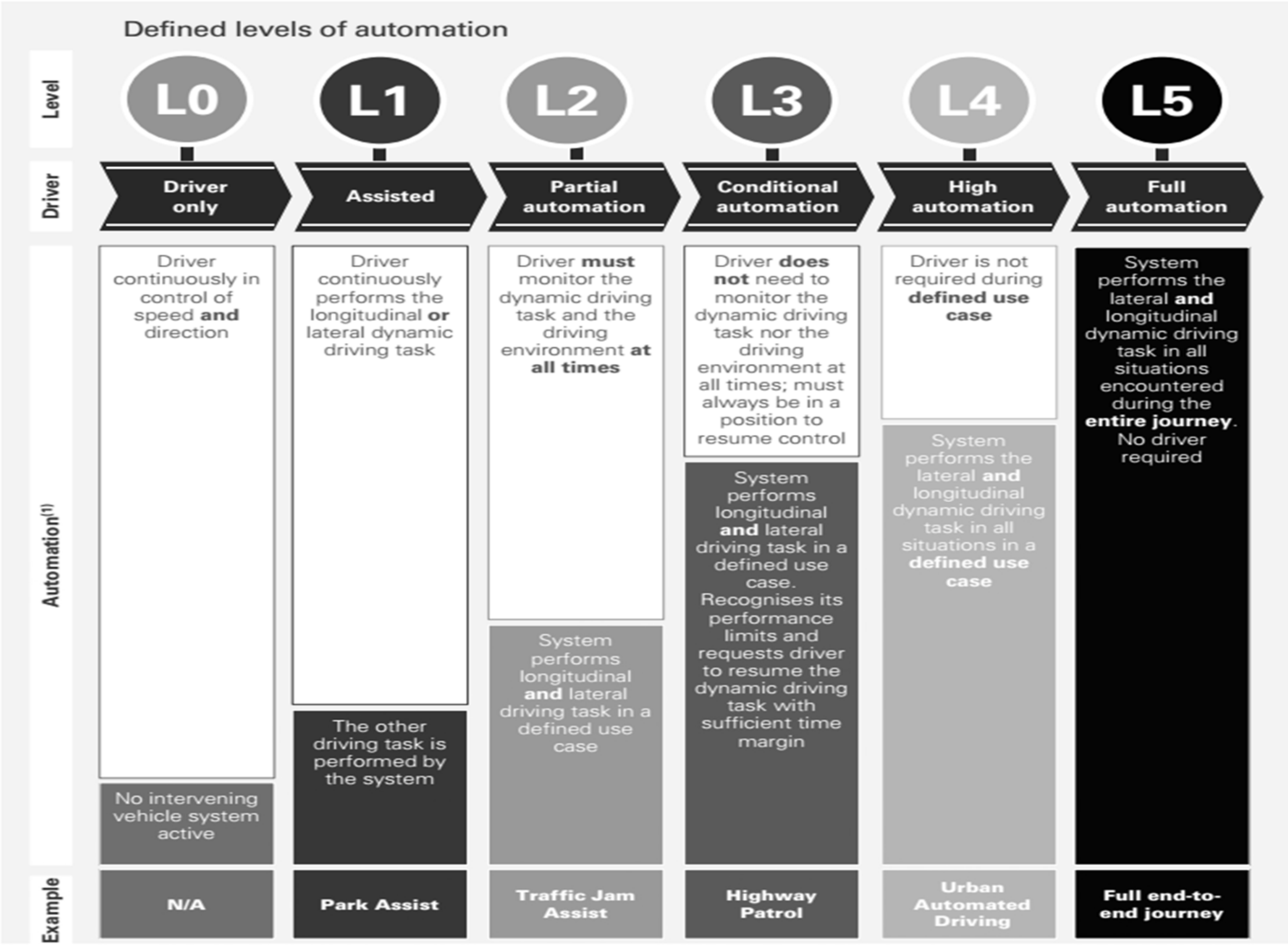
NVIDIA :

2020 NVIDIA

January 2021 :
1er July 2021 :



Levels of Autonomous Vehicles



Note: (1) In performing our study we have found there to be different and significant economic benefits arising from connected, Level 3, 4 and 5 autonomous vehicles. In this report, all types of autonomous vehicles have been considered including cars, trucks and pods.
Source: Level of automation terms from SAE J3016.

Levels of Autonomous Vehicles (NHTSA 2013)

***Level 1* – Function-specific Automation:** Automation of specific control functions, such as cruise control, lane guidance and automated parallel parking. Drivers are fully engaged and responsible for overall vehicle control (hands on the steering wheel and foot on the pedal at all times).

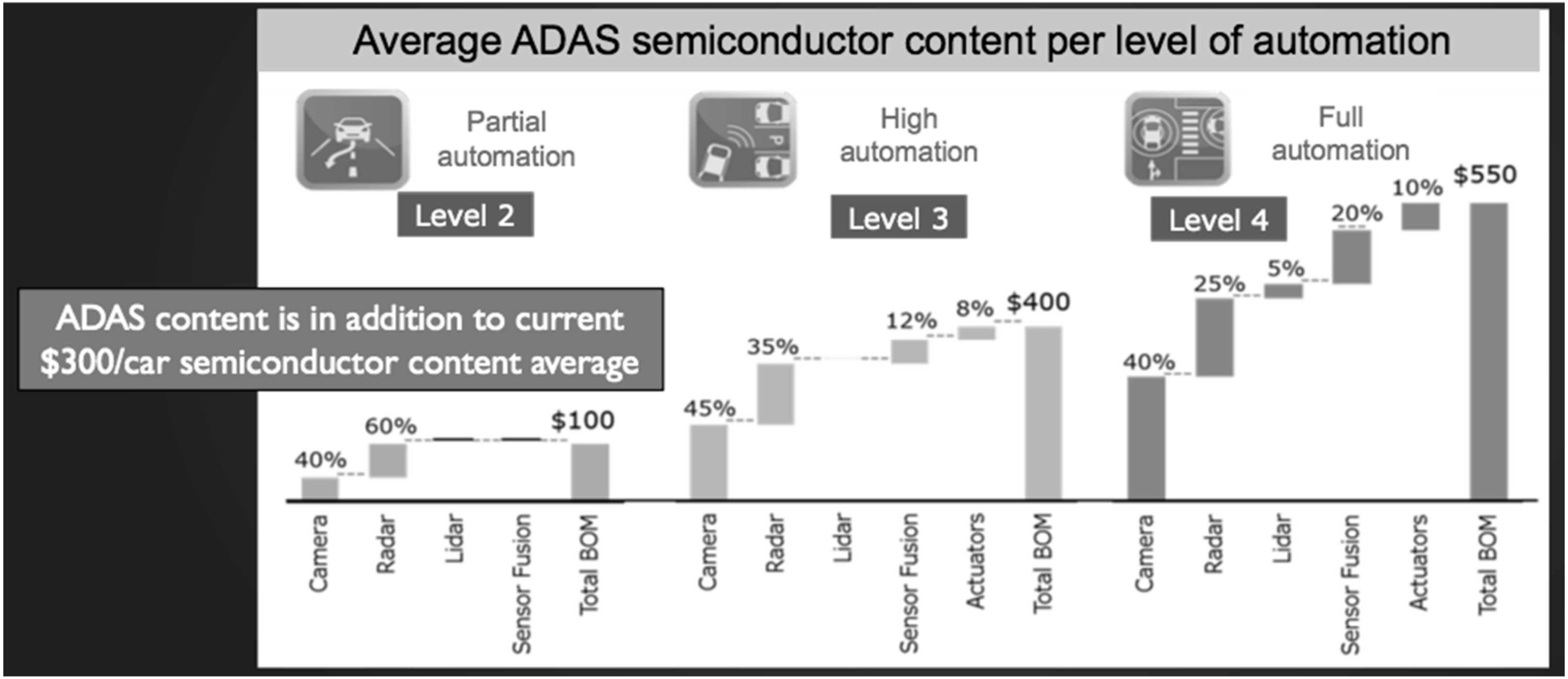
***Level 2* - Combined Function Automation:** Automation of multiple and integrated control functions, such as adaptive cruise control with lane centering. Drivers are responsible for monitoring the roadway and are expected to be available for control at all times, but under certain conditions can disengaged from vehicle operation (hands off the steering wheel and foot off pedal simultaneously).

***Level 3* - Limited Self-Driving Automation:** Drivers can cede all safety-critical functions under certain conditions and rely on the vehicle to monitor when conditions require transition back to driver control.

***Level 4* – Self-Driving Under Specified Conditions:** Vehicles can perform all driving functions under specified conditions.

***Level 5* - Full Self-Driving Automation:** Vehicles can System performs all driving functions on all normal road types, speed ranges and environmental conditions.

First stage : Driving Assistance overview

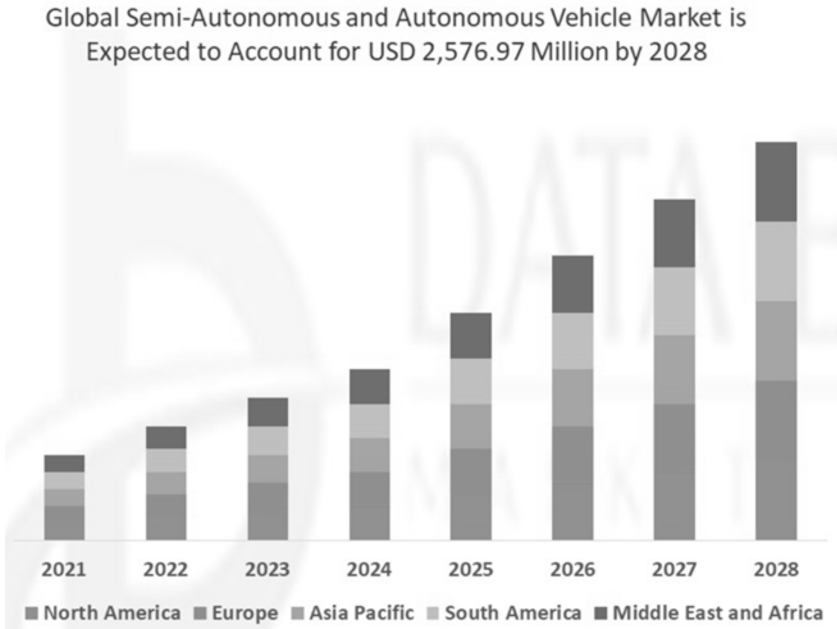


BOM : Bill Of Material
ADAS : Advanced Driving Assistance System

Source: Infineon

ADAS was the first stage of automation to improve security

Sourcing overview



Source : Data Bridge

Car makers

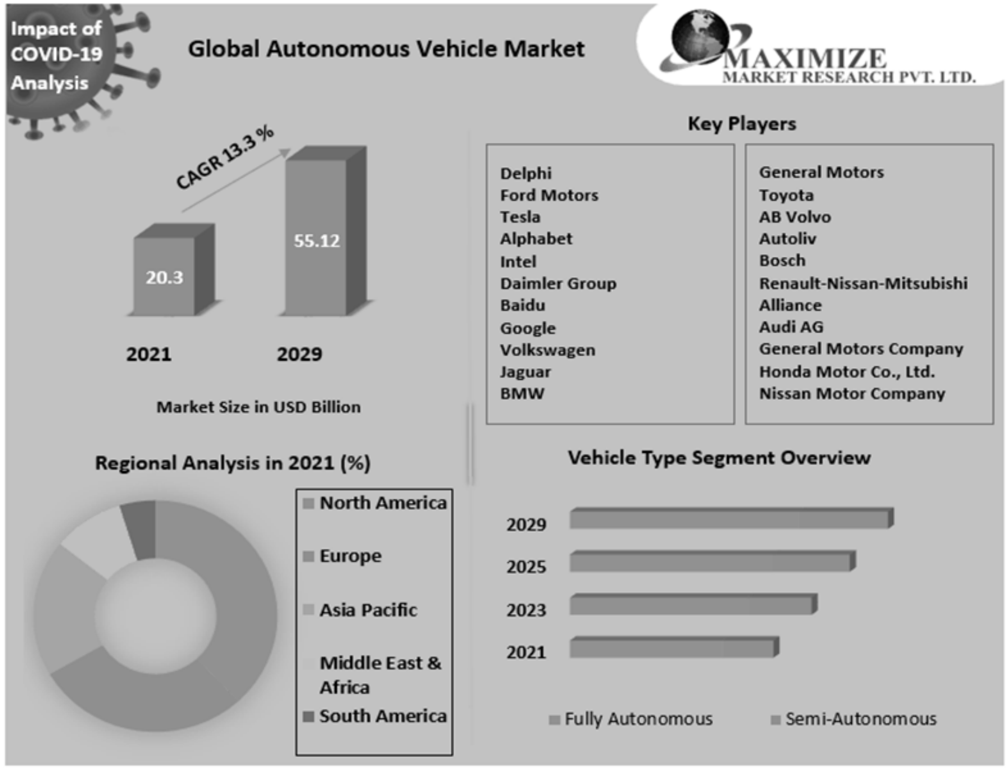
- None escapes this race !

Electronic suppliers (Tier1)

- NVIDIA, CONTI, BOSCH, DENSO, VALEO…

Technologies suppliers (Tier2)

- GPU & IA
- Sensors
- WiFi & Cellular



Autonomous Vehicle – Required & Services

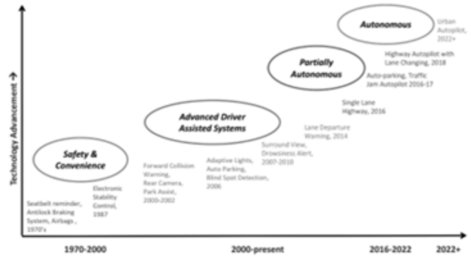
Environment

- Complete set of sensors (redundancy expected) able to detect a huge variety of targets whatever weather conditions (Rain, snow, rough road, tunnels, etc.),
- Radio networks: Short range for vehicle-to-vehicle communications and long range for data exchanges, Software updating, infrastructures messages or emergency publications,

And :

- Navigation : GPS Localization and maps,
- Sub domains Supervision (Powertrain, Chassis, MMI,...),
- Diagnostic capability (Workshop situation),
- Legal issues (Regulations & Liability)

SELF DRIVING CAR PUZZLE



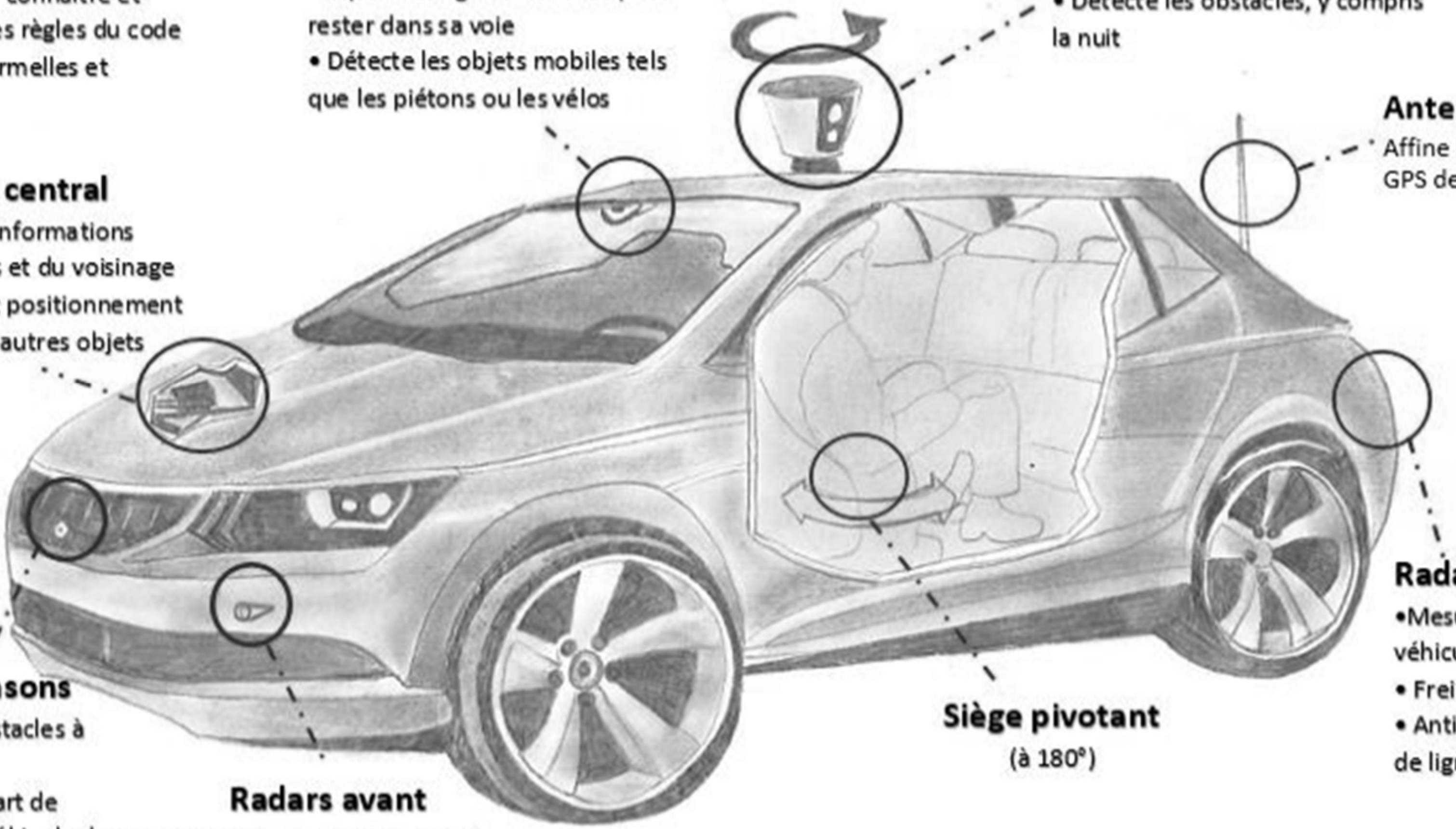
Le logiciel est programmé pour adapter la vitesse et la trajectoire du véhicule en estimant les mouvements des autres véhicules ou des piètons.
Le logiciel doit connaitre et comprendre les règles du code de la route (formelles et informelles)

Caméra vidéo
- Située derrière le rétroviseur
- Repère les feux
- Déchiffre les panneaux de signalisation
- Repère les lignes blanches pour rester dans sa voie
- Détecte les objets mobiles tels que les piétons ou les vélos

LiDAR
- Scanne en permanence l'environnement à 360° sur 50 m et en fait une cartographie en 3D
- Détecte les obstacles, y compris la nuit

Antenne GPS
Affine le positionnement GPS de la voiture

Ordinateur central
- Traitement d'informations cartographiques et du voisinage
- Localisation et positionnement par rapport aux autres objets



Radars arrière
- Mesure la vitesse des véhicules éloignés
- Freinage d'urgence
- Anti-franchissement de ligne

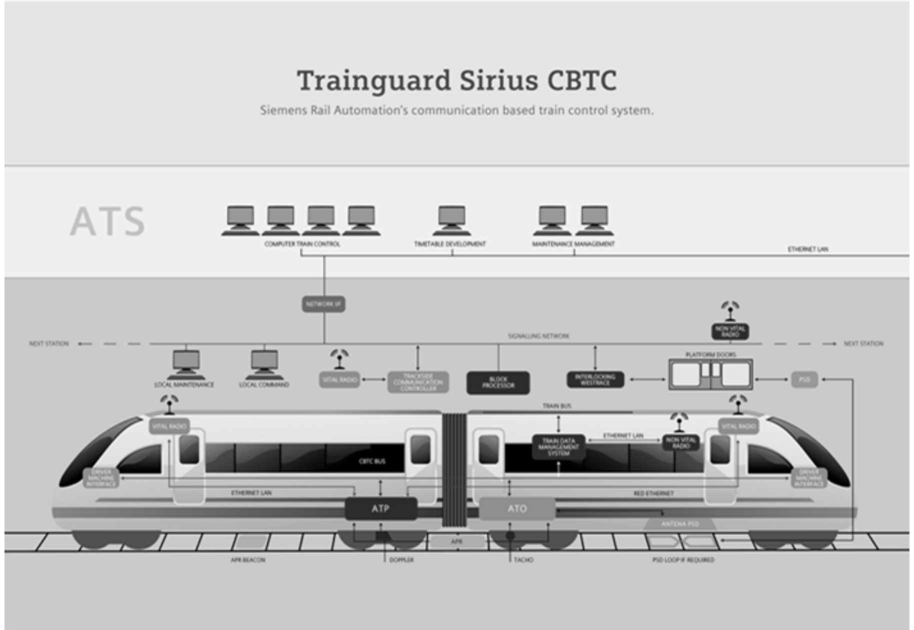
Capteur ultrasons
- Détecte des obstacles à courte portée
- Conserve un écart de sécurité avec le véhicule de devant

Siège pivotant
(à 180°)

Radars avant
- Détecte la position des objets environnants, proches ou éloignés
- Mesure la vitesse des véhicules
- Freinage d'urgence
- Anti-franchissement de ligne

Silicon brain + Sensors + Connections

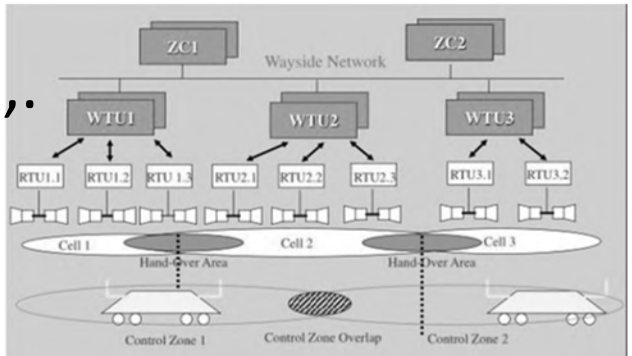
Rail Transportation field



L14 Meteor automated system is installed since 1998, it's the first fully automatic subway in Paris.
Automation enables a better line capacity by reducing shuttles intervals.

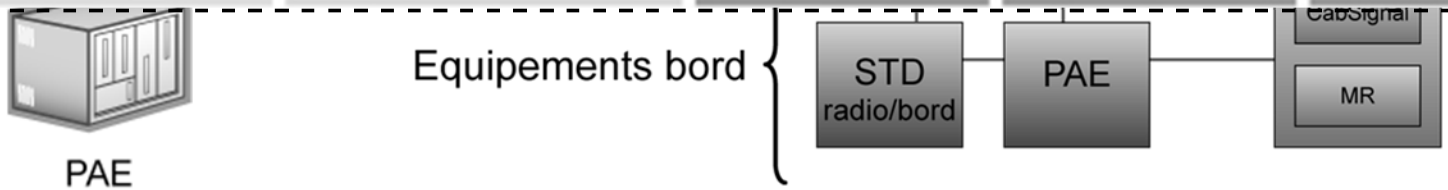
Automated system belongs on several sub-systems :

- Grounded servers (To plan traffic, Movement authority, shuttles monitoring, troubleshooting,…),
- Grounded sensors (train localization, actuators,.
- Radio cells & dedicated redundant networks,
- Video & passenger's ads,
- On board Radio & highly secured computer



Automated shuttle - Architecture

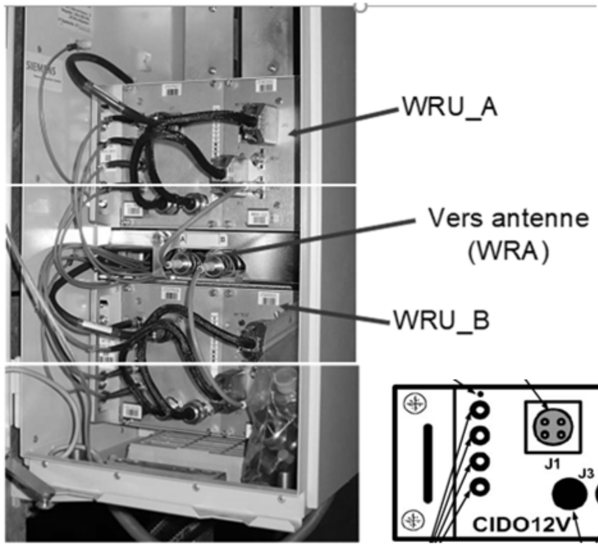
Grade of Automation	Driving Operation	Starting	Braking	Door Closure	Operation in Disruptions
GoA 0	On-sight Driving	Driver	Driver	Driver	Driver
GoA 1	Manual Drive with Train Control (ATP)	Driver	Driver	Driver	Driver
GoA 2	Partly Automatic Train OperationwithDriver (STO)	Automatic	Automatic	Driver	Driver
GoA 3	Attended, Driverless Train Operation (DTO)	Automatic	Automatic	Train Attendant	Train Attendant
GoA 4	Fully Automatic, Driverless Train Operation (UTO)	Automatic	Automatic	Automatic	Automatic

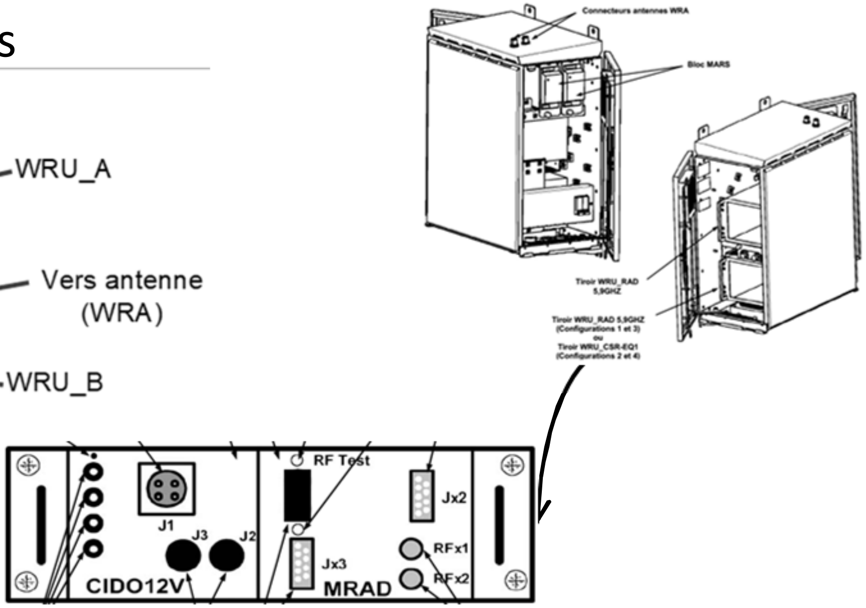


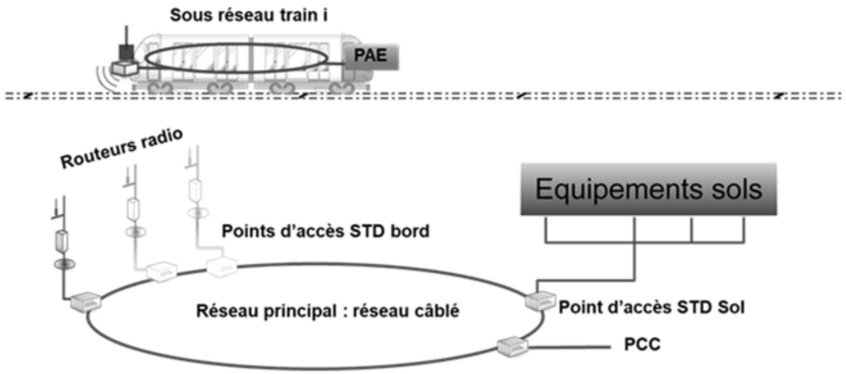
Source : Siemens

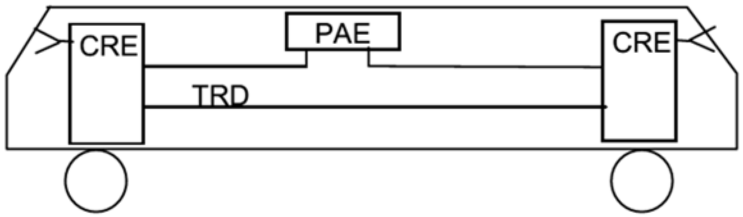
Paris L1 Motion System

Grounded devices







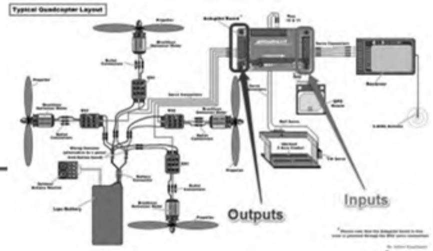


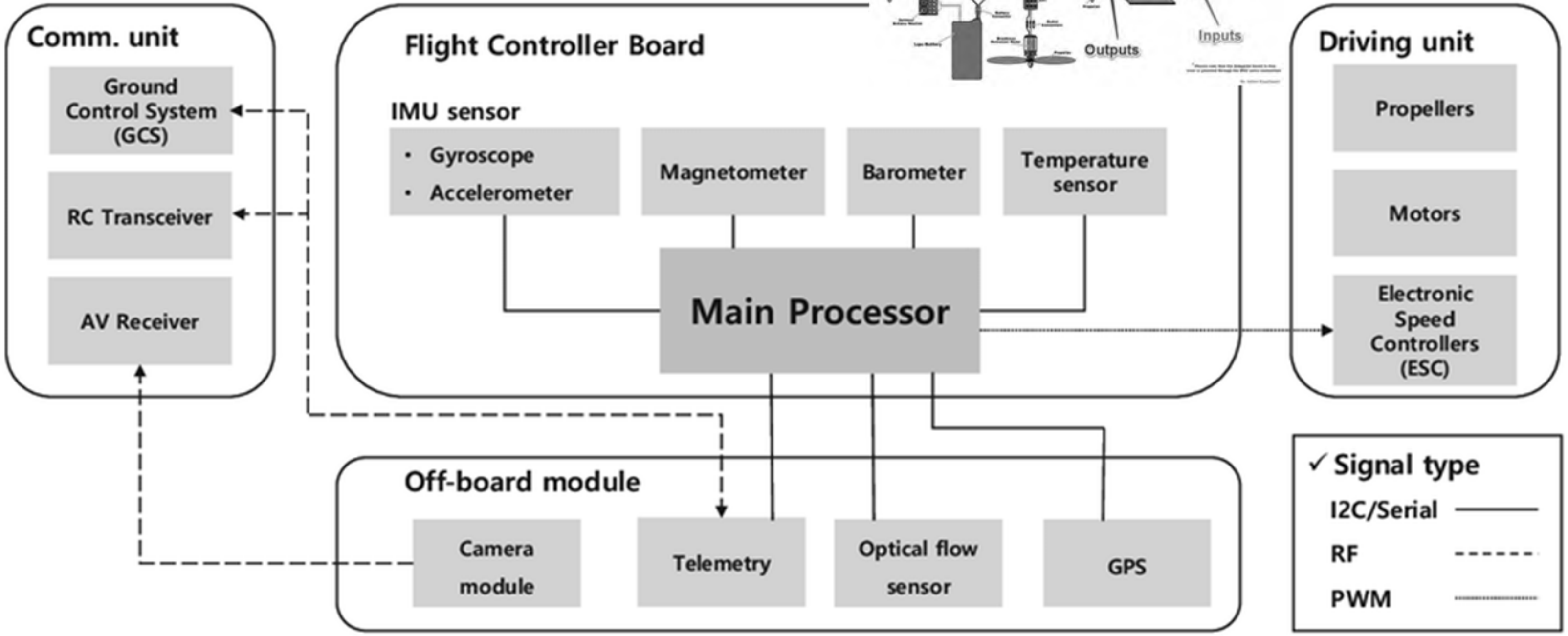
Embedded Radio system is made with :

- 2 sets of connected Modem + Antenna interconnected with a coaxial cable, located at both ends of the train.
- 1 wired interconnexion between both Modem (TRD serial link).
- 1 connection between each Modem and one of bothc embedded motion supervisor.

Source : Formation @STS

Drone Framework

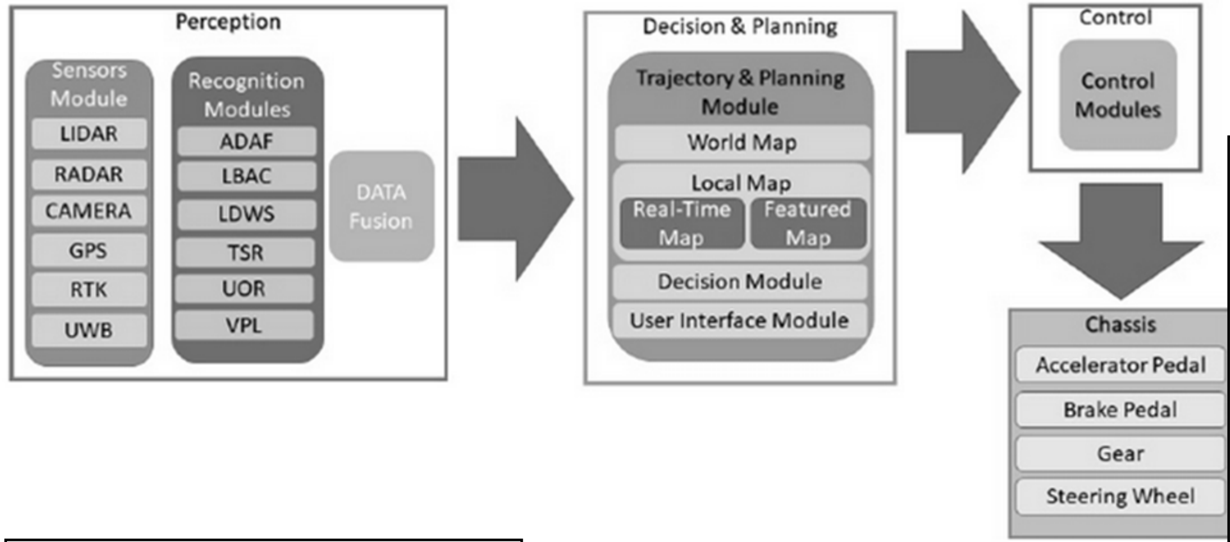




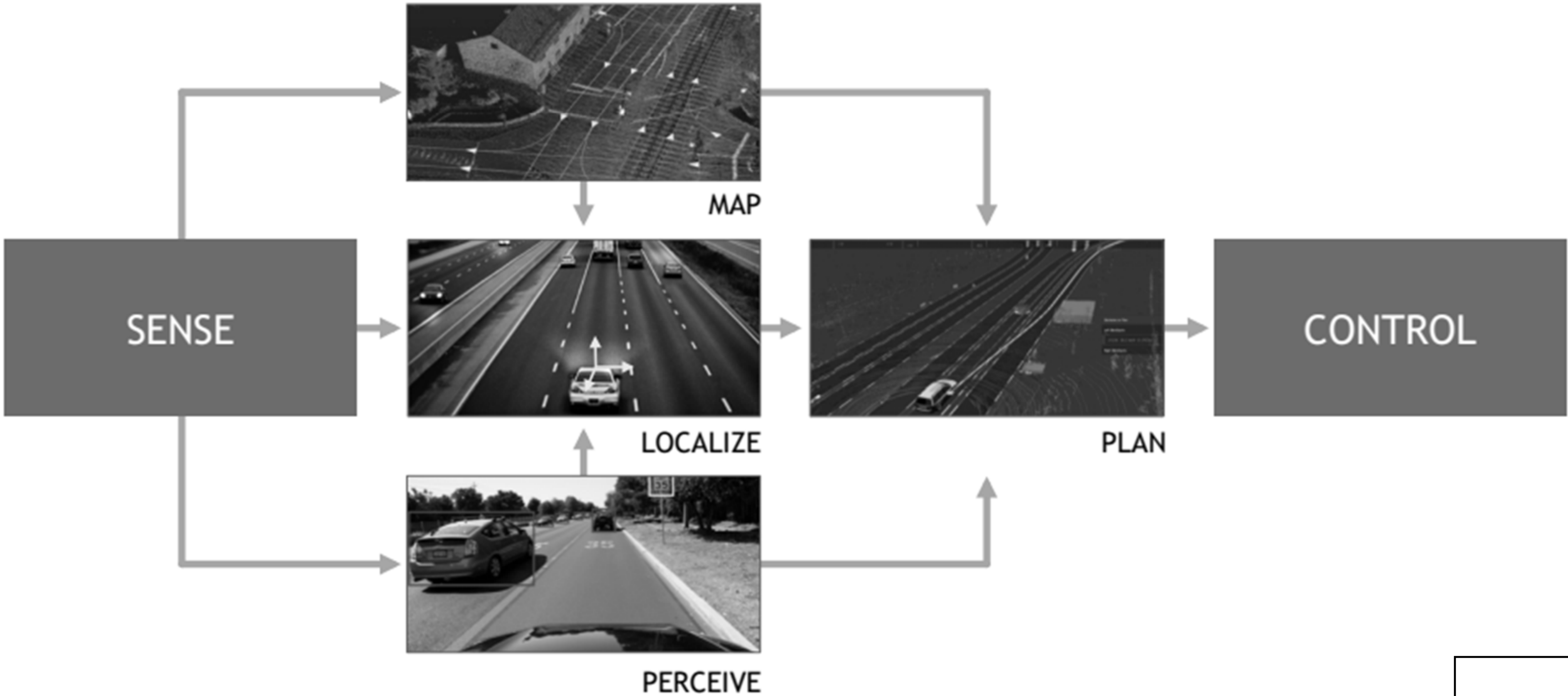
Drones puzzle :

- Complete set of sensors : Camera, Inertial unit, UltraSonic, Radar,…
- Computation : Flight management, Sensors fusion, Telemetry,…
- Power modules : E-Motors, DC-DC convertors, Battery management,…
- Communications capabilities : Ground to air I/F, GPS, Wifi/5G,…

Drones field spread from “child toys” to military applications, over the air deliveries or professional stuff. Embedded technologies cover a large area of electronics units.



System Architecture



Sensors - overview

Sense unknown and dynamic environment - **Challenge !**

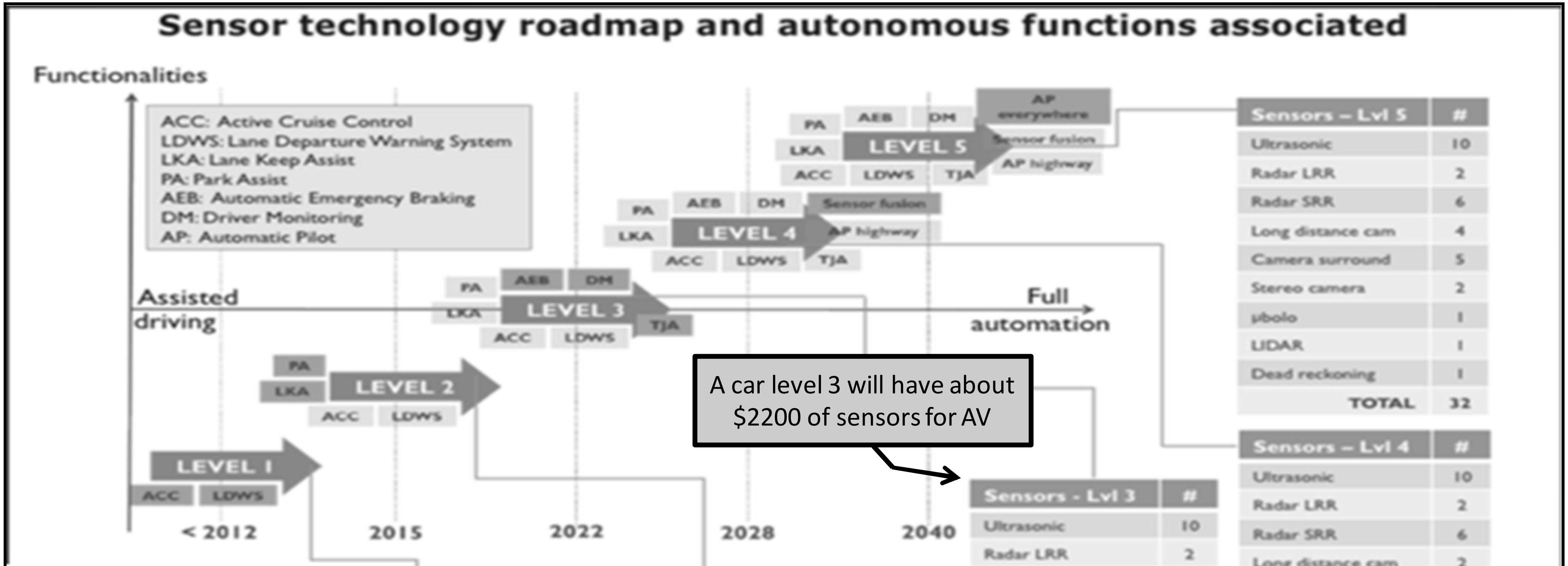
Radar : Monitor the position of other cars

Lidar : Enable 3D map

Camera : Detect traffic lights; track lane; road signs

And : GPS; Wheel speed sensor; Ultrasonic;

Sensor Roadmap



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

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

Connections - overview

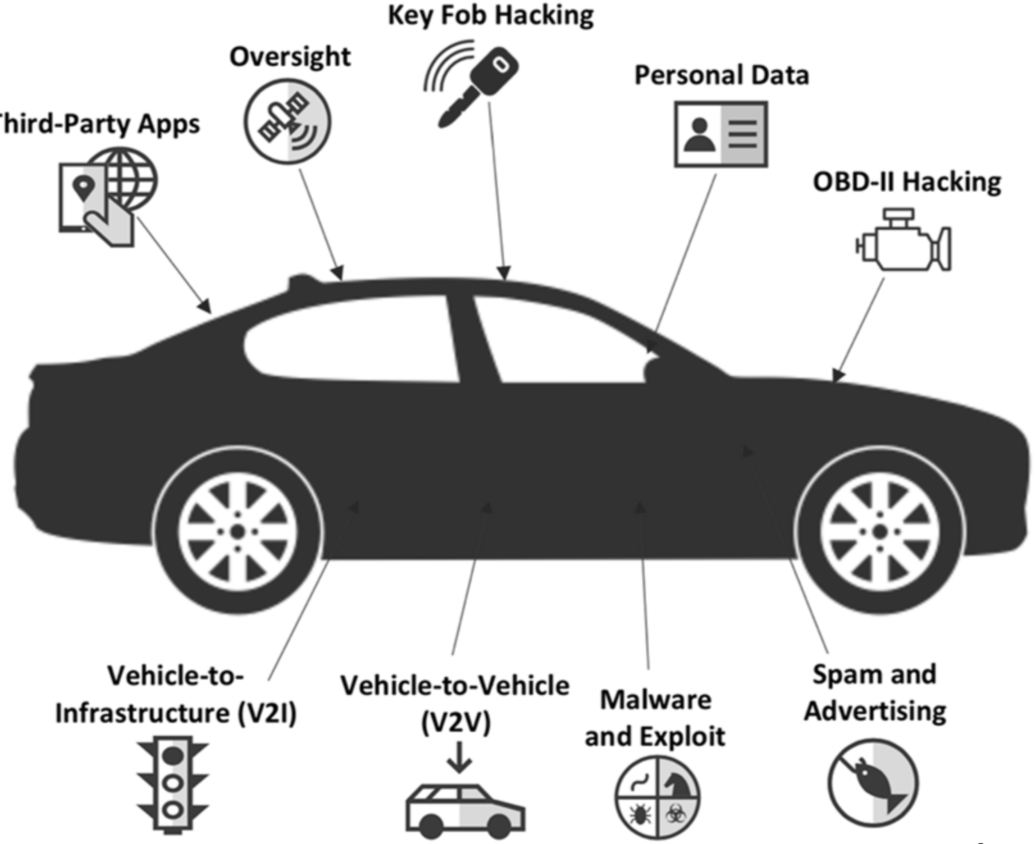
Wireless

Several wireless nodes are available inside a vhcl :

- Keyless,
- Flat tires detection,
- Telematic (Bluetooth),
- Internet (Wifi),
- Cellular (4G, 5G).

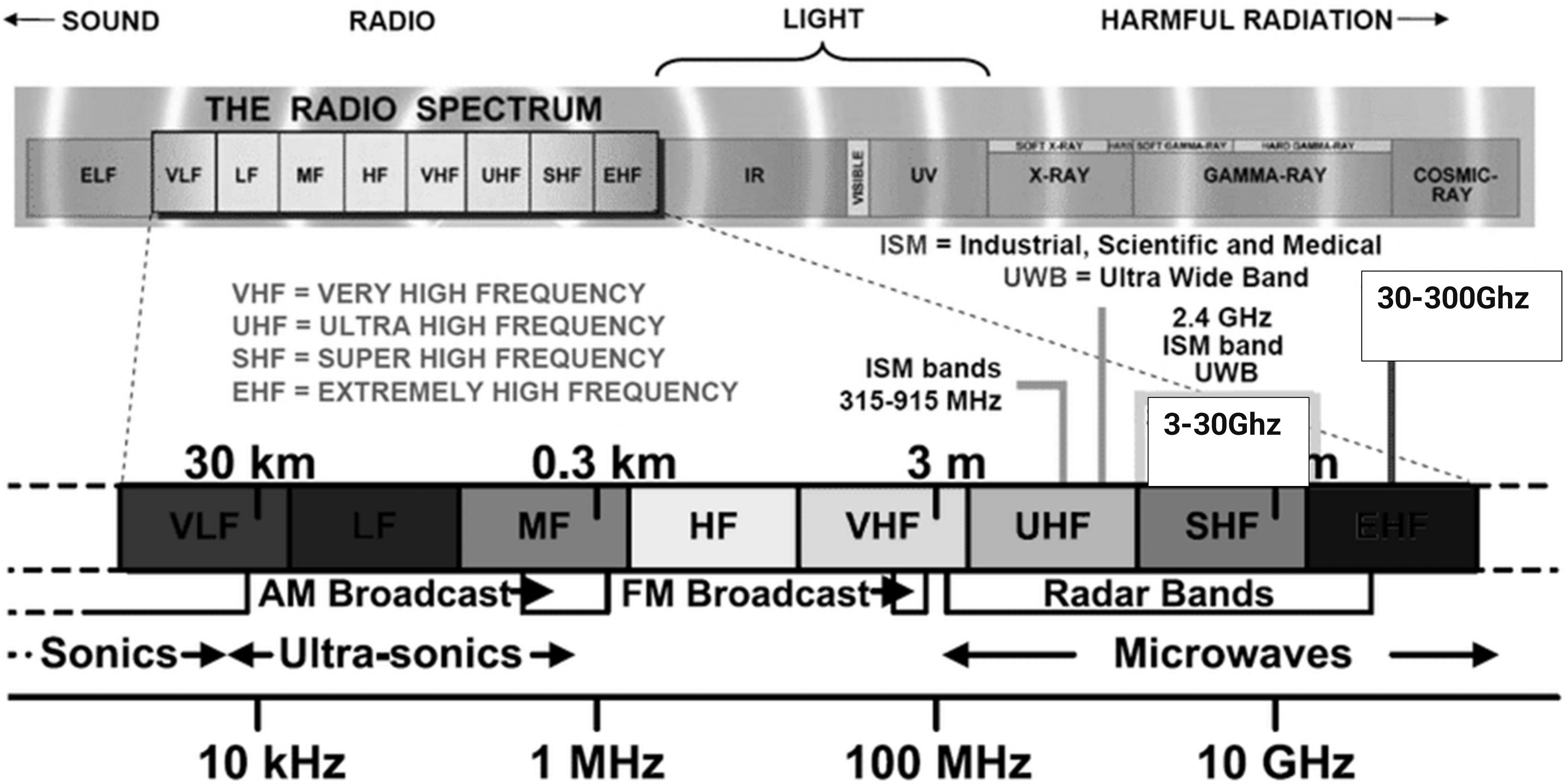
Wired

- OBD (CAN Bus),
- Telematic (USB),
- Services (Ethernet).



Source : McAfee

Electromagnetic Spectrum frequency band



3G : 900 MHz et 2,1 GHz

4G : 700 et 800 MHz, 1,8 ; 2,1 et 2,6 GHz

5G : Bandes 4G + ~3,5 GHz puis 26 GHz (futur).

Autonomous Car – Key points

Driving assistances belong on s**emiconductor** into automobiles

- Collection of sensors (Laser, Radar, Camera,…),
- Powerful ECU (MultiCore ECU, GPU, FPGA,…)
- High level Safety relevant software

Sensors

- Supervisor has to handle sensor fusion with multiple types of sensors inputs would be fused together to form decision

Example: LIDAR + Radar could be used for front collision avoidance.

ECUs

- A main supervisor is connected to several ECUs
  - Mapped on adapted and/or dedicated Electronic architecture (Centralized vs distributed)
  - Computing & Fusion sensors require dedicated processors (GPU, ASICs, FPGA,…)
  - High level of integration (BGA, SOC, Mechatronic,…)

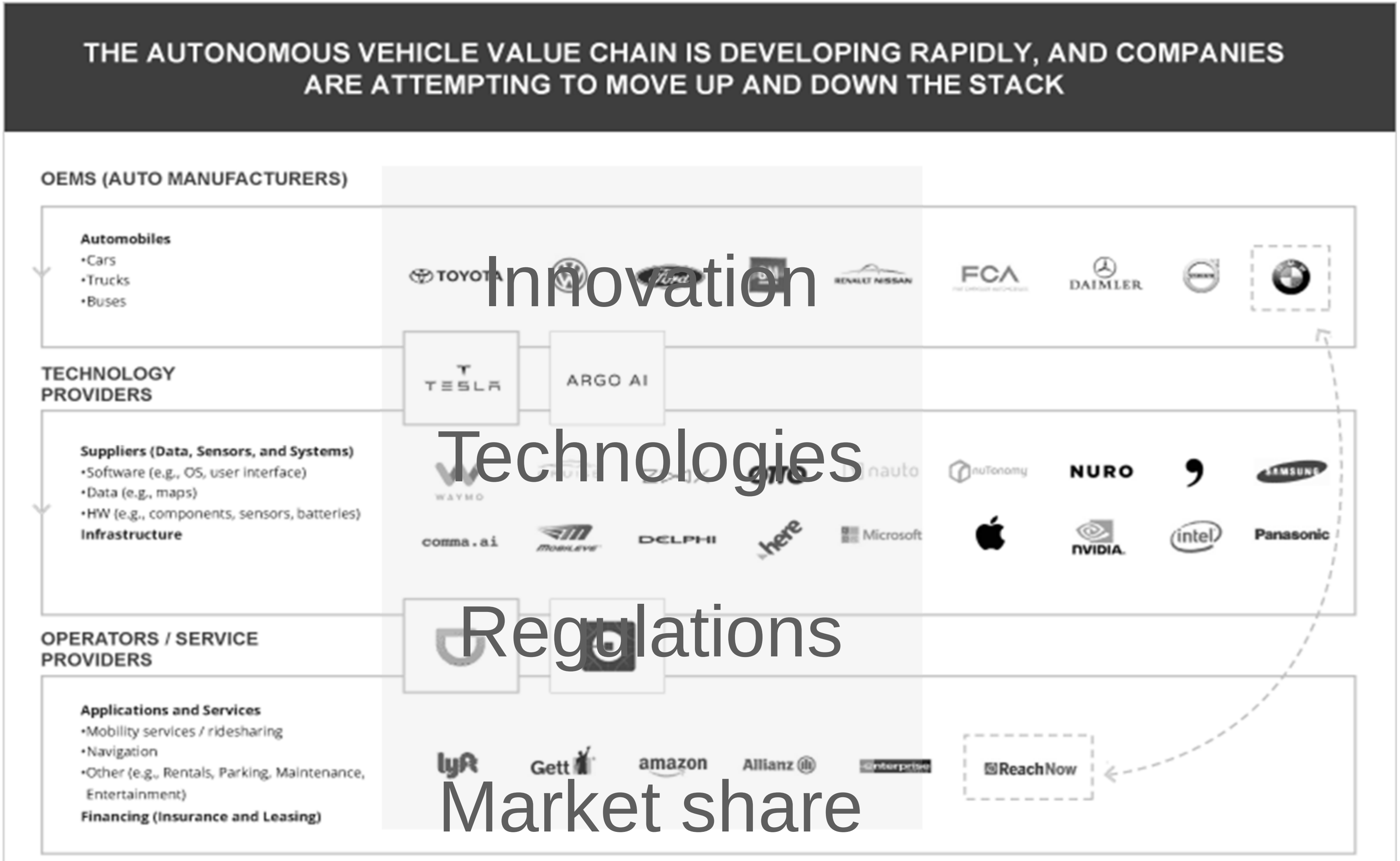
Software

- Sensors treatment & fusion lead to many complex software modules (ex: pedestrian recognition (deep learning), vhcl motion,…),
- Camera need dedicated fast image processor and advanced process nodes ,
- Silicon performances pusher to meet reliability requirements & real time constraints,
- Stringent development process and highest skills (+tools).

Connections

- 5G, Wifi, Bluetooth, keyless, OBD connector,…

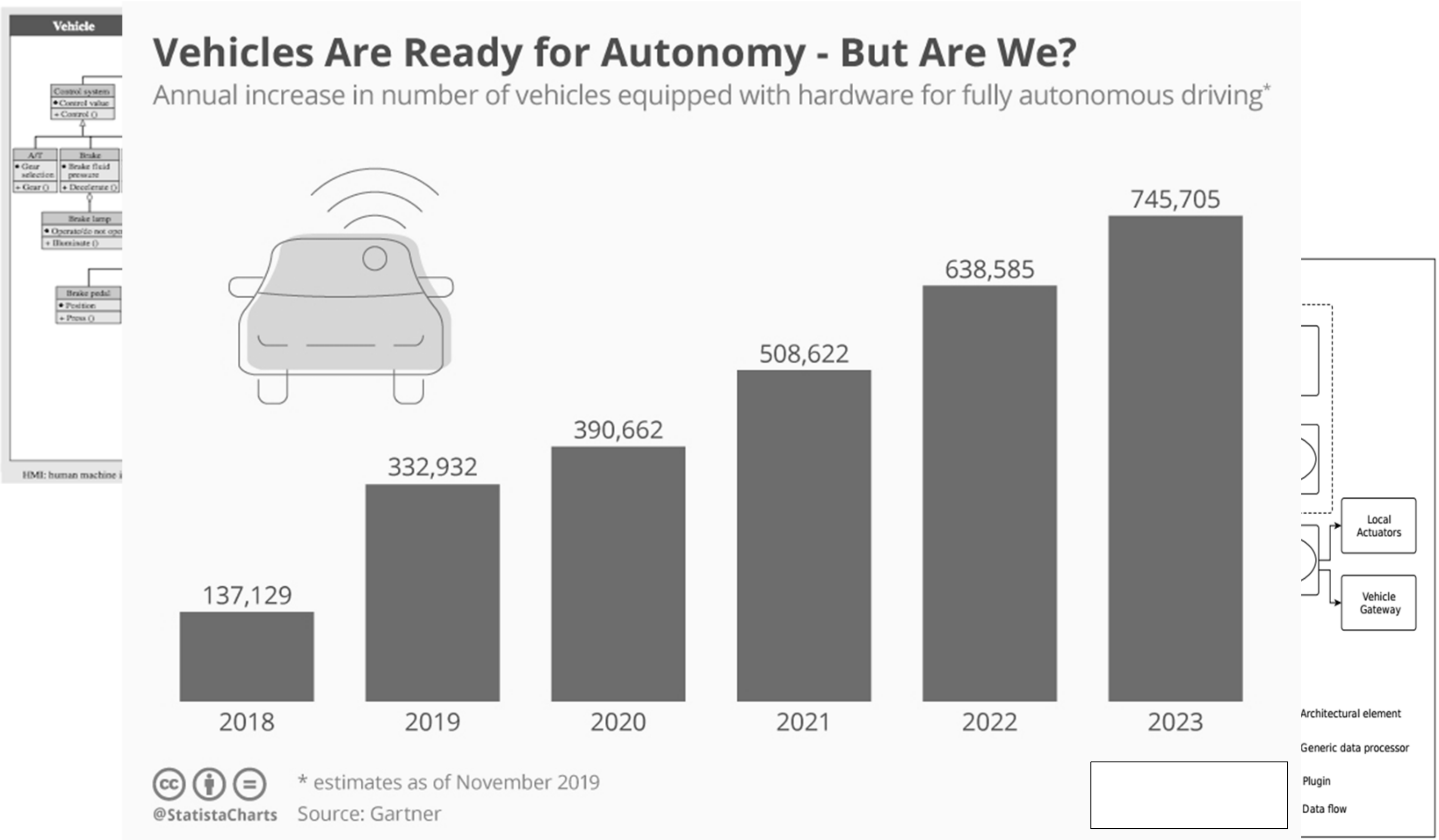
Key points & Players



The State of Today's Autonomous Vehicle Market - Madrona Venture Group

Increasing complexity of the competitive landscape for individual mobility will force OEMs to compete on multiple fronts

Functional Deluge ➔ Software



Autonomous required functions that belongs on several highly safety relevant SW modules (and associated ECUs)… distributed on the most sub domains of vehicle.

And what about Electronic parts ?

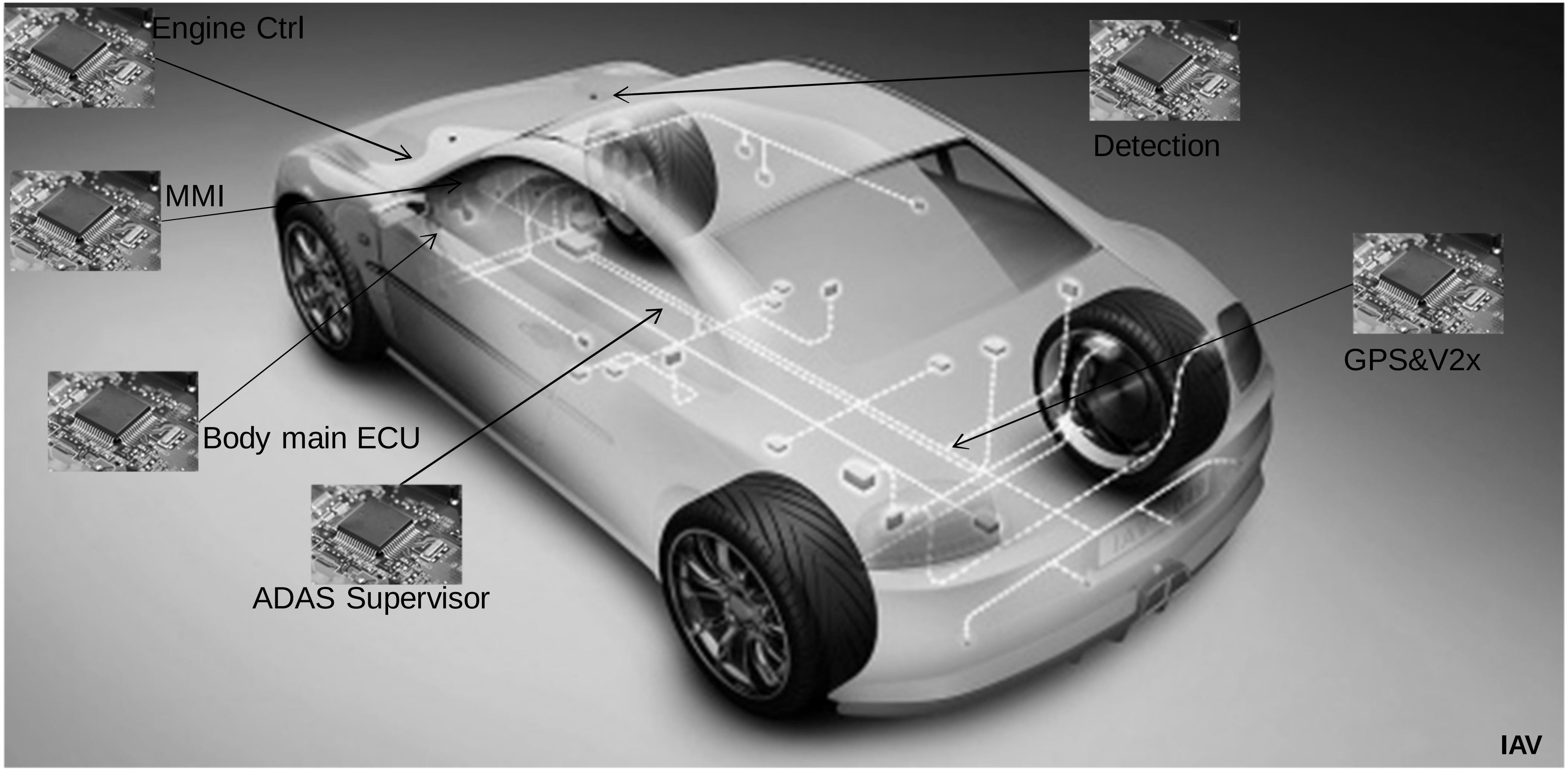
Challenges

Set of requirements to apply on EEA* to comply with autonomous system constraints & performances (and connected) ?

- ✓ Optimized architecture : Centralized vs Distributed to fulfill Safety requirements and scalability,
- ✓ Migration path between current EEA and fully suitable design… Big bang approach must be avoided for quality & cost issues,
- ✓ Modular modules to develop to grant expected performances & integration efforts

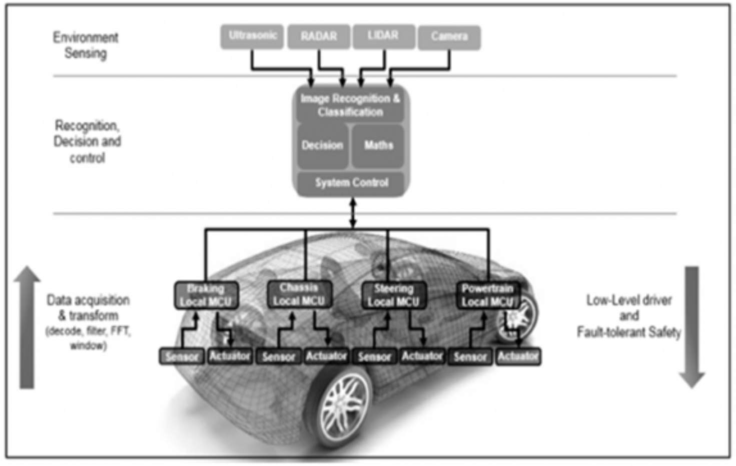
***EEA**: Electrical & Electronic Architecture

ECUs - Contribution

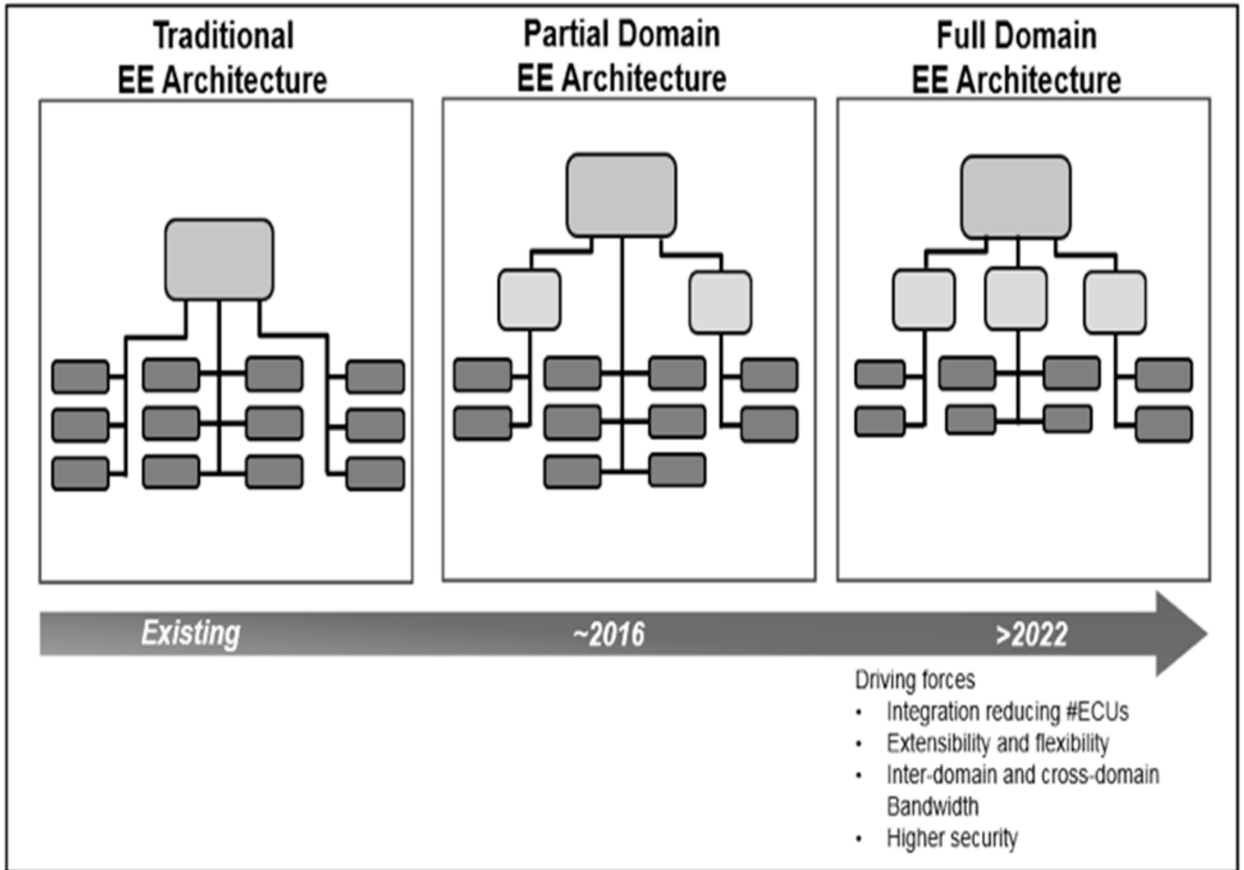


All the functional domain are involved, that is lead to huge development and seek for new technologies.

Involved sub-domains



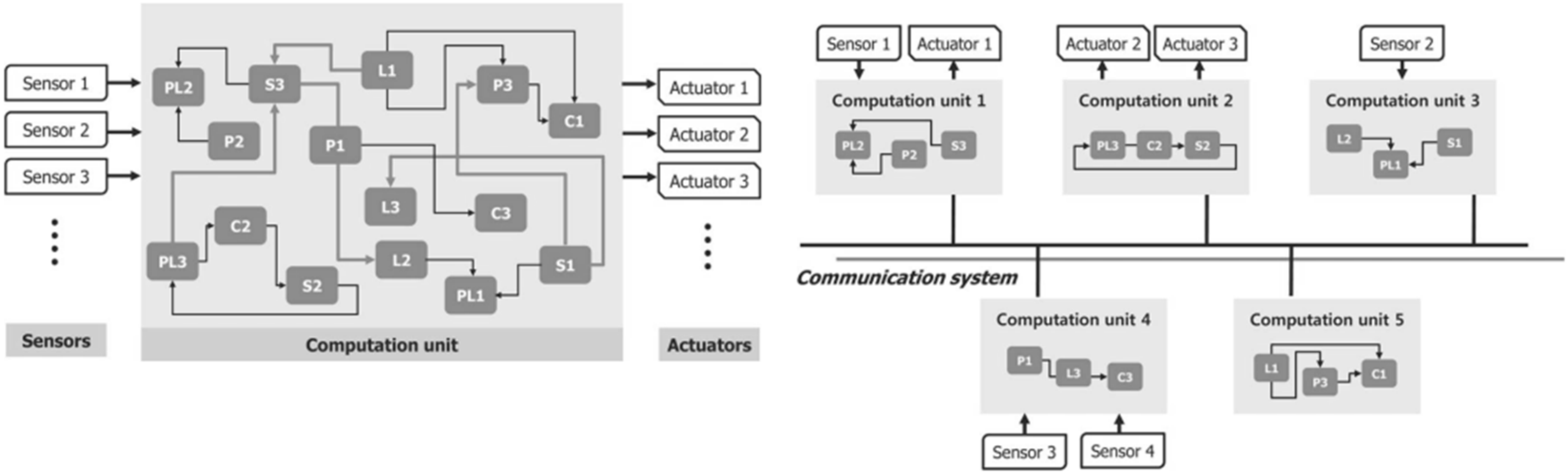
ADAS functions need more severe requirements which belong on EEA, included performances and safety issues.
Previous sub-domains clustering which was a golden rules need to be replaced with overall supervision.



Local sub-domain supervision need to contribute to motion supervisor.

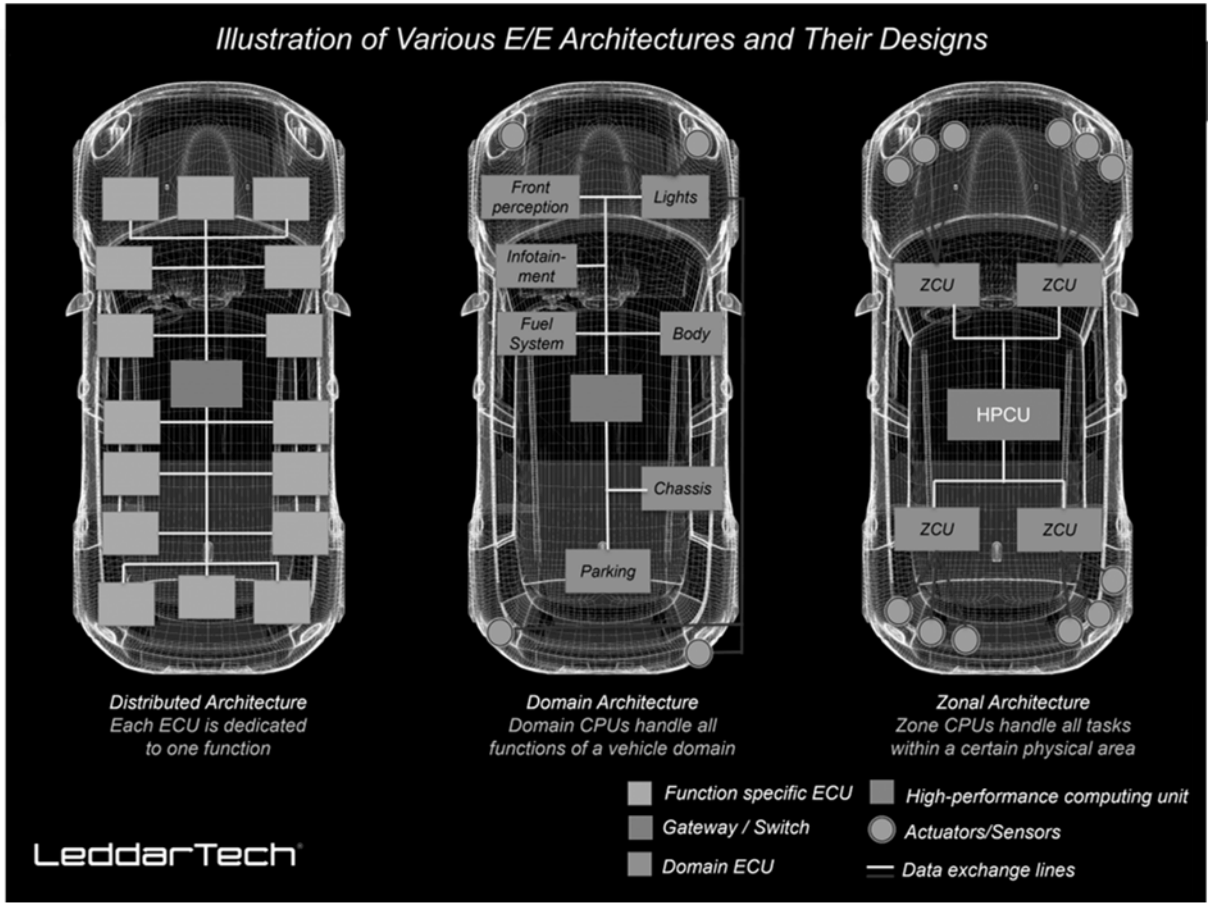
This level of connection involve additional complexity which need to be mastered.
Furthermore, development process between care maker and supplier need to be more cooperative.

E-Architecture : Centralized vs Distributed



	Centralized	Distributed
Complexity	Simplify configuration, Big harness, Availability to insure, poor scalability,	Integration effort, I/Fs need to be well defined, SW integration effort,
Performances	high computational capability required,	Specialized local computations,
Cost	Suitable only for high range brand	Easy to decline

E-Architecture : Centralized vs Distributed



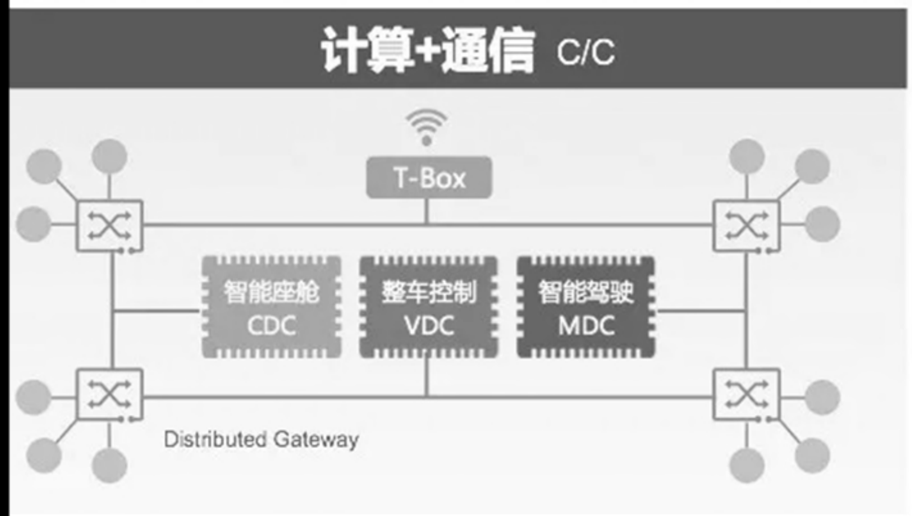


Diagram from Huawei's presentation - *Beijing on Oct. 22*

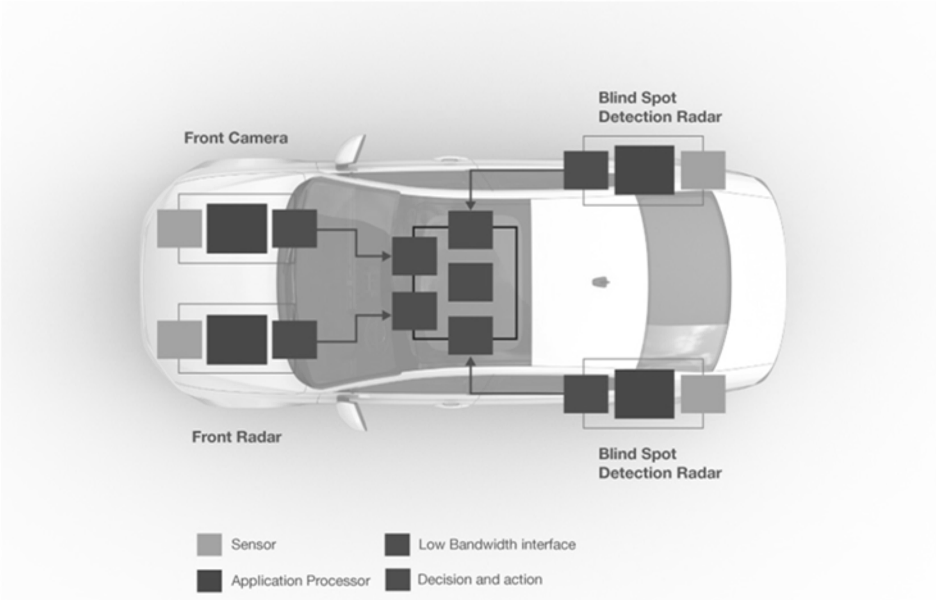
« Conventional » distributed AEE was optimized for a large framework of options and declination. The gap in term of CPU capabilities, networks and sensors due to autonomous vehicle impose an another AEE paradigm : Zonal architecture to decrease harness impact and reinforce ECU integration.

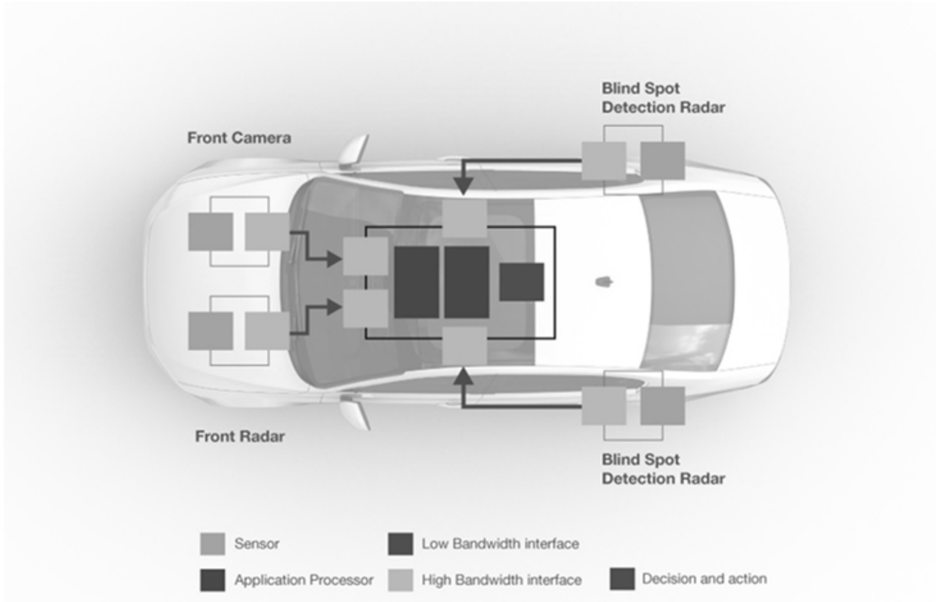
E-Architecture : Centralized vs Distributed

How to choose it ?

There is no universal solution, optimized choice belongs on several criteria :

- ✓ Technology maturity,
- ✓ Equipment rate (standard vs option),
- ✓ Brand policy
- ✓ Future proof consideration,





https://www.5gtechnologyworld.com/how-adas-is-paving-the-way-for-autonomous-driving/

Architecture : Centralized vs Distributed

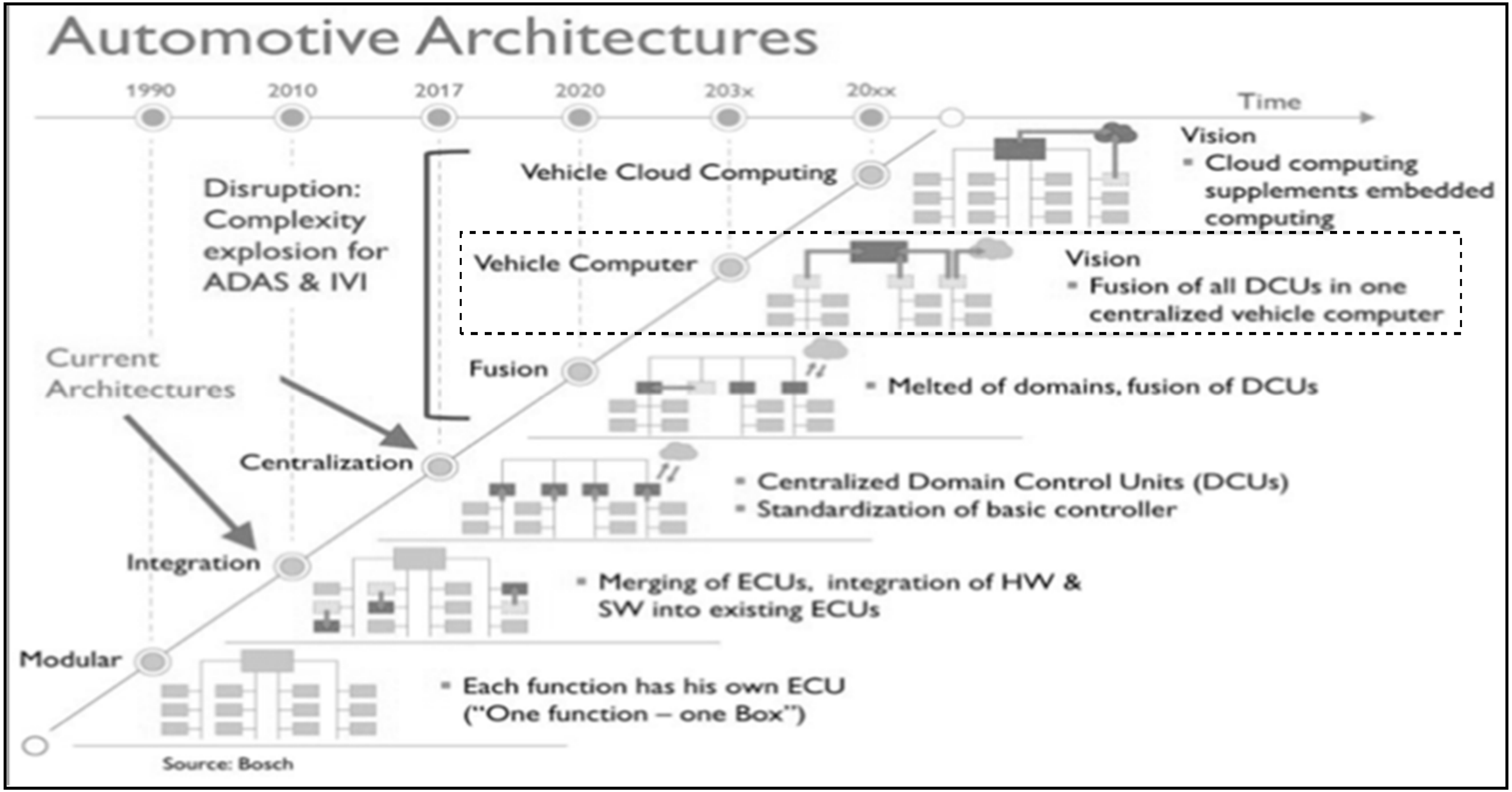
https://www.autovision-news.com/

Trend is to centralize with super-ECUs : Criteria

Advantages	Drawback
Reliability	Safety / Redondancy ?
Integration effort – Less interfaces	
Bus load	
Energy foot print	
Less ECUs but…	Biggest shape.
Less wires, but…	Connectors saturation and wires length.

Distributed electronic architecture is very modular (1 ECU / function), compliant with supplier portfolio and adapted for the carry over.
But…lead to a lot of ECUs, harness and hard to integrate (due to buses interfaces).
Today mainstream is domain centralization, hyper-centralized will come for fusion motivations.

Electronic Architecture



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

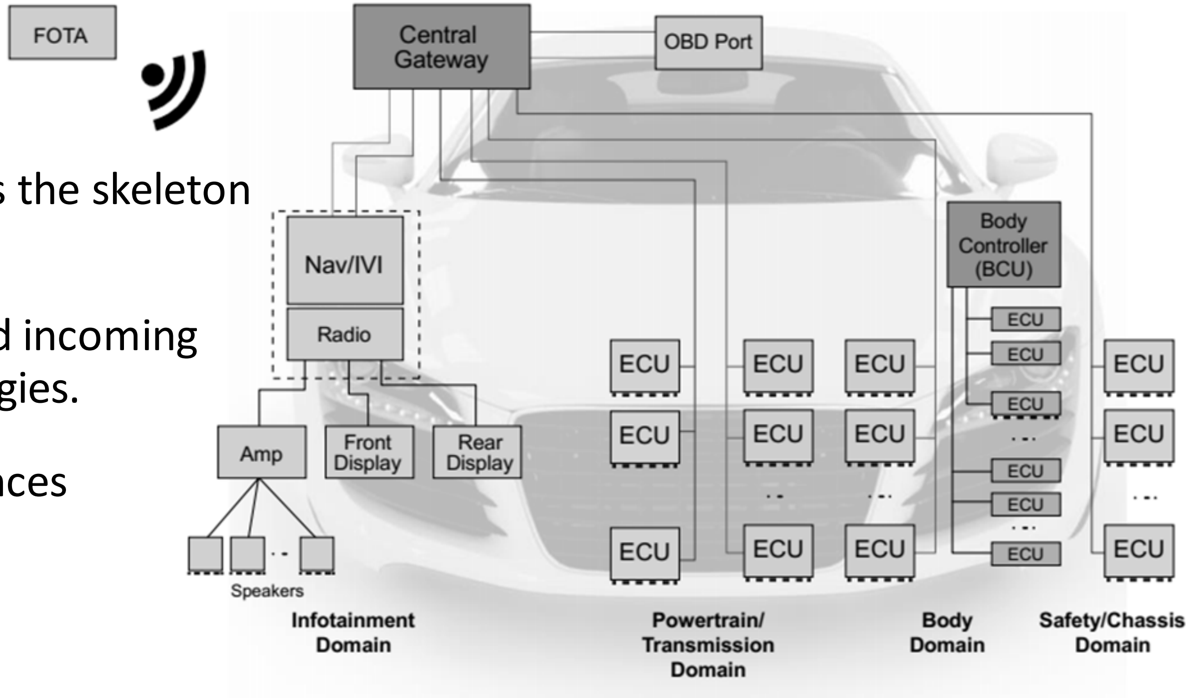
Usually, electronic architect engineer "move on" step by step and have maximized backward compatibility. Due to autonomous (& highly connected) system, new paradigm have to be deployed ⇒ Centralized and melted.

Electronic Architecture

Electronic Architecture is the skeleton to connect EE stuff.

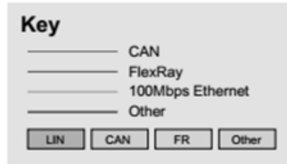
It belongs on current and incoming state of the art technologies.

Data flow is a consequences



- 30-50 ECUs per average car
- Top end cars have
  - 150 ECUs
  - 150 network connections
  - >5 km copper wire (>60 kg)
  - 100 motors
  - 500 LEDs
  - >5 cameras

Source : NXP



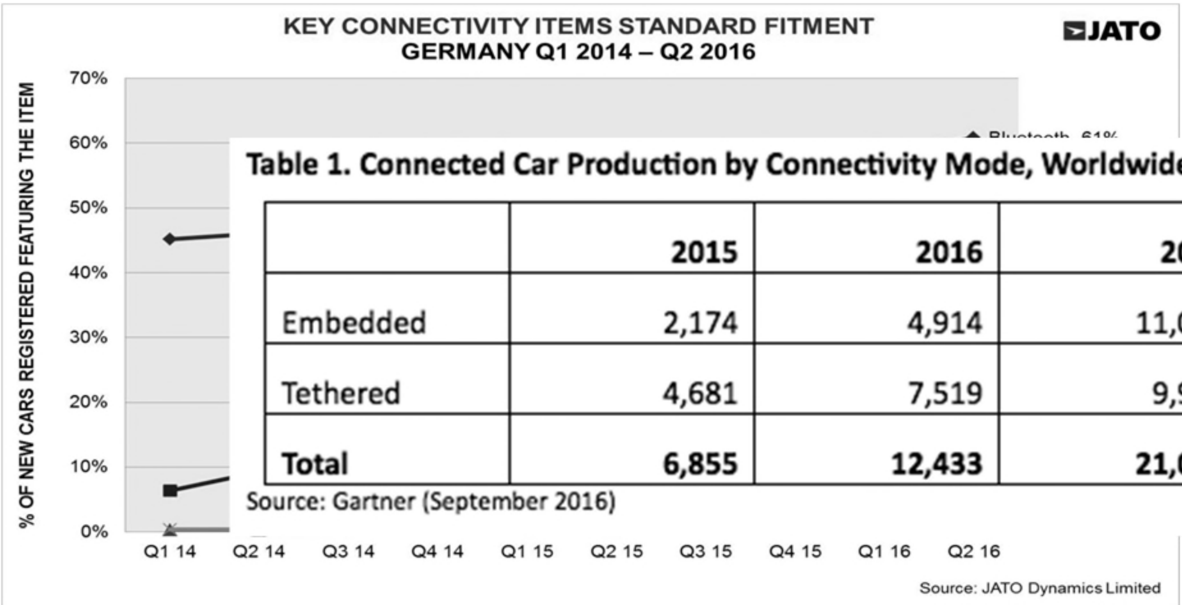


Table 1. Connected Car Production by Connectivity Mode, Worldwide (Thousands)

	2015	2016	2017	2018	2019	2020
Embedded	2,174	4,914	11,097	21,394	33,928	42,949
Tethered	4,681	7,519	9,971	12,374	14,995	17,994
Total	**6,855**	**12,433**	**21,068**	**33,768**	**48,923**	**60,943**

Source: Gartner (September 2016)

Mechanical architecture : Drive by Wire

X by wire means that a set of computers/sensors/actuators have replaced all the previous mechanical links between the driver and the vehicle.

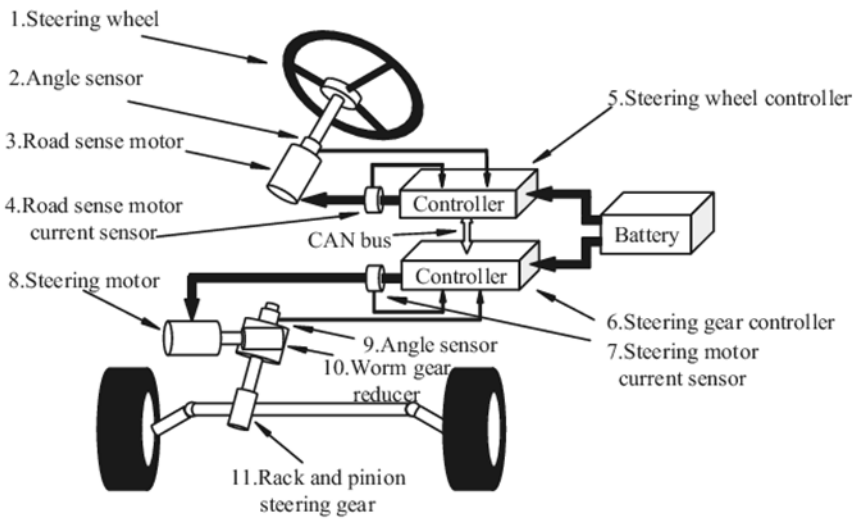


Fig. 1 schematic of Steer-by-Wire system

https://www.semanticscholar.org

https://www.fka.de/

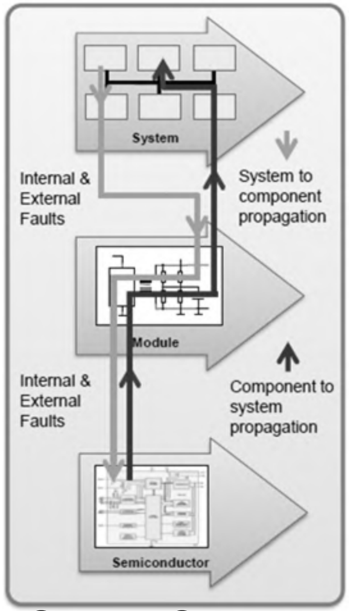
Motivations : Drivability; active safety; weight & integration; global motion approach;… but

X by wire require dedicated electronic design (redundancy; self checking ; failsafe ; standards compliant (ex: ISO2626-2).

Processors & Software

Today's car has the computing power of 20 modern PCs, features about <u>100 million lines of code</u>, and processes up to 25 gigabytes of data per hour.

The question is : How & When we'll be able to deploy a fleet of fully autonomous driving systems, safe enough to leave humans completely out of the driving loop ?

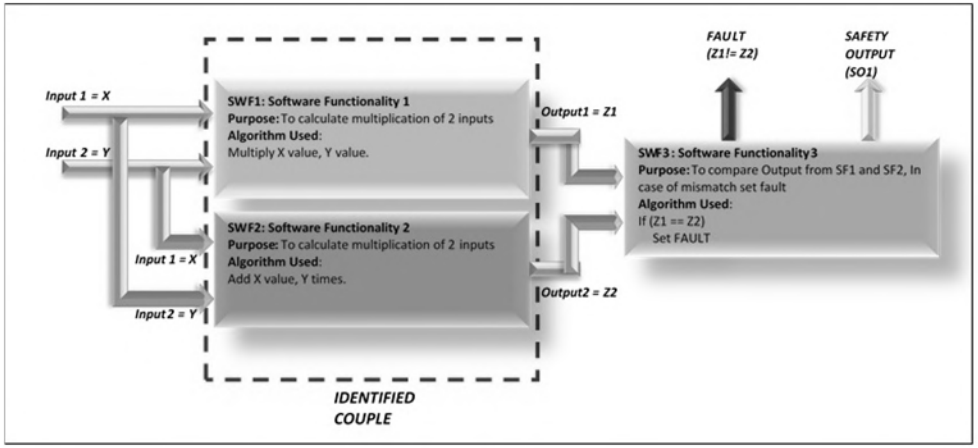


Source : Synopsys

Process design & Components ⍰ verification (ISO 26262)

- ✓ Avoid blocking of execution, deadlocks, time budget violation,…
- ✓ Memory content corruption, unauthorized R&W access,
- ✓ Self monitoring software & Self-tested chips before each driving cycle with an extremely high level of diagnostic coverage,
- ✓ Step lock processors (Run time barrier).

Automotive SW panorama : Multiple entities encounter multiple dependencies (Time to market constraint, cost mitigation, many third party,…).



Technologies

Embedded

Embedded system is generally a combination of microprocessor based electronic boards, software (w or w/o R.T constraints), sensors and actuators.

Embedded

Constraints :

- ✓ Harsh Environment,
- ✓ Weight,
- ✓ Cooling,
- ✓ Energy
- ✓ Maintainability (including workshop services),
- ✓ Safety
- ✓ Updating
- ✓ Size
- ✓ Cost
- ✓ …

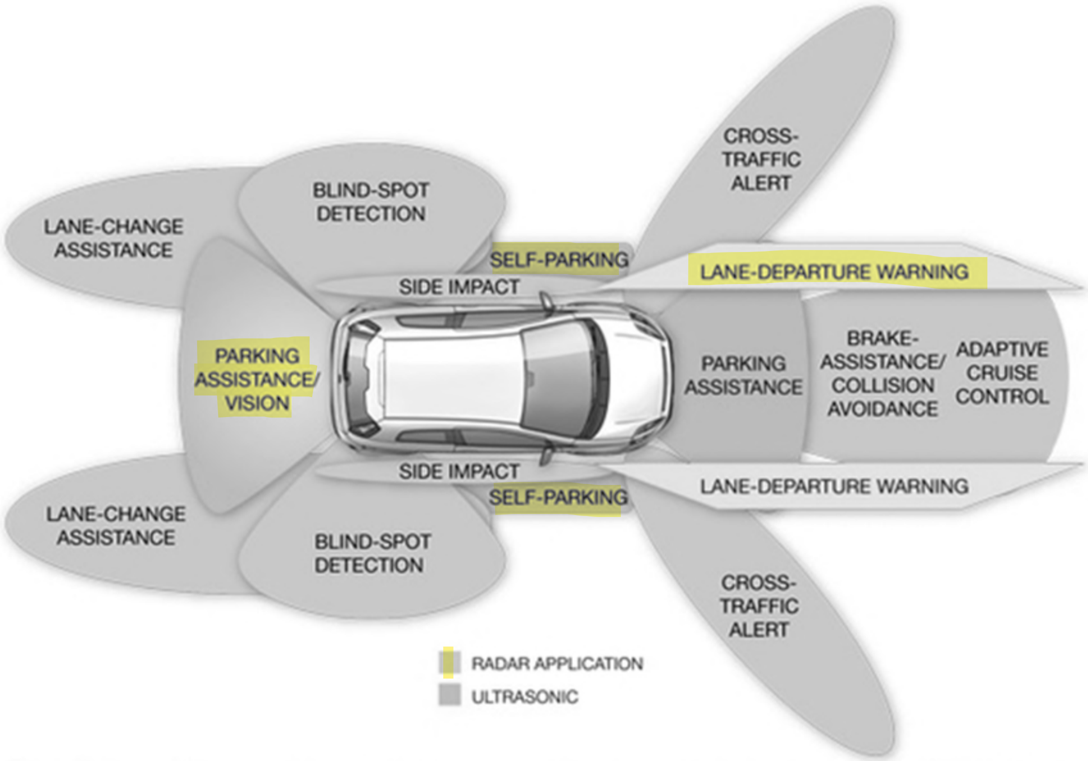
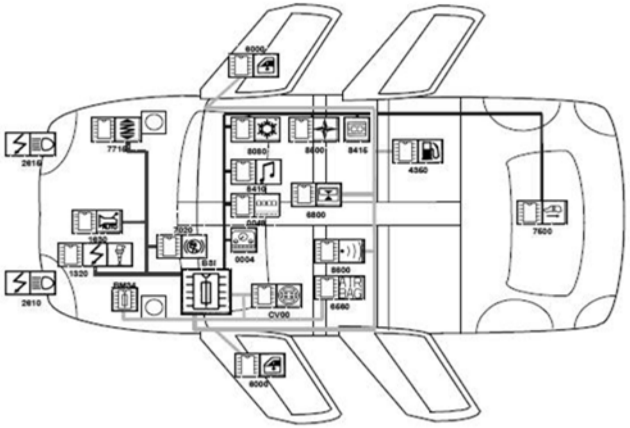
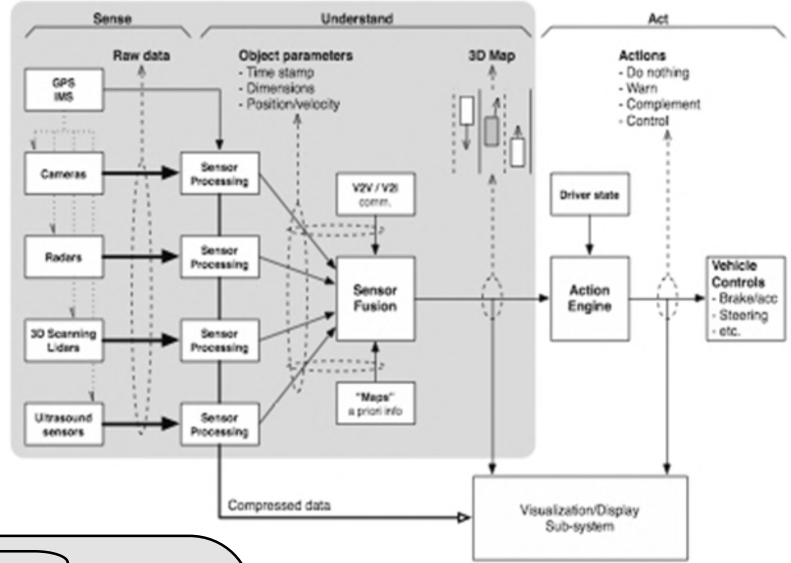


Figure 2 Several driver-assistance systems are currently using radar technology to provide blind-spot detection, parking assistance, collision avoidance, and other driver aids (courtesy Analog Devices).

Technologies





Supervisor

Data fusion

Radar
ShortRange
MedRange
LongRange

Lidar
MedRange
LongRange

Camera
Mono
Stéréo
Multiple

UltraSon

Infra-Red

Wheelspeed

V2X

V2I

Autonomous passengers Car

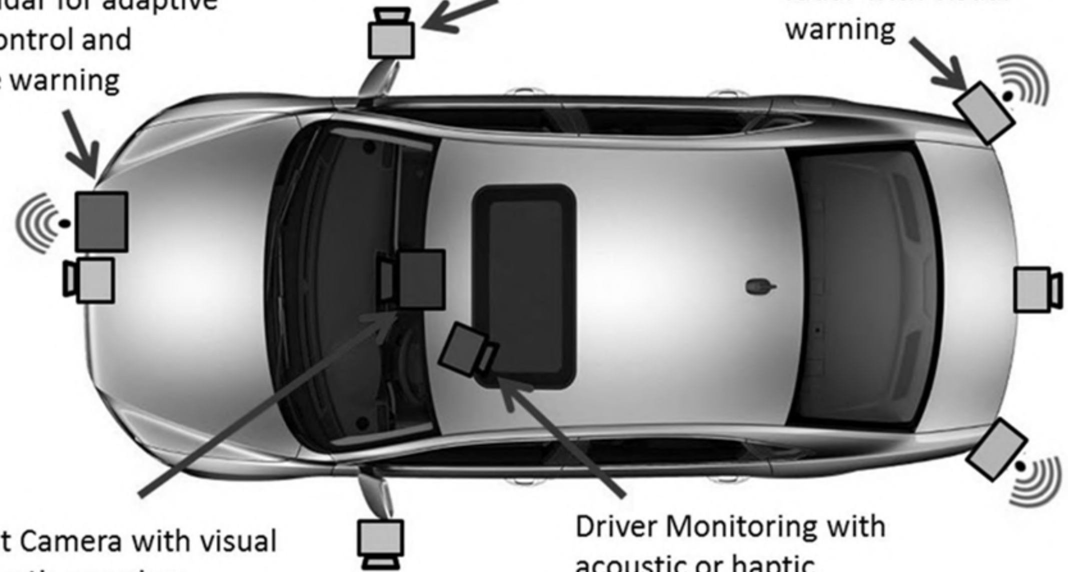
Sensors Belt :

- Radar,
- Lidar,
- Camera,
- Ultrasonic
- Inertial unit

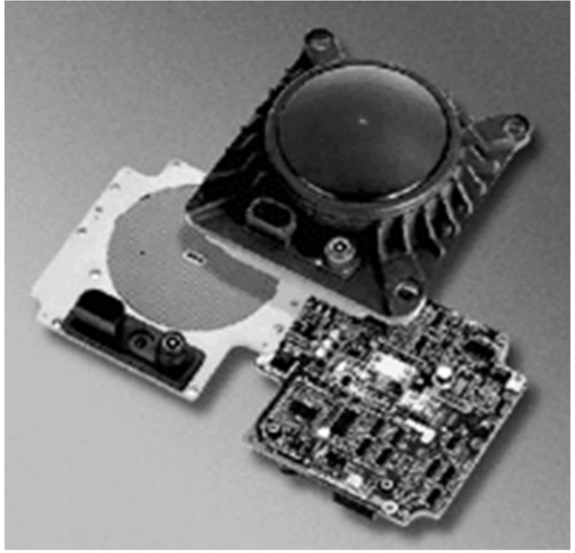
Scene scanning, localization & Identification

Sensors belt

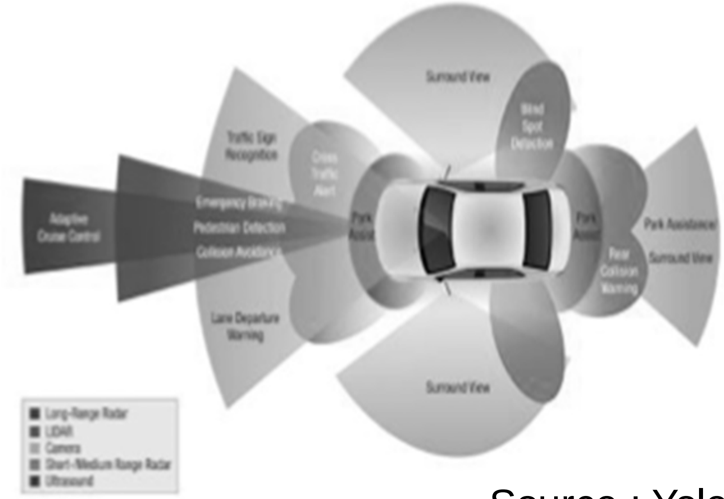
it requires combining the information coming from different types of sensors



Sensors	Range	Functionalities
Ultrasonic	Very short	Parking, pedestrian
Radar	Short to Long	Parking Road, Highway (Cruise Ctrl)
Lidar	Long	3D mapping of surrounding
Camera	Short/Middle	Shape recognition, Night & darkness detection (IR)



RADAR



Source : Yole

RADAR : Radio Detection and Ranging

RADAR capabilities are based on sending radio frequency signals and measuring the signals reflected back to the radar by the targets, named as backscattered signals.

The signals are then processed by the radar to extract the target information such as

- Distance, speed, angular position,
- Target characteristics evaluation.

Placed in front of a car, a RADAR can measure speed & distance of objects up to 150-200 meters

RADAR

History and evolution

1886 The physicist Heinrich Hertz found that electromagnetic waves could be reflected from various objects and focused into beams by appropriate reflectors.

The first patent on the phenomena was obtained in **1904** by German engineer Christian Hiilsmeyer who called this device the "Telemobiloskop“ (Range : 3km).

In **20’s and 30’s** many studies was driven by military applications, specially in Great Britain and USA

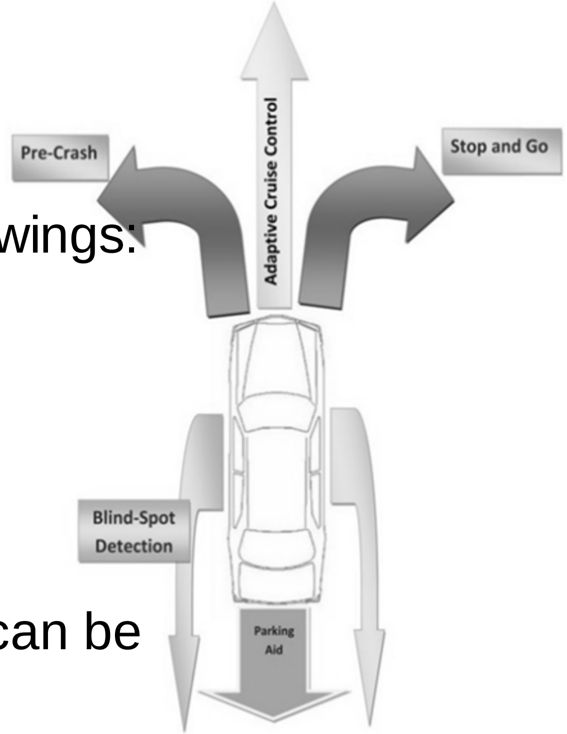
And automotive ?

Japanese car maker was the first, in the 80’s to introduce a Radar into their products for collision warning applications. In 90’s, Radar was introduced on European market.

First applications belongs on 24Ghz (Cruise control,…) and since few years 77Ghz (to 81Ghz) for a better bandwidth (coupled with FM Continuous wave).

Automotive Radar are in the race for 30 years, <u>technology is mature</u> (improvements are still incoming) easy to integrate and relatively cost effective.

RADAR



Source SaberTek

The basic output information of the automotive radars is the followings:

- ✓ Detection of objects
- ✓ Relative position of the objects to the vehicle
- ✓ Relative speed of the objects to the vehicle

Based on this information the following user-level functionalities can be implemented:

Alert the driver about any potential danger

Prevent collision by intervening with the control of the vehicle in hazardous situations

Take over partial control of the vehicle (e.g., adaptive cruise control)

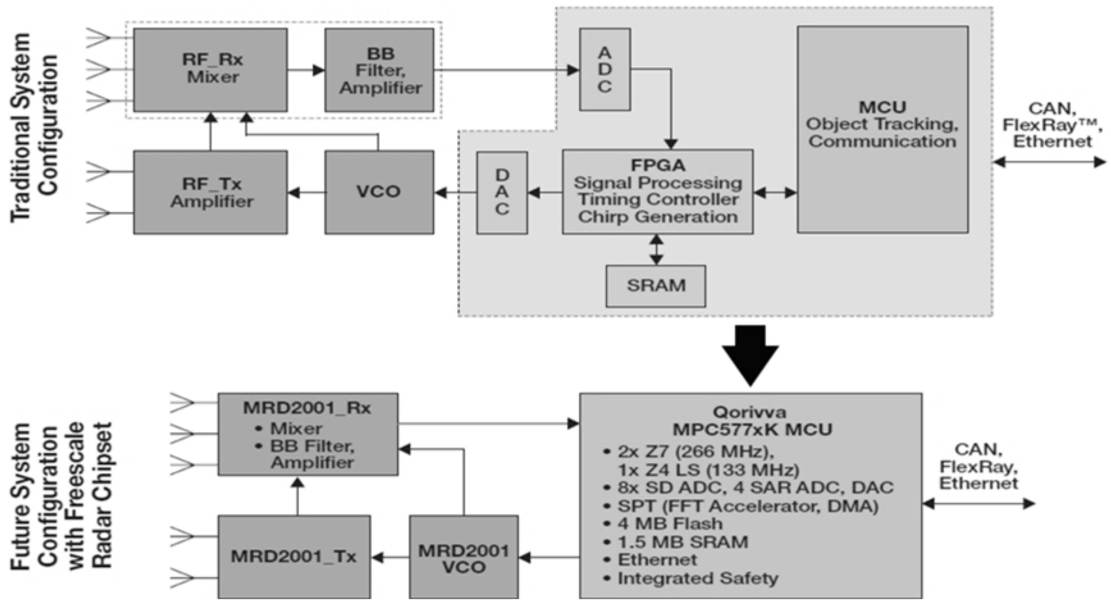
Assist the driver in parking the car

The reflectivity limitations of radar are typically even more severe than those of Lidar :

…It works well on metallic objects, such as vehicles, but nonmetallic objects, such as pedestrians, are essentially invisible to a radar sensor…

RADAR

Short, middle and long range coexist for different functions. This example includes a µController MCU DualCore with Lockstep mechanism), a dedicated circuit, networks interfaces, memories and, of course, dedicated IC for HF treatment itself.



Source : Freescale

The radar core includes :

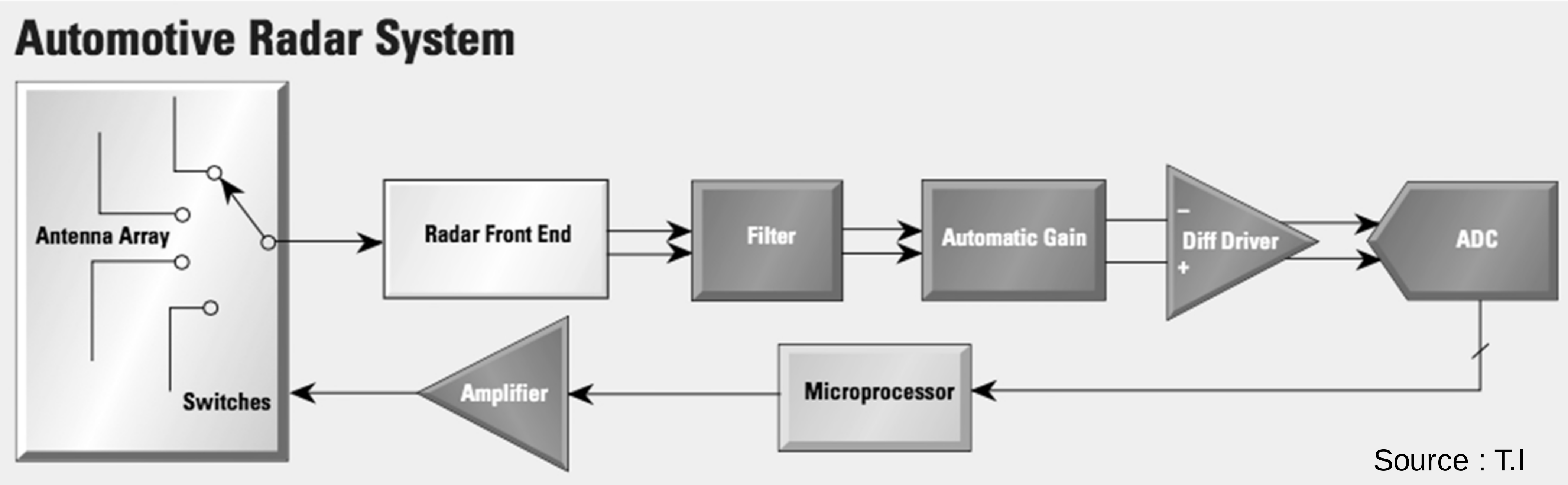
- A signal processing toolbox with an accelerated FFT engine,

- DMA control, and ADC block with multiple converters and DAC block,

- A chipset which is made up of a three-channel Rx chip, two-channel Tx chip and a VCO forming a full radar signal processing solution.

Silicon vendors have developed complete set of ICs for a single PCB solution

RADAR



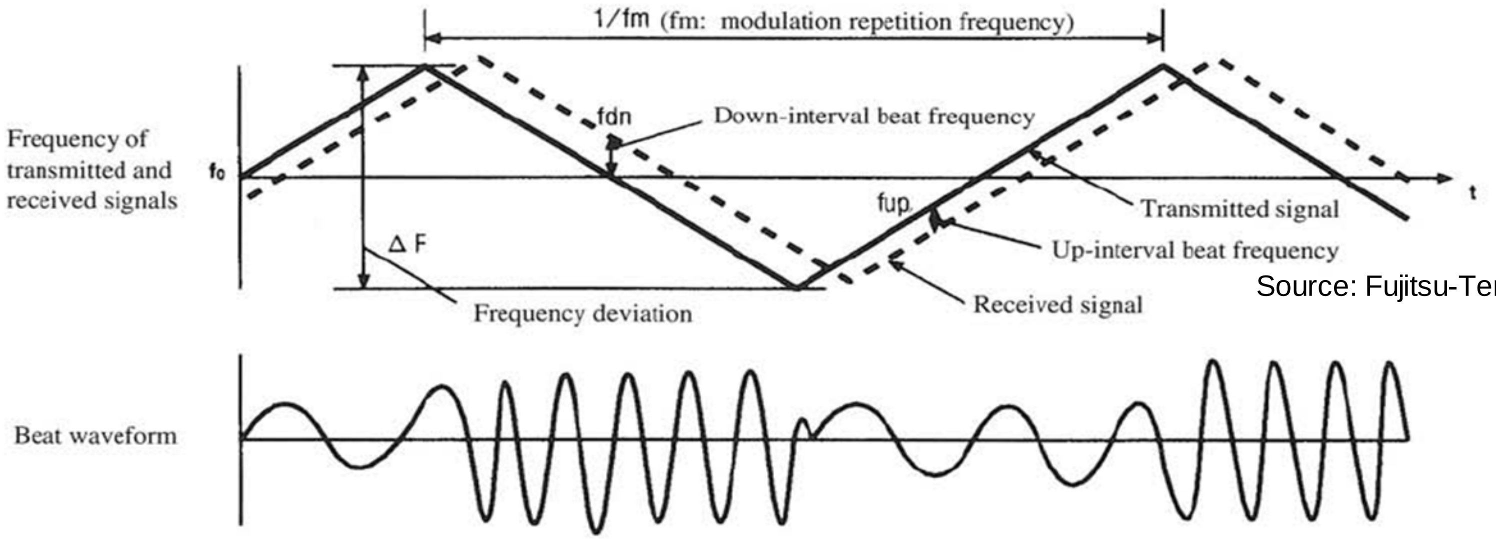
As cost decreases, radar systems (e.g., for blind-spot detection), are being installed in more classes of vehicles.
Automotive radar systems can be classified in two sets:

- **Long-range radar (LRR)** - \$125-150 (up 150-200m)
  - Accuracy : few tens of cm to 1m.
- **Medium/short-range radar (SRR)** - \$50-100 (5 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.

RADAR

Radar system can be continuous wave (CW) or pulsed. In continuous-wave (CW) radars, the frequency difference between transmitted signal and echo received (Doppler frequency) allows target speed estimation.



Source: Fujitsu-Ten

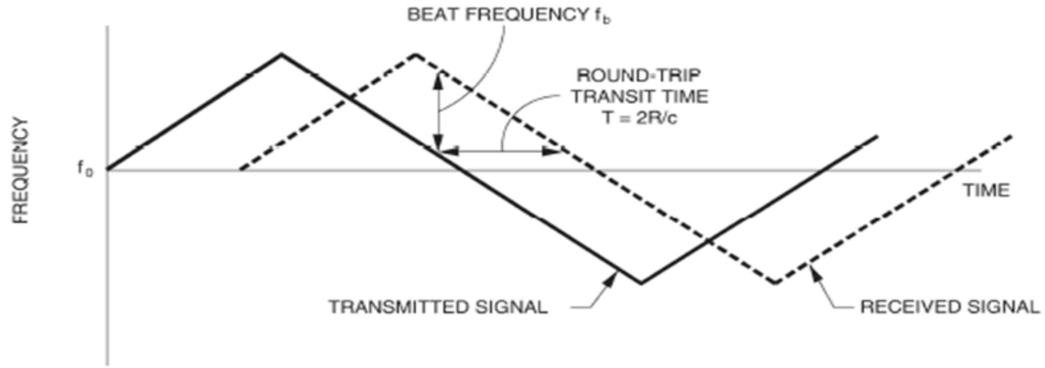
The most widely used technology is the FM-CW (Frequency Modulated Continuous Wave). In FMCW radars, a ramp waveform is used to generate a signal with varying frequency in time domain. The radar signal is reflected by the target and received by the radar sensor.

Beat signals are obtained from the transmitted and received signals and the beat frequency is proportional to the distance between the target and the radar sensor.

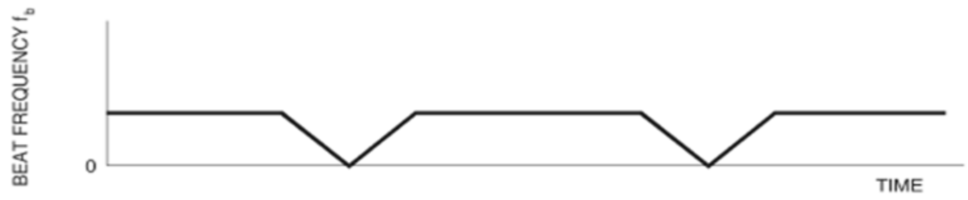
Relative speed and relative distance can be determined by measuring the beat frequencies.

RADAR

The FMCW-based sensor continuously sends signals with a periodical frequency modulated carrier wave. The frequency of the emitted wave changes linearly with time.



a) Relationship between the transmitted and received signal frequencies.

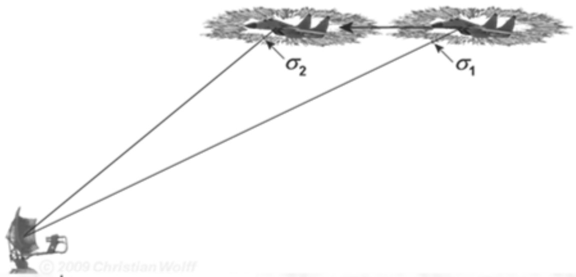


b) Beat frequency.

The reflected signal has a frequency corresponding to the time instant of its emission, but due to TOF, it has been delayed proportionally to double distance of the sender/receiver.
Evaluation of the frequency difference between emitted and received signals (reflected) is performed in a mixer.

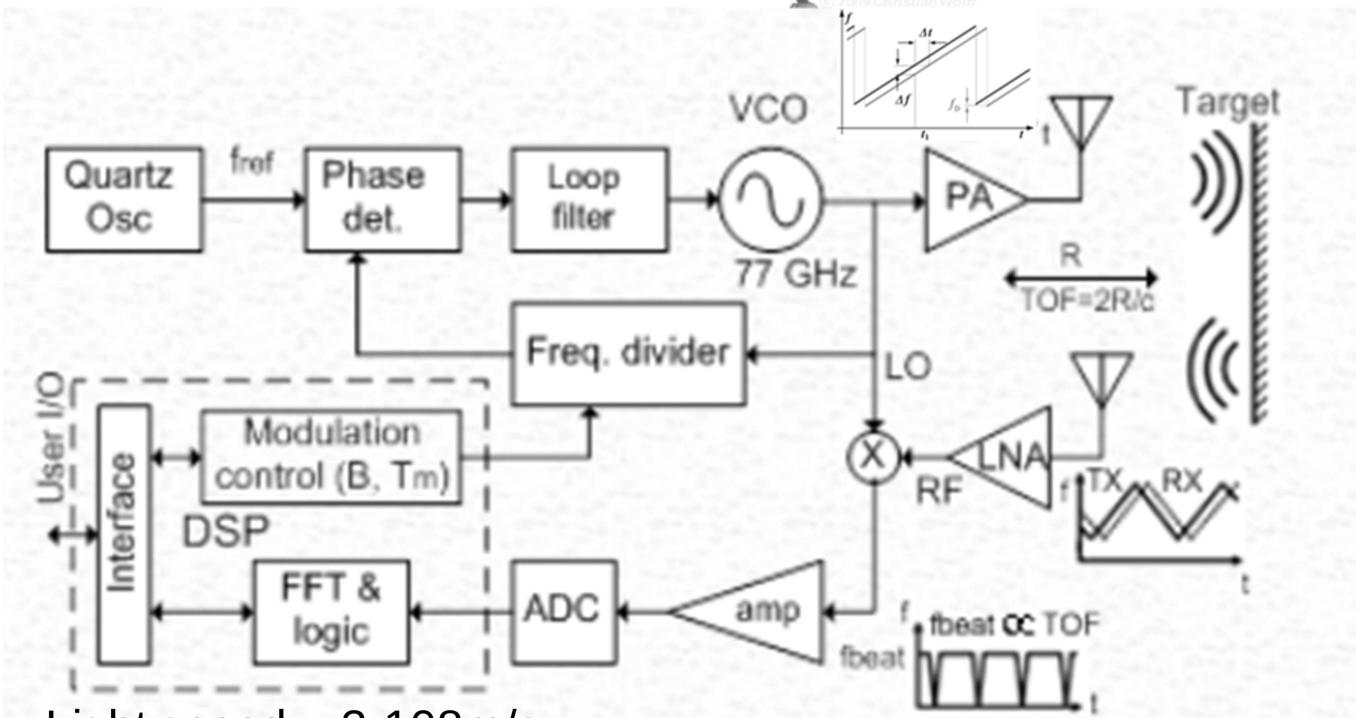
Beat frequency can be calculated from the following equation: $Fb=\Delta t*df_t/dt=2R/c*df_t/dt$
avec df_t/dt = The rate of change of the transmitter frequency

RADAR



Target speed evaluation is computed

thanks to Doppler effect.



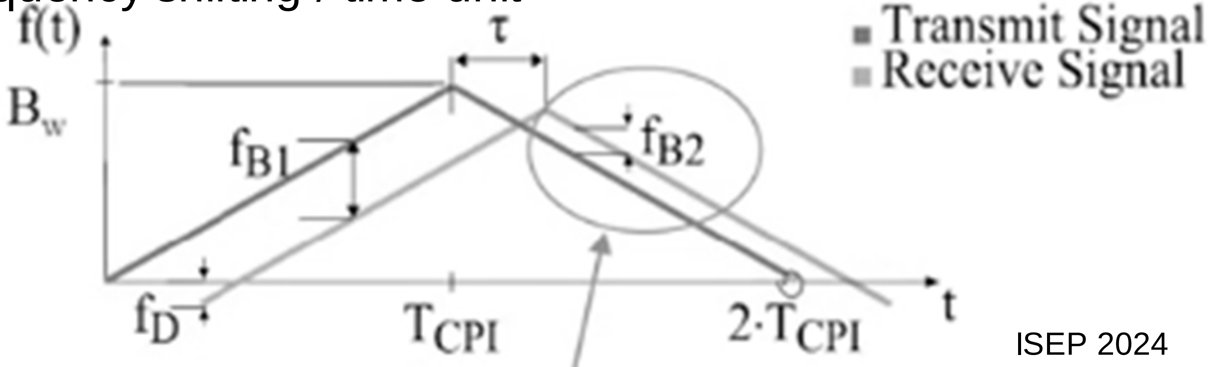
$$R = \sqrt[4]{\frac{P_t G^2 \sigma \lambda^2}{(4\pi)^3 P_r}} \qquad f_d = -\frac{2}{\lambda} v_r$$

R: Distance (Max range)
G: antenna Gain
Pt: transmitted Pwr;
Pr : Received Pwr
Ϭ : Target Equivalent Surface

Rt computation is :

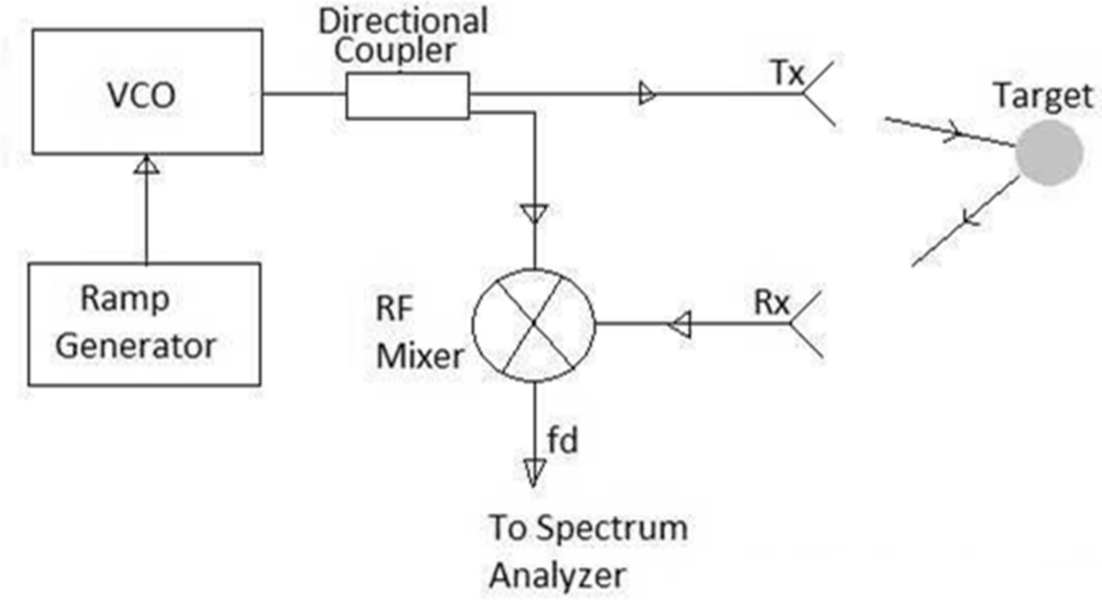
$$R_t = \frac{c_0 \cdot |\Delta t|}{2} = \frac{c_0 \cdot |\Delta f|}{2 \cdot (df/dt)}$$

c0 = Light speed = 3·108m/s
Δt = Time delay [s]
Δf = Frequency shifting [Hz]
Rt = target distance [m]
df/dt = frequency shifting / time unit



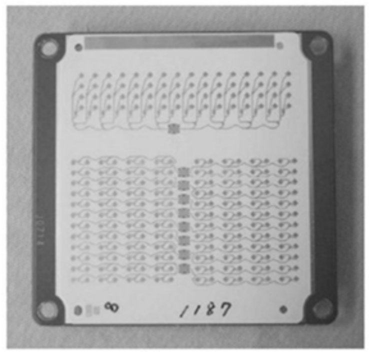
Target moving :
Fb1= 2/c*Bw.R/Tcpi – 2/λ*vt

RADAR

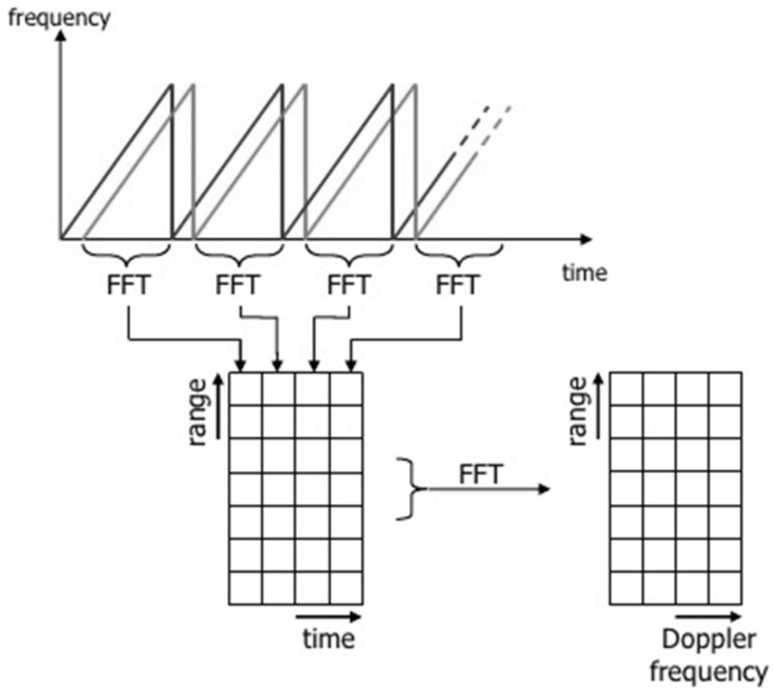


A frequency-modulated continuous-wave radar (FMCW) uses a voltage controlled oscillator to generate a sweep signal. The Tx/Rx-mixed signal (beat frequency) is analyzed by a window FFT to get the ranges to all obstacles

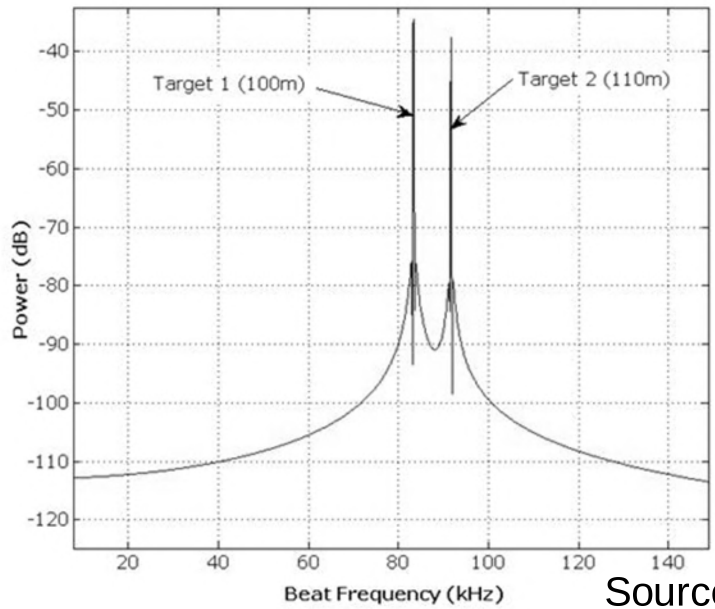
Component side



Antenna side

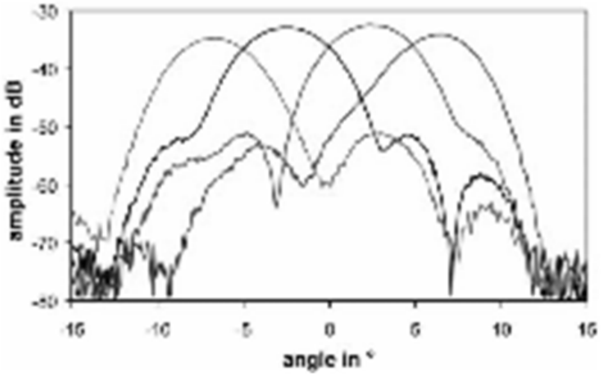


Result of one FFT:



Source : WorldPress

RADAR



In order to be meet automotive cost and size factor constraint, the complete system could be designed on 2 printed circuit board (Antenna & Processing).

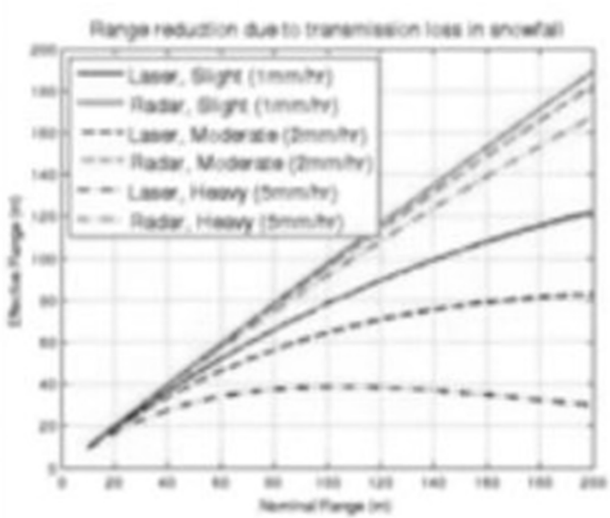
FMCW technique used.

2 kinds of radar are available :

- ✓ Short range detection : ~5m to 30m ,
- ✓ Long range detection : >150 à 200m (expected detection angle : ~30° , 4 antennas)

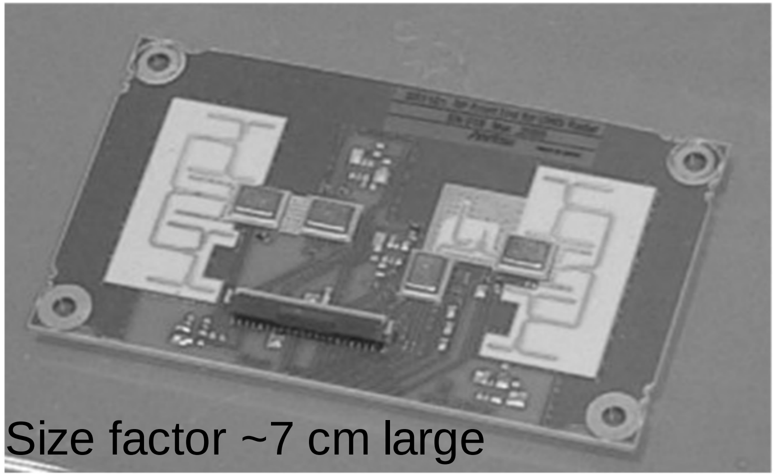
Silicon-Germanium transistor can operate up to 77Ghz (thin base ~50nm).

Antennas are printed on the PCB, smart components are in CMOS technology



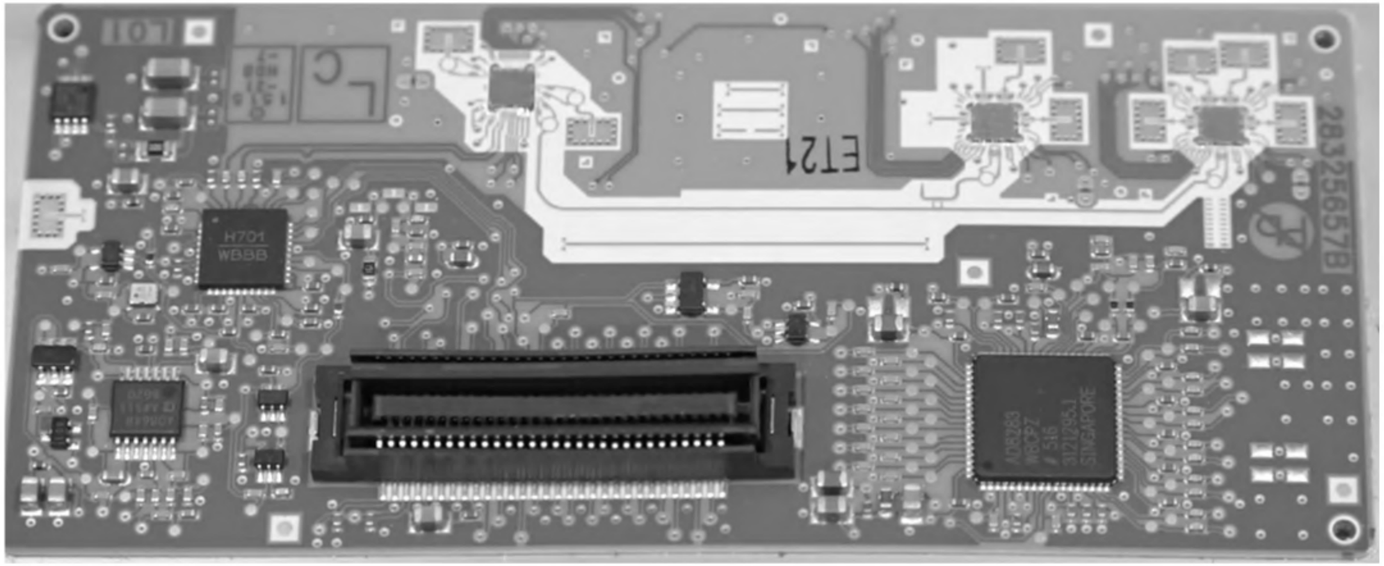
RADAR vs LIDAR

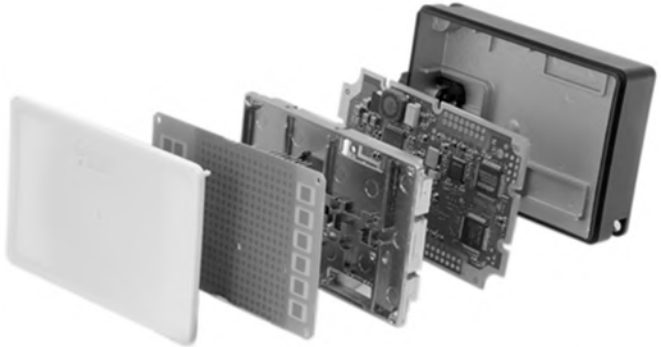
In case of bad weather condition, RADAR is quite insensible, LIDAR Range falls down

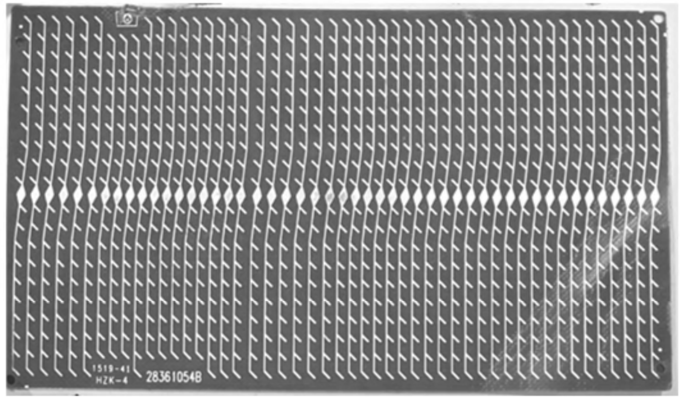


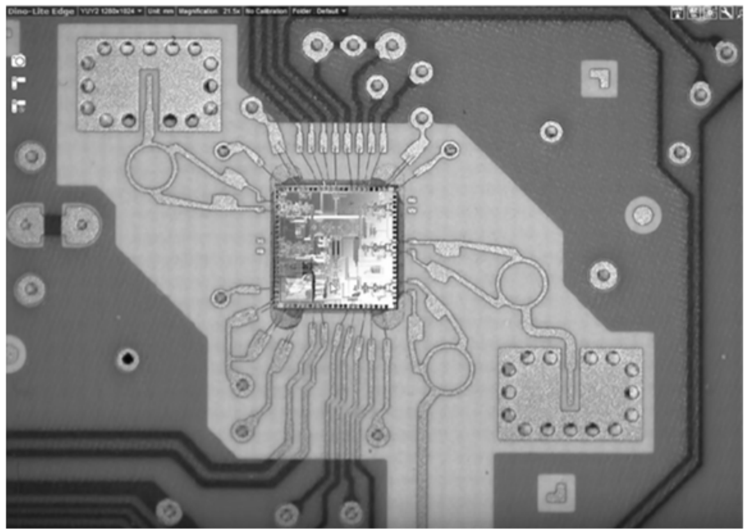
Size factor ~7 cm large

RADAR - TearDown

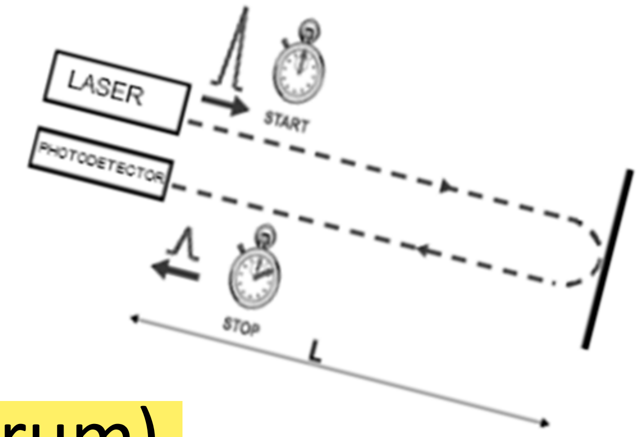








LIDAR (Laser)



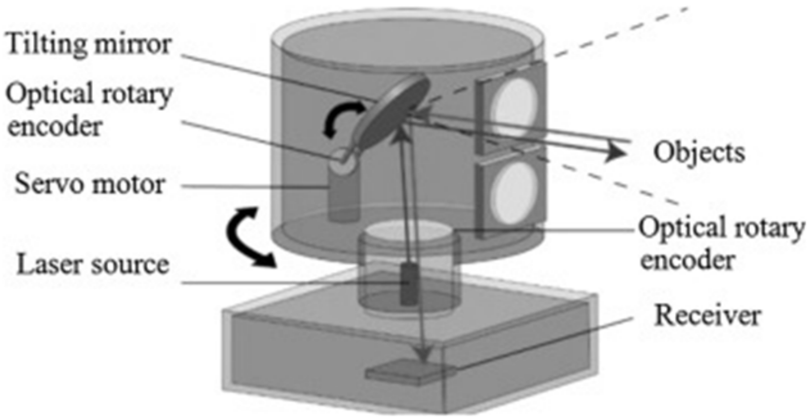
Time of flight is used (scattered signal, same as Radar) :

- Infrared pulses emission (invisible spectrum),
- View span detection modulated with a mirror or solid state laser,
- Max distance up to 150-200m (~100m with flash LiDAR).

Allow a very accurate measure, closed to +/- 1 to 5 cm but weather sensibility can decrease performances (fog, snow,…) !

Most players work on LIDAR development

LIDAR : Types design



Source : www.sciencedirect.com

source emits the laser light onto the tilting mirror and then reflected by the mirror onto objects

Mechanical Scanning LiDAR

This type of LiDAR uses a **rotating mirror or prism** to direct the laser beam in different directions.

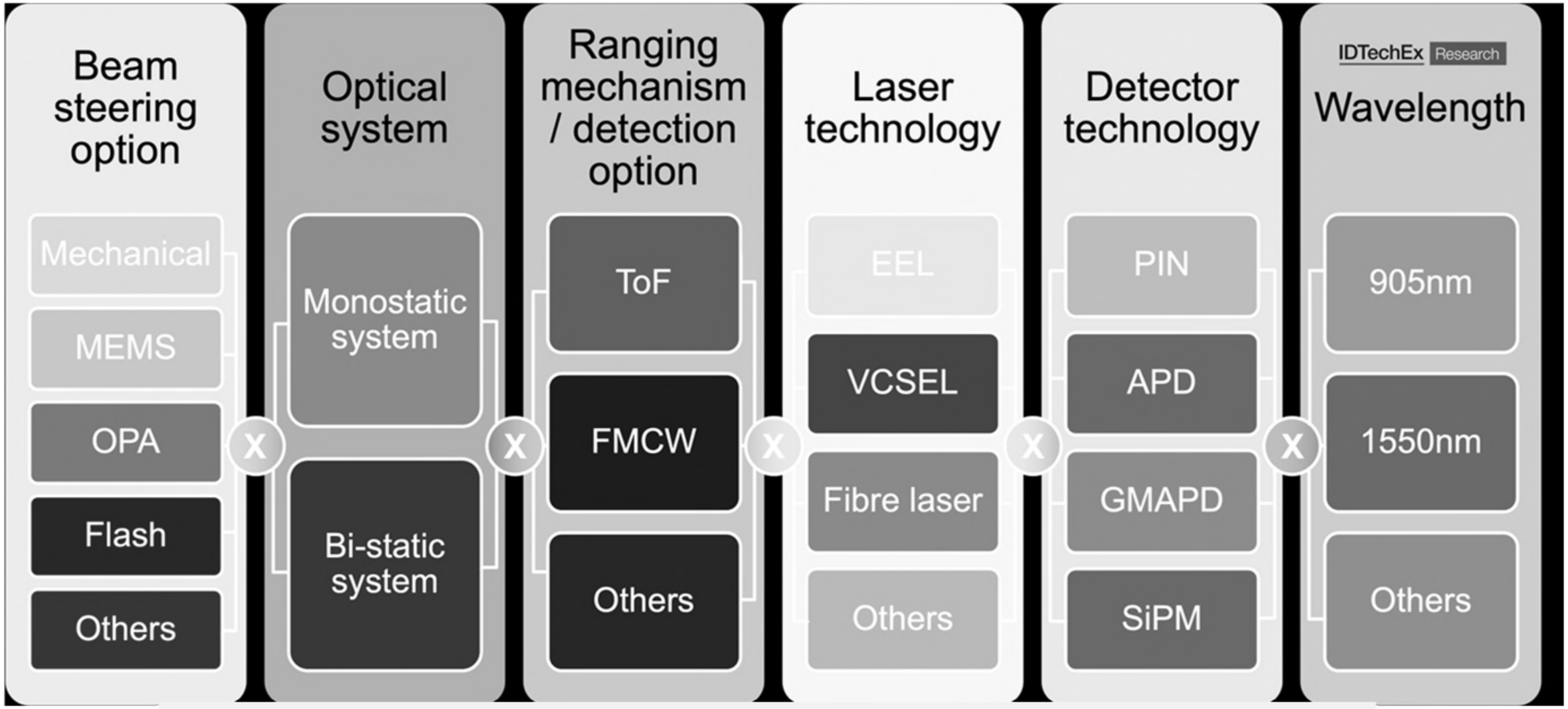
Solid-State-LiDAR

Solid-state LiDAR systems **without the use of mechanically moving scan components** (faster scan rates, lower energy consumption and **greater reliability** than mechanical LiDAR scanners).

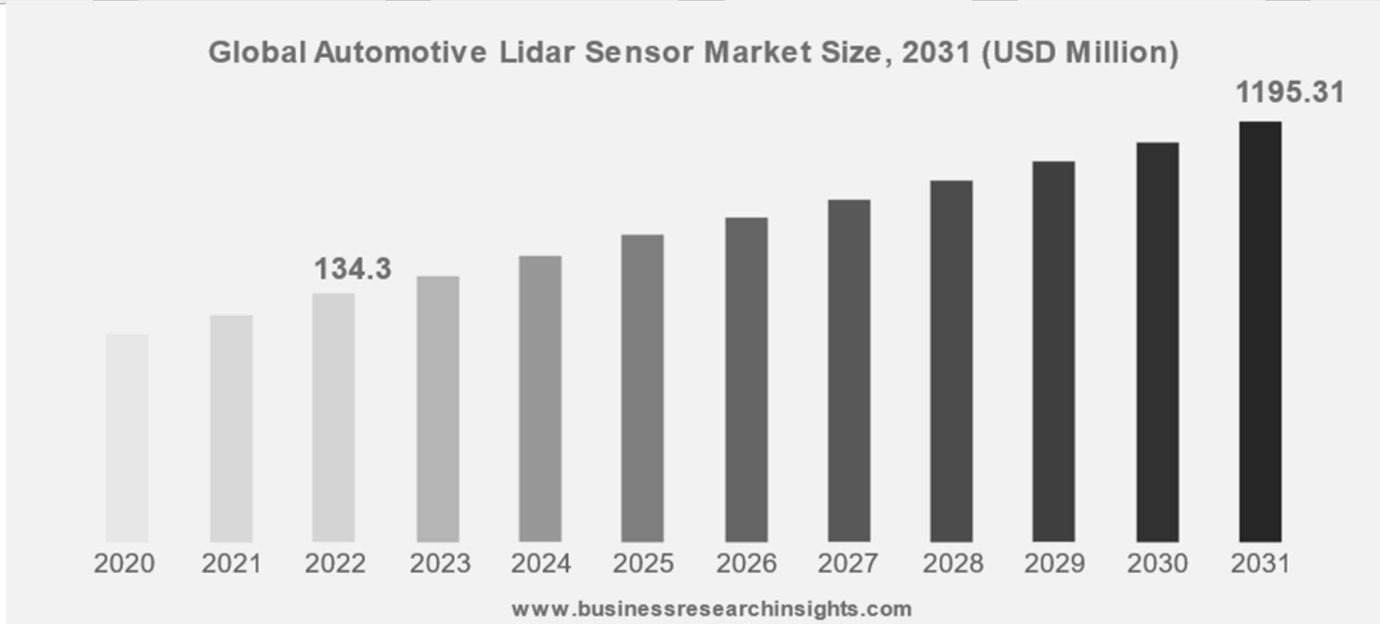
3D-Flash-LiDAR

Flash-LiDAR **relies on a single laser pulse** that captures the entire field of view in a brief moment (3D map in just one shot, higher speed but limitations in terms of range & resolution).

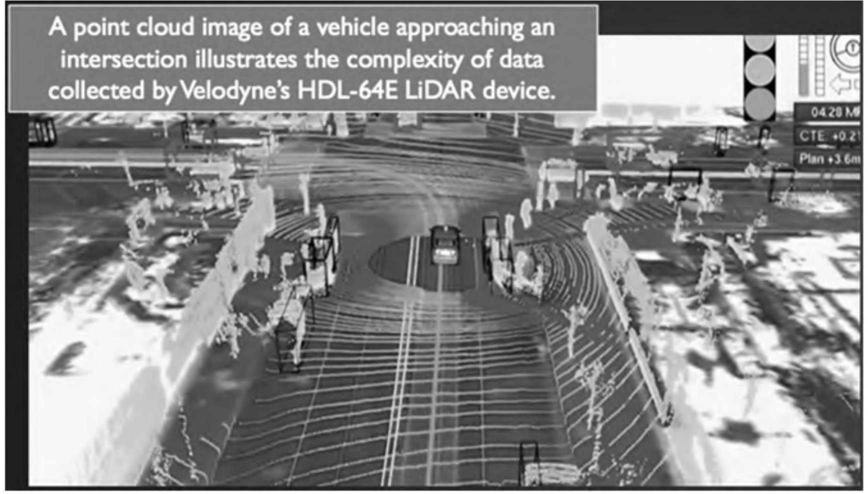
LIDAR : Types design



Source: IDTechEx

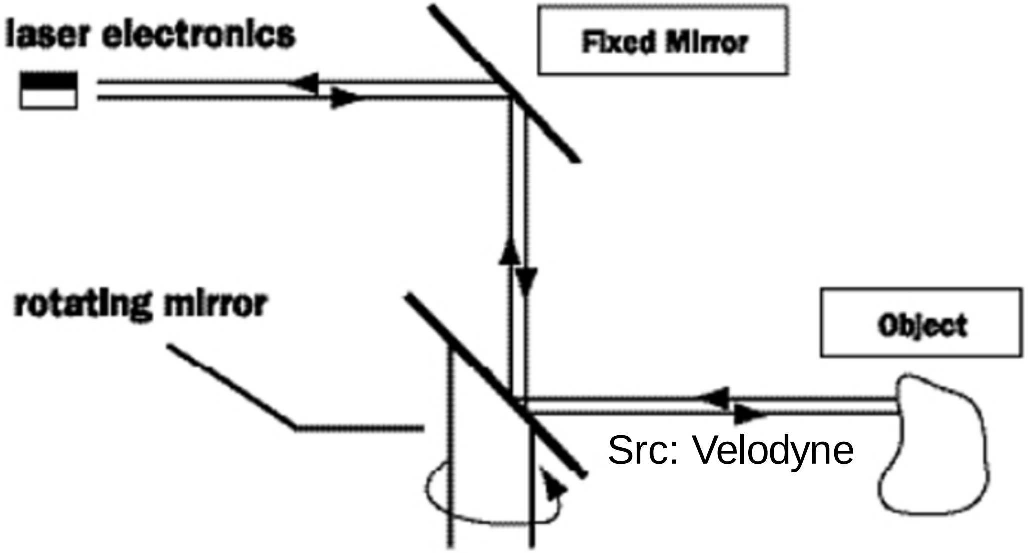


LIDAR



LIDAR (Light Detection and Ranging) is a system that uses rotating laser

e



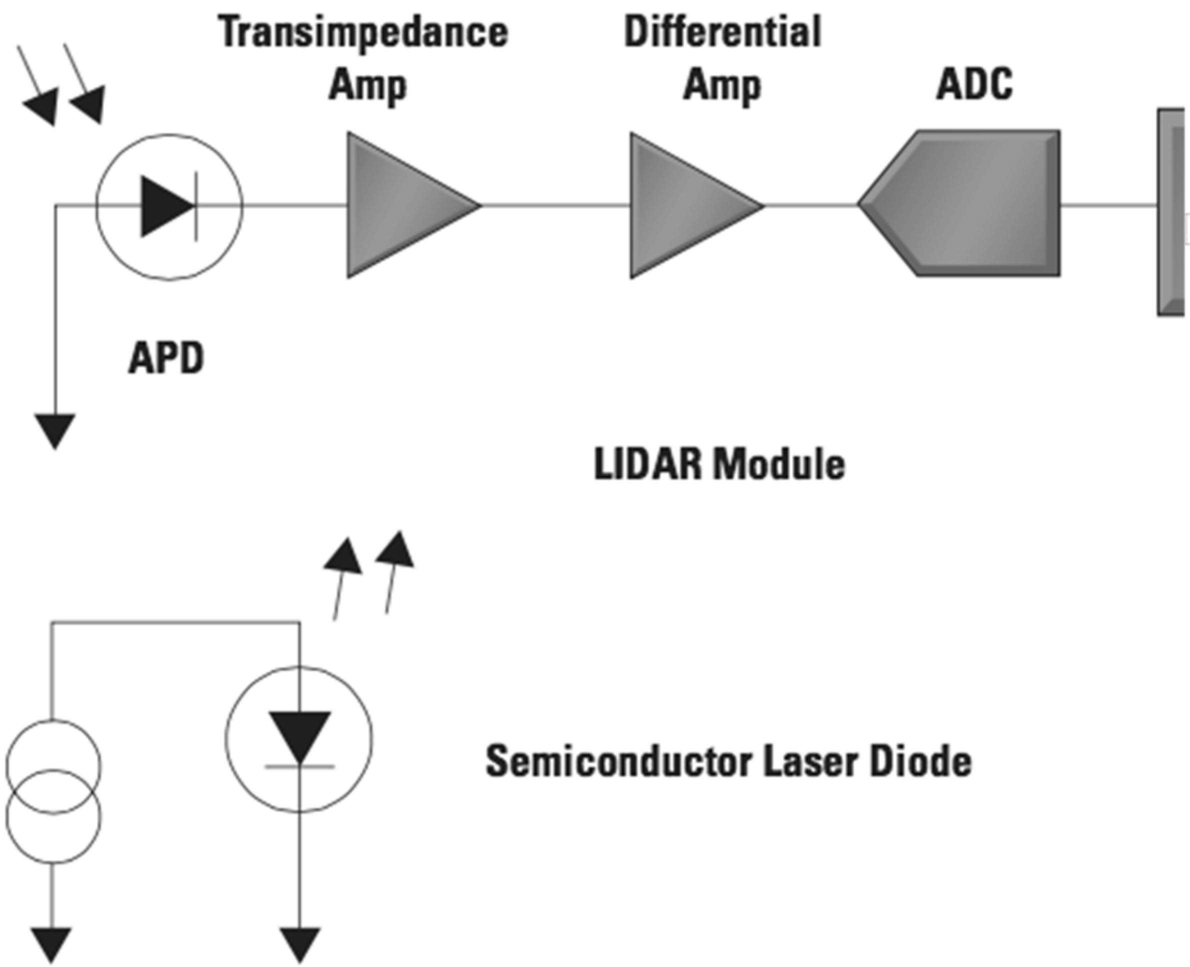
360° view is achieved with the rotation of the mirror. Mirror is in charge to reflect the laser and the return light to detector. Azimuth can also be controlled.
Point cloud is collected, image of the target and associated distance (after computation).

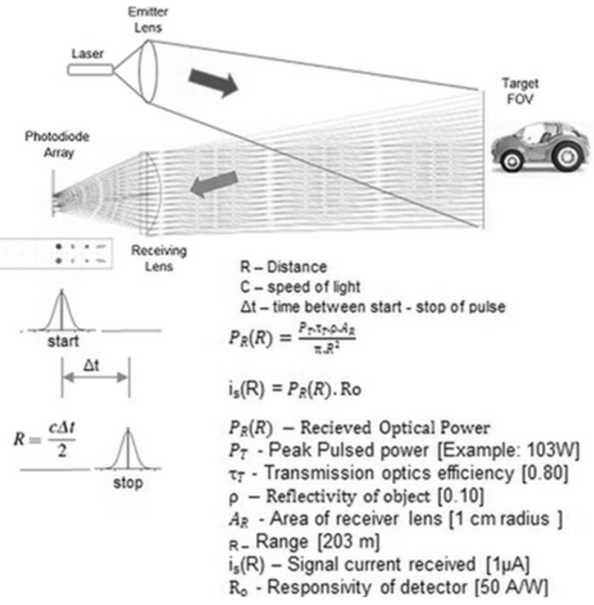
LIDAR technology is not fully mature for automotive requirements (high rates, reliability, cost,…) and many studies are running.
Many types of sensors & design exist, Mechanical vs Solid state, continuous vs pulsed, Laser diodes, SoC,…

Expected range can overcomes 200m, 500k points/s, 0.1° - 0.2° resolution. Precision is around ~10cm at 10m to few tens at 100m (better resolution is incomming).

Main advantages of LIDAR is to be efficient (compare to camera) & occurate even in bad weather situation and/or darkness and shape detection capabilities.

LIDAR





GSPs=G samples per second

The range measurement accuracy that can be achieved is directly related to the ADC sampling frequency. The Speed of light c = 3·108m/s.
At 1 GSPs, the ADC has a clock period of 1 ns. In a 1 ns sampling instant, light will travel 0.3m or 30cm. Therefore the resolution at 1 GSPs is 30 cm/m, meaning an accuracy of +/- 15cm is achievable at 1 GSPs over any given distance. The error will increase as sampling frequency is reduced.

LIDAR

The distance(D) from the LiDAR sensor to the target is calculated by dividing the time difference (ΔT) by 2 and multiplying it by the speed of light (c).
Equation (3) describes the relationship between the emitted power Ps and received power Pr of LiDAR systems.

$$P_r = \frac{P_s \cdot T_A \cdot \eta_t}{A_s} \cdot \frac{\Gamma_\rho \cdot T_A}{\pi r^2} \cdot \frac{A_R \cdot \eta_r}{1}$$

The main variables in Equation (2) are listed

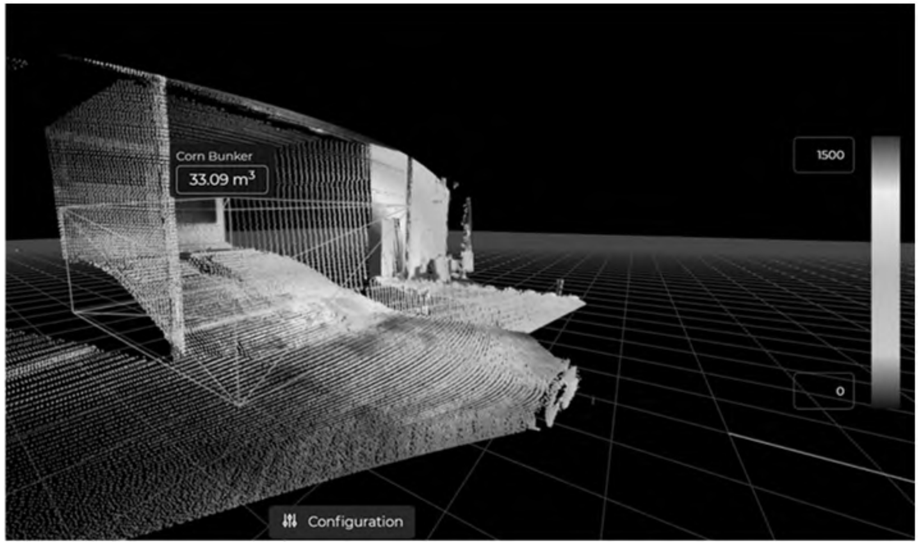
Symbol	Quantity	Units
P_r	Received power	W
P_s	Emitted power	W
T_A	Atmospheric transmission	-
η_t	Optical efficiency of the emitter	-
A_s	Beam spread area of the emitter at the target	m^2
Γ	Target cross-section	m^2
ρ	Reflectance of the target	-
r	Distance between LiDAR and the target	m
A_R	Optical aperture of the receiver	m^2
η_r	Optical efficiency of the receiver	-

No	Company	Model	Physical Size (cm^3)	Power Consumption (W)[1]	PPS (M/s)	Range (m)[2]
①1550 nm, FMCW/RMCW, 1D opto-mechanical scan						
1	**Baraja (RMCW)**	Spectrum HD	3500 --> 300[4]	20	2	250
2	**Insight (FMCW)**	Insight 1600	585	30	3.4	250
②905 nm, 1D or 2D opto-mechanical scan						
1	**Innoviz**	InnovizOne	485	17	2.9	120
2	**Innoviz**	InnovizTwo	550	20	10	200
3	**Cepton**	Vista X-90	784	12	1.0	200
4	**Valeo**	Scala 2	635	10	0.3	80
5	**Valeo**	Scala 3	1025	15	15	150
③Flash or scan with no moving parts						
1	**Continental**	HFL 110	840	25[3]	0.1	22
2	**Ibeo**	NEXT	950	8	0.8	140
④1550 nm, ToF, 2D opto-mechanical scan						
1	**Luminar**	Iris	1730[3]	25	9.0	250
2	**Continental**	HRL 131 (based on Aeye 4Sight LiDAR Platform)	4500 --> 1800[4]	28	Customer Dependent	330

Note 1: Steady state typical values, varies with operating temperature and use conditions
Note 2: At 10% Reflectivity
Note 3: Estimated
Note 4: Miniaturization with Tier 1 co-design(Baraja-Veoneer, Aeye-Continental)

This table compares the size and power consumption of LiDAR designs across range and performances (points/second) parameters.

LIDAR - Tips



(Image: Blickfeld)

Cost reduction => No spinning parts !

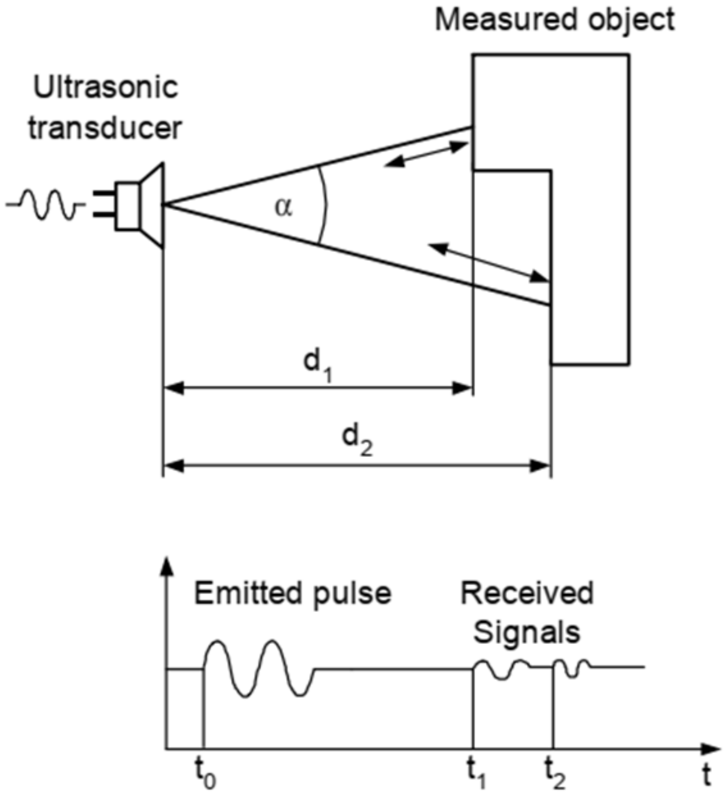
Smart lidar sensors necessitate advanced optical and electronic hardware components, along with capable software for analyzing the collected data in most cases.

Several techno are available : MEMs, Flash, FMCW,… anyway, it's belonged on a set of photodiodes array, lens, Asics,… in 2D (linear array of R-Tx pairs) and 3D types.

Field of View (FOV) ➔ ex : ~120-130° wide to ~10-30° vertical « opening » and 20 to 30 fps.

Tips on wave-length : 905nm laser are mature and SI receiver work, (costly) 1550nm laser offer better performances (range&precision) but require InGaAs receiver and are more sensible to weather conditions (rain).

Ultrasonic



Using of the above human ear capacities

→ 20k to 200kHz,

Belongs on 2 parts :

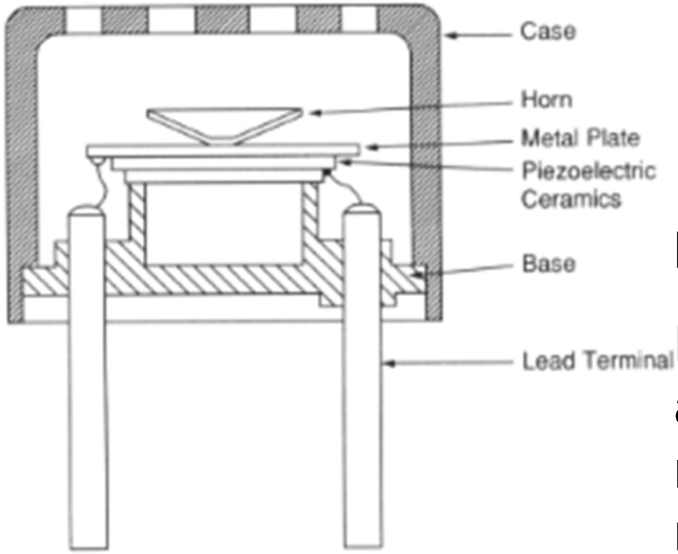
- Emitter
- Receptor

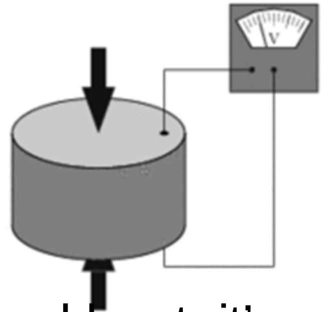
Distance evaluation is computed thanks to Time of Flight between transmitted pulses and scattered signal (2 continues transmission).

Big advantage of U.S : Low cost and good accuracy (for low range distance).

Drawback : Max range < 10m, environmental conditions sensibility

UltraSonic





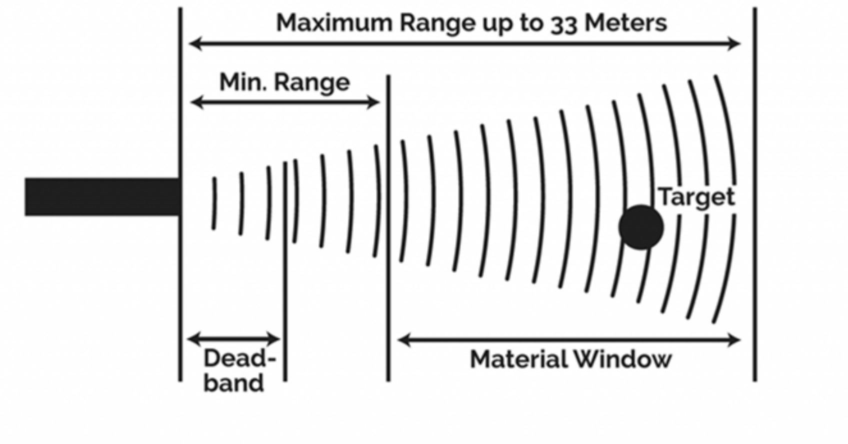
Piezo

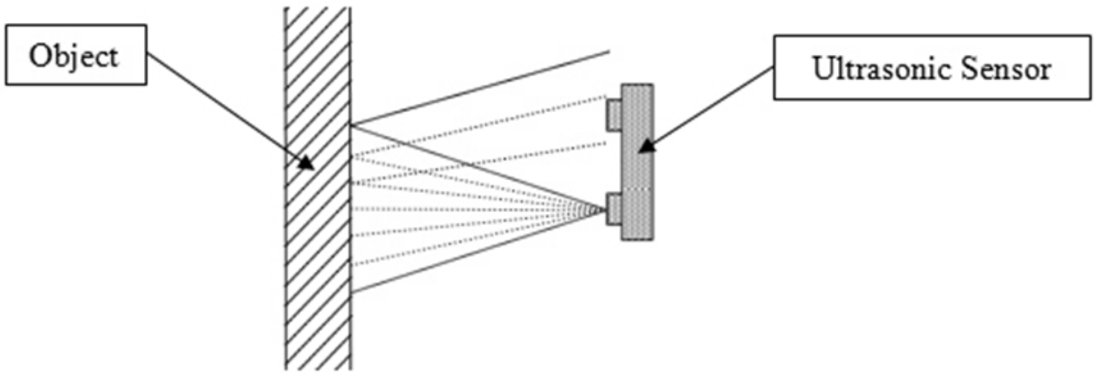
Means electricity resulting from pressure and heat, it’s an electromechanical interaction between the mechanical and the electrical state in crystalline material. Piezoelectric effect is a reversible process, if an electric filed is applied to one mechanical parts (among pair), the opposite part move as well.

Object Positioning

Sensor can not accurately measure the distance of an object that:

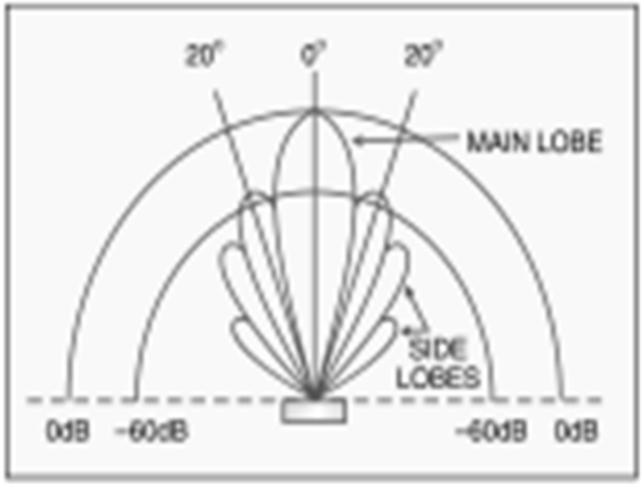
- ✓ is more than 3 to 4 meters away,
- ✓ that has reflective surface at shallow angle so the sound will not be reflected back to the sensor,
- ✓ is too small to reflect back to the sensor.

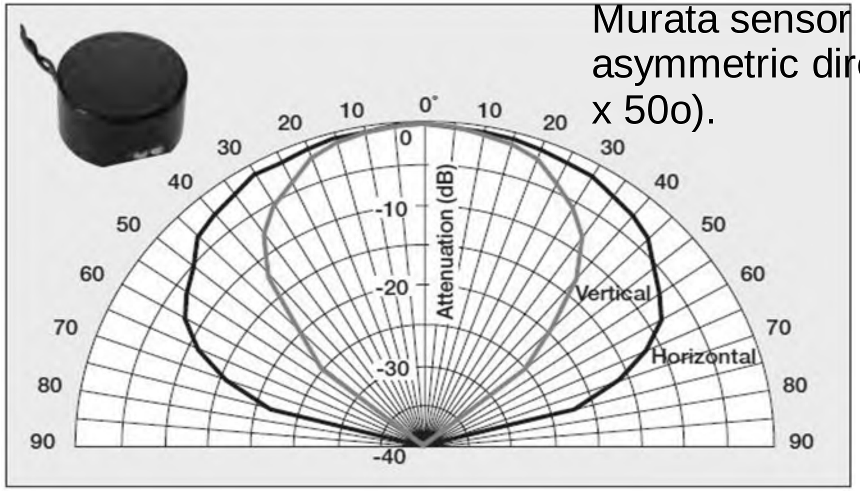




UltraSonic

Ultrasonic is above 20kHz, outside human audible frequency, it can be very produced with high directivity.



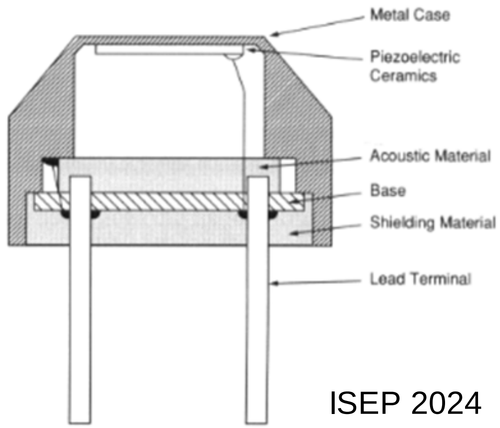


Murata sensor with asymmetric directivity (110o x 50o).

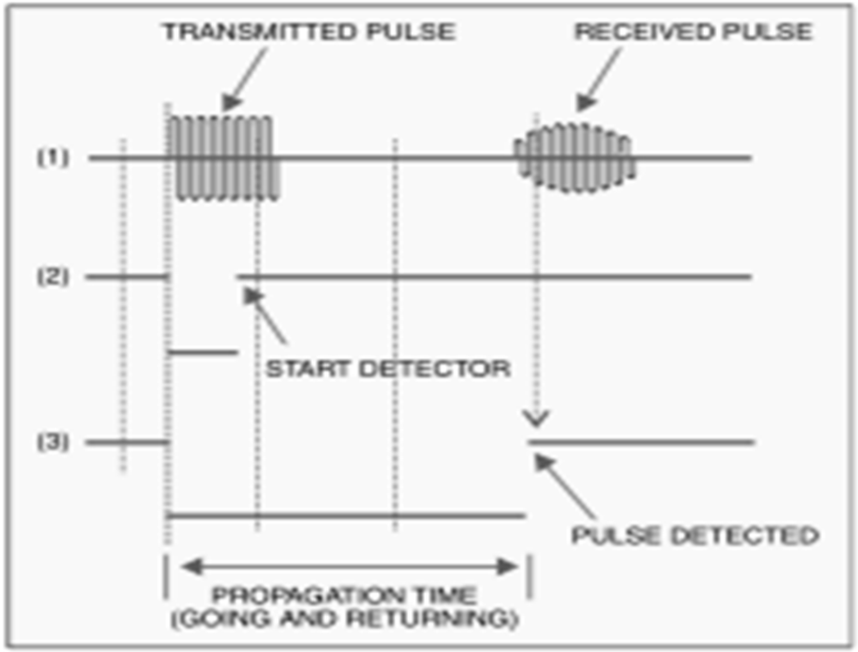
Ultrasound travels in the air at around 340m/s like other sounds. The time it takes for an ultrasound wave to travel 10cm is approximately 3ms, as opposed to 3.3ns for light and radio waves.

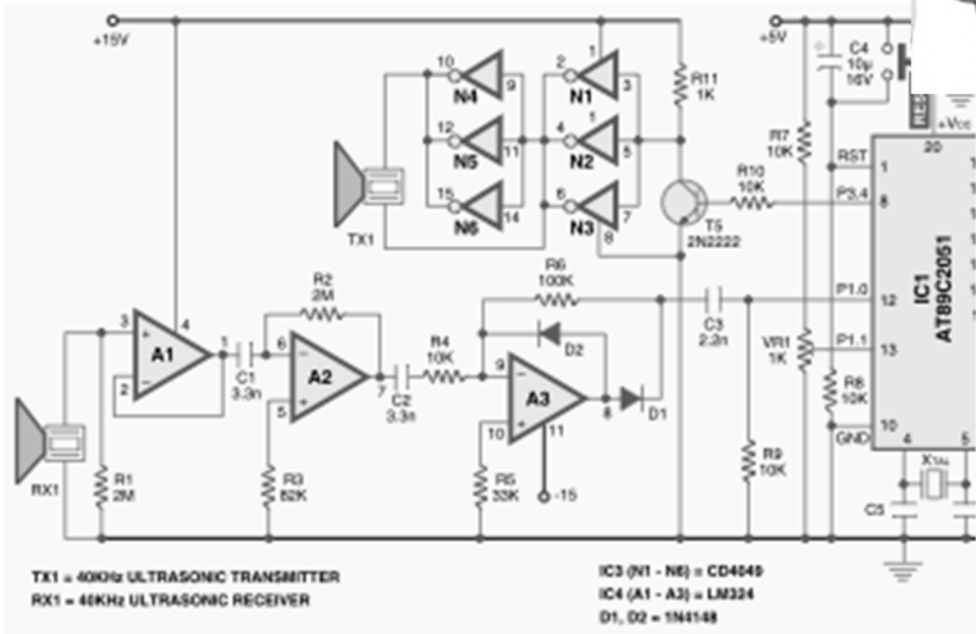
- ✓ This time travel enables low cost digital computation

Due to severe environment, U.S sensors have to be waterproof, this protection involves less sensibility compare to unprotected one. To compensate this drawback, designed have to increase driving voltage (up to 30-40v).

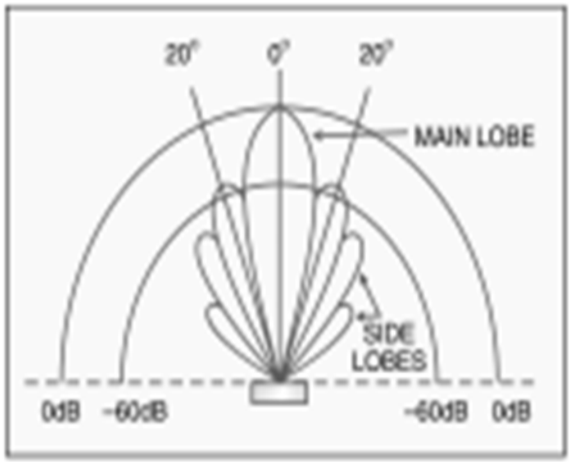


UltraSonic

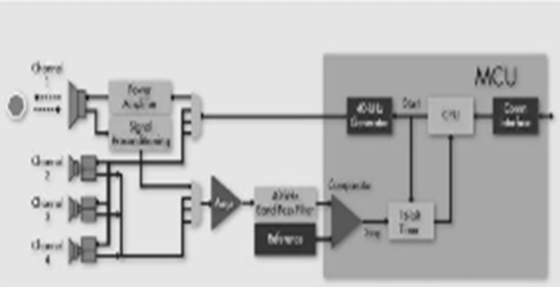




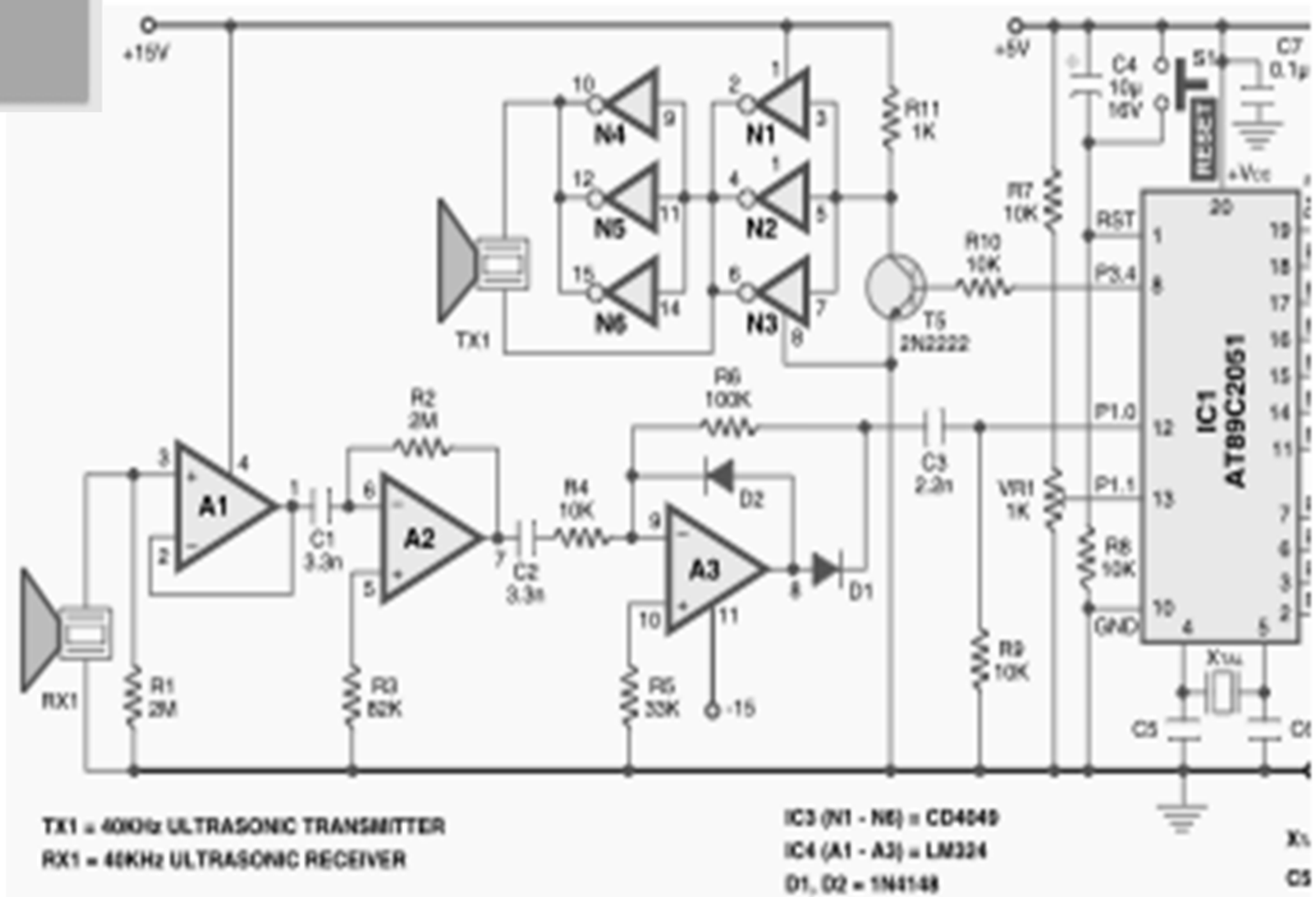
The pulses of burst (40kHz) generate with the microcontroller are amplified to drive the U.S actuator. Scattered signal is amplified as well and filtered to be computed by the microcontroller



U.S transmitter sent acoustic wave beam, most part of the energy is located in the main lobe. Secondary lobes impose a constraint to maintain a distance of few cm to avoid perturbations.



UltraSonic

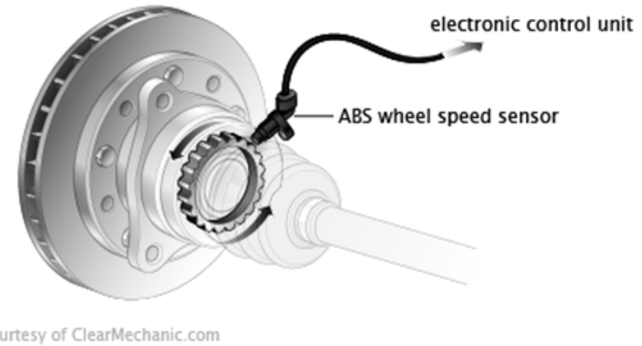


The microcontroller generates 40kz pulses, these bursts are amplified by T5. Inverting buffer drives the ultrasonic transmitter. N1, N2 and N3 inverters are connected in parallel to increase T5 output signal. N1, N2, N3 output is connected to a second set of 3 inverters (N4, N5 and N6). Outputs of both sets of parallel inverters are applied as a push- pull drive to the U.S transmitter.

The echo signal received by the receiver sensor after reflection need to be amplified. Amplification is done by quad operational amplifier LM324. The first stage (A1) is a buffer with unity gain, A1 output is a voltage mirror of input (A1 pin 3) and coupled to the second stage by a 3.3nF (small-value) capacitor. The second stage (inverting) uses a 2-mega-ohm resistor for feedback. The third stage is a precision rectifier amplifier with a gain of 10. The rectifier functions, unlike a simple diode, even for signal voltage of less than 0.6V.

The output is filtered to accept 40kHz frequencies and connected to pin 12 of microcontroller (AtoD input).

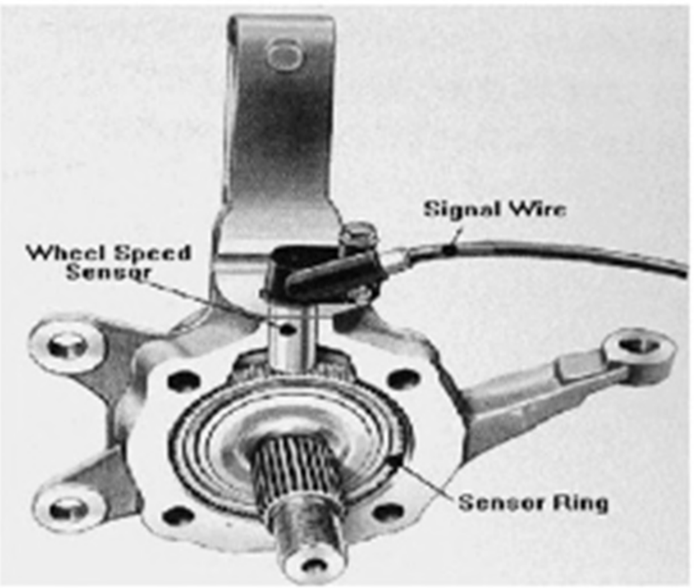
Vehicle speed

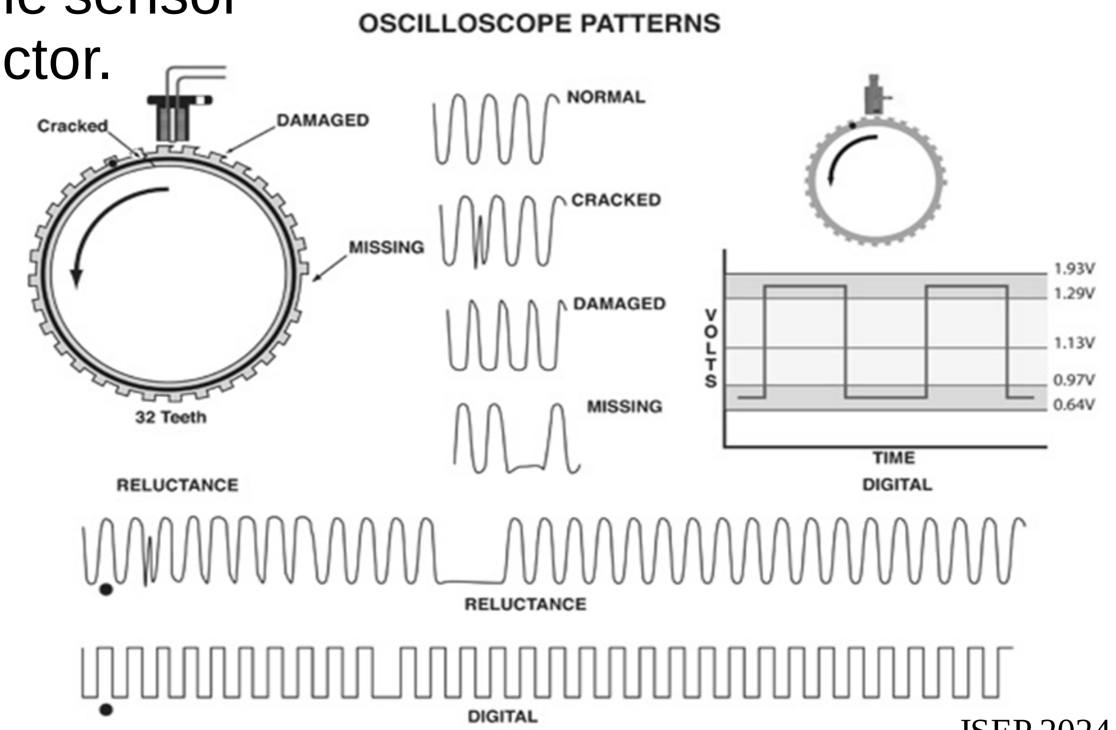


Both active and passive wheel speed sensors are used, output signals are square or sinus wave.

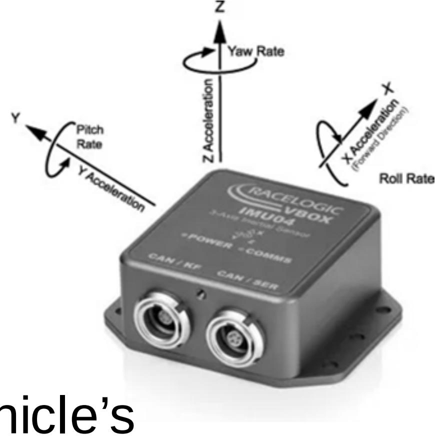
This sensors allow measurements below <1km/h and up to >300km/h, they are reliable and request few set of components.

This sensors suffer lot of stress (temperature, moisture, chocks, vibrations,...) on the sensor itself but also on harness and connector.





Inertial central unit



GPS can lead to a 1 to 10m error and requires a connection to a set of satellites. Target is to reduce this error to less than 10cm.

Inertial Measurement Unit (IMU) is a sensor capable of defining the vehicle's movements along the yaw, pitch, roll axes. This sensor calculates accelerations along X, Y, Z axes, orientation, inclination, and altitude (flying requirements).

At the heart of the IMU ADMA inertial plant

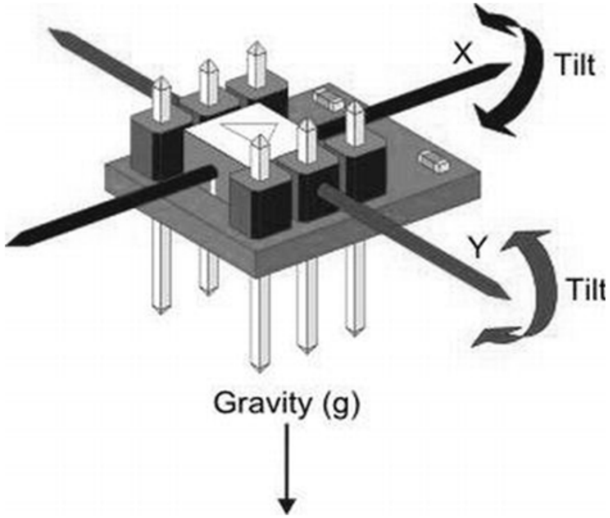
- 3 optical fiber gyroscopes for measuring rotational movements in space.
- 3 accelerometers for linear motion.

Precise absolute position determined by a GPS receiver coupled with data correction.

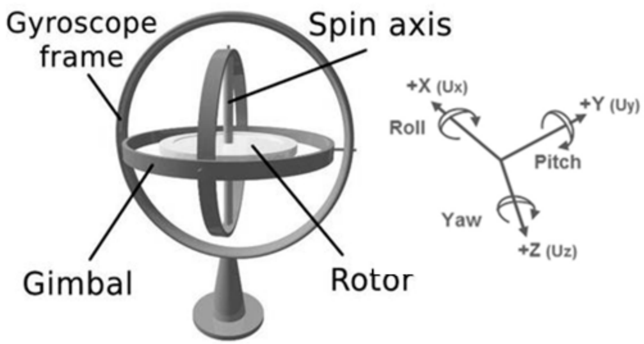
Fusion of GPS and IMU overreach intrinsic limitation of both. Combined with computation (Kalman filter,…), GPS & IMU fusion provide a precise localization, particularly in GPS-denied environments.

Inertial central unit

IMU is an electronic unit that collects angular velocity and linear acceleration data sent to the central processor in a single module. The IMU consists primarily of two separate sensors. One of these is the accelerometer, and the other is a gyroscope. The accelerometer generates three separate analog signals on three axes.



With a known starting location and precise acceleration measurements, the IMU provides information on current vehicle location and orientation.



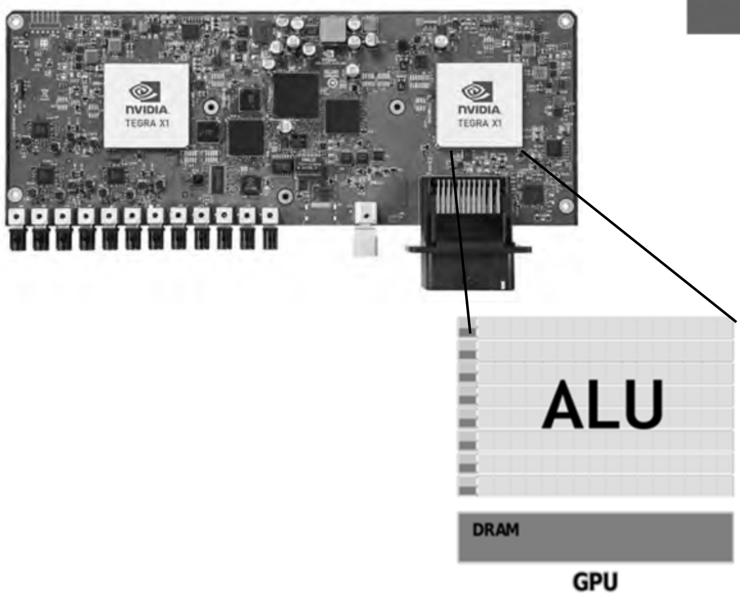
The second sensor inside the IMU is the gyroscope. It is formed by turning a wheel quickly around its axis. When a force is applied on the horizontal axis, a gyroscope rotating on the horizontal axis begins to rotate around the axis.

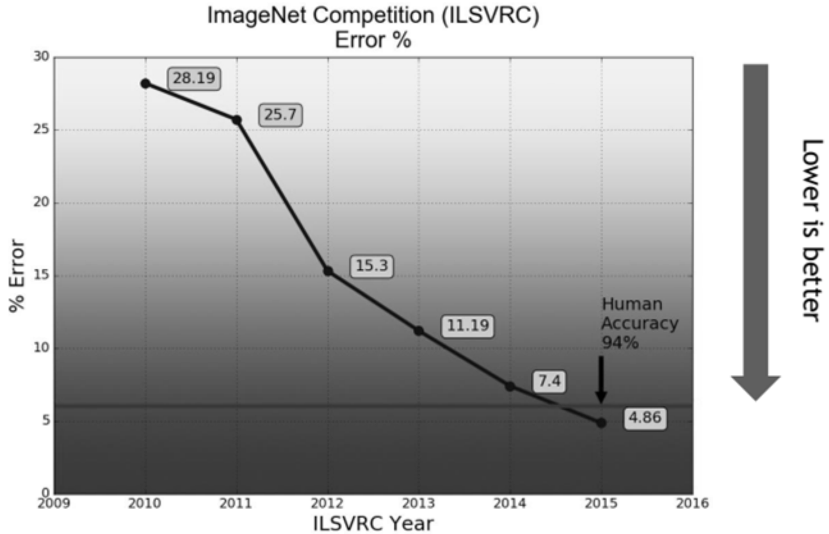
IMUs do not suffer from multi-path effects or signal degradation in urban canyons or forested roads.

Camera


sign
people
people
people

+

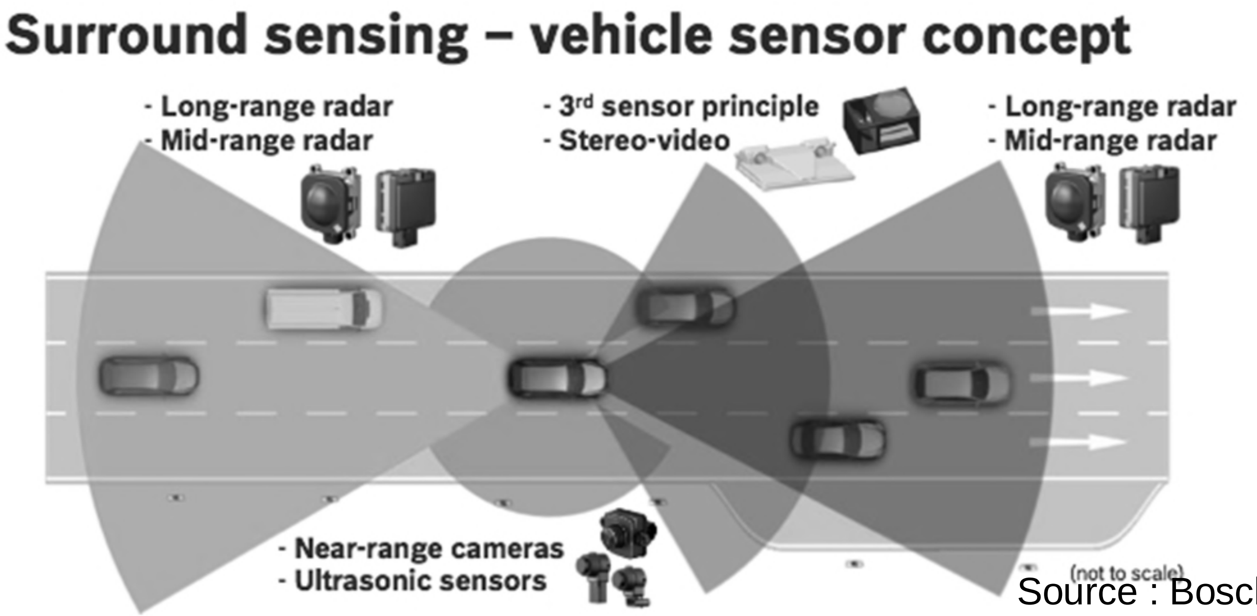

NVIDIA
TEGRA X1
NVIDIA
TEGRA X1
ALU
DRAM
GPU


ImageNet Competition (ILSVRC)
Error %
% Error
ILSVRC Year
28.19
25.7
15.3
11.19
7.4
4.86
Human
Accuracy
94%
Lower is better

Camera

Stereo Cameras give a 3D "vision" of the environment:

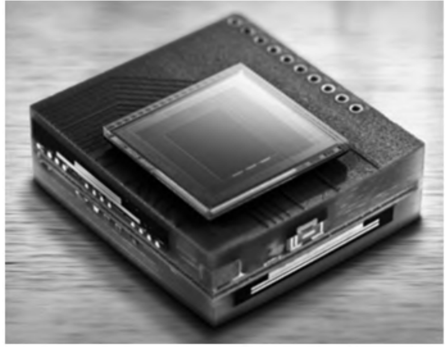
- ✓ Topography of the road (Declensions, Speed bumps, Parking blocks, road hole,…)
- ✓ Work of engineering and high targets (Bridges(Decks), Trees), Width of the road (narrow passage, parking lot),
- ✓ Characteristics of an object (Dimensions(Size), distance) Cars, Trucks, 2 wheels, Pedestrian...
- ✓ Railroad crossing, walls, animals...



Source : Bosch

The Stereo Camera is the only sensor that can provide 2D/3D information

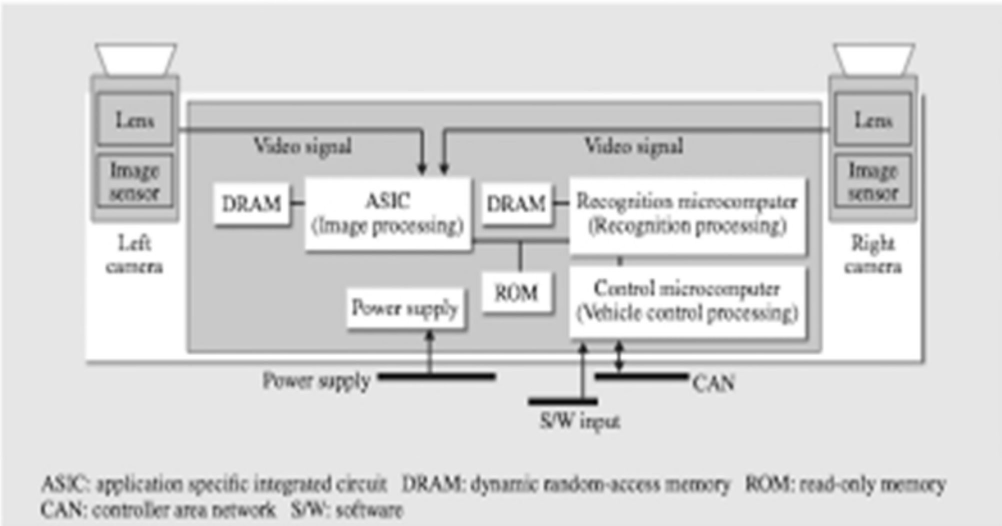
Camera



A stereo camera consists of separate left and right cameras. It can be used as an environmental recognition sensor capable of determining the position and three-dimensional shape of an object from the difference between the images of the object captured simultaneously by the two cameras

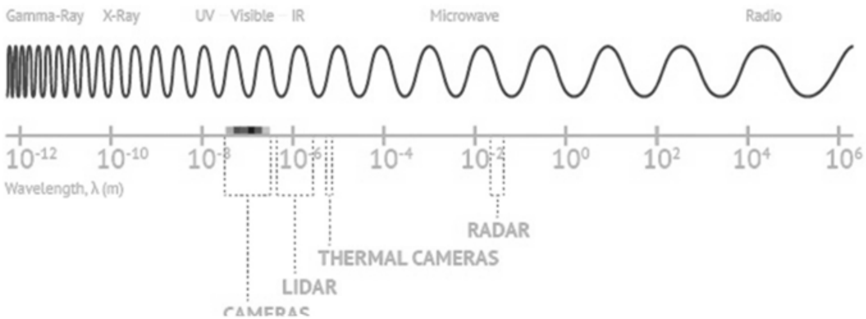
Design of Stereo Camera

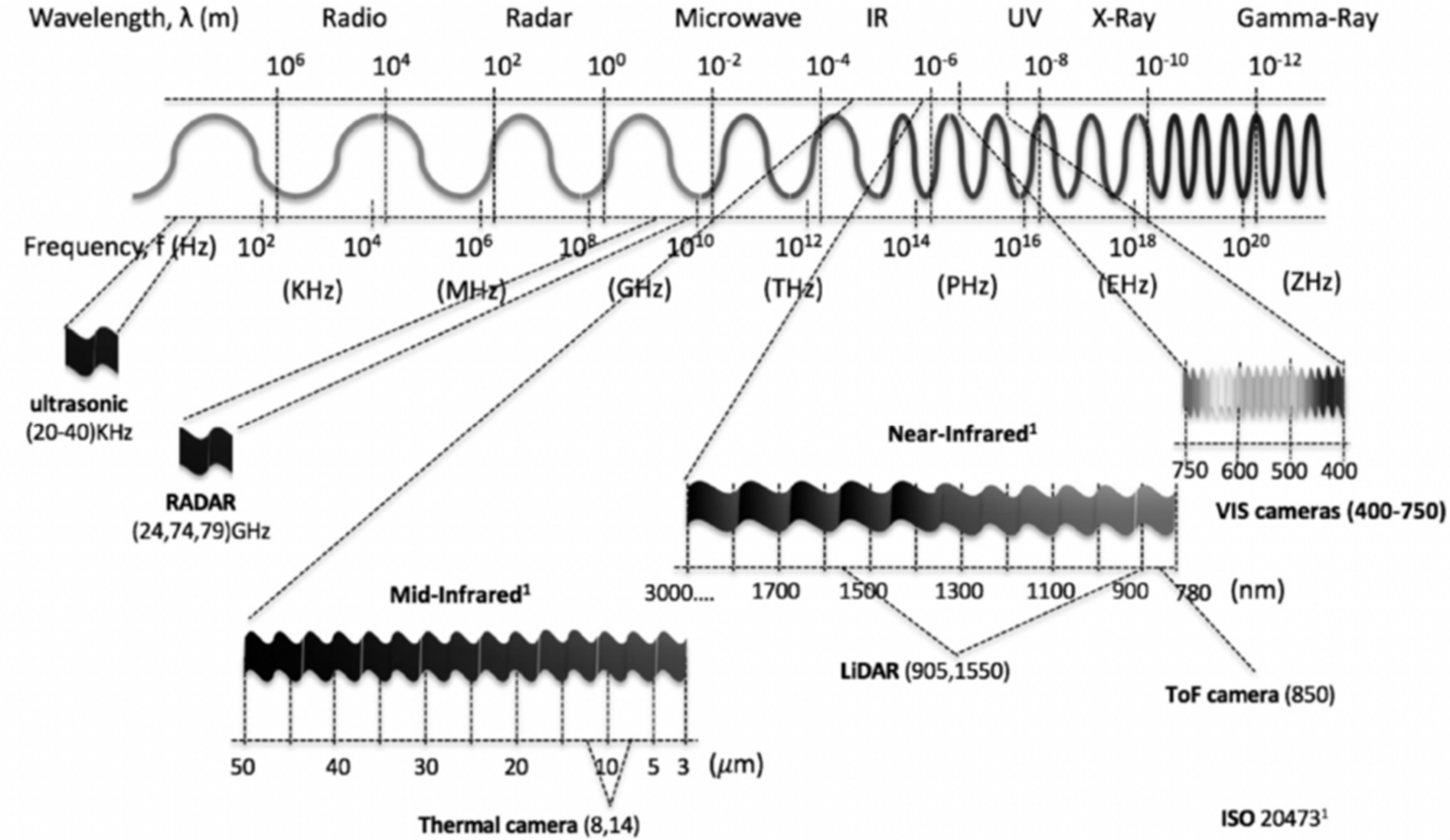
The images from the left and right cameras are input to an image processing application-specific integrated circuit (ASIC). The ASIC corrects distortion and peripheral darkening (lower light intensity around the edge of the lens) and then matches the two images to generate the disparity image. The recognition microcomputer then uses this information to detect obstacles such as other vehicles and pedestrians, identify white lines,...



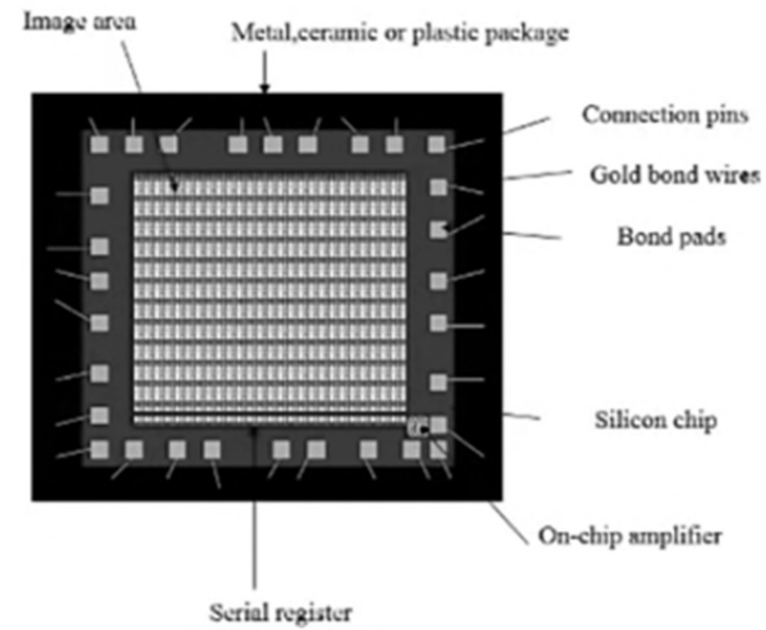
Block Diagram of Stereo Camera. This stereo camera jointly developed with Fuji Heavy Industries, Ltd. uses an ASIC to increase the speed of the disparity and other computationally intensive calculations.

Electromagnetic Spectrum



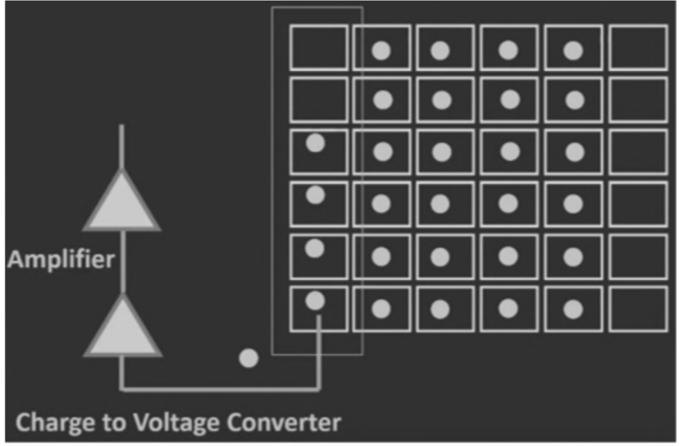


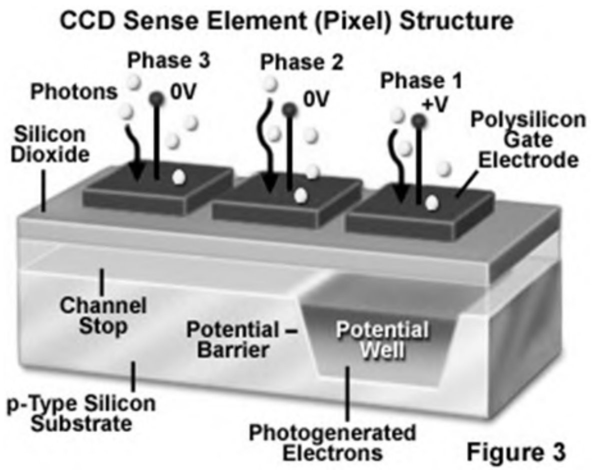
Camera

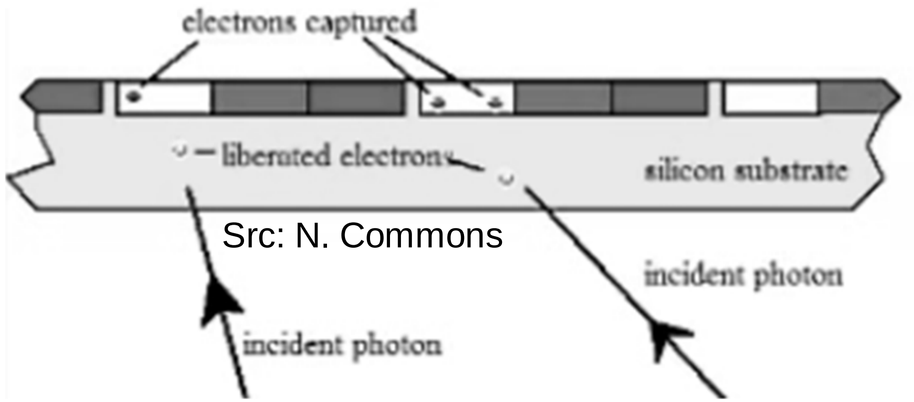


The image area of the CCD consists of numerous pixels. positioned at the focal plane of the camera.

The pixels convert light intensity to electrical charge which is stored in the pixel – Each pixel can be considered to behave as a capacitor.







Src: N. Commons

When a photon strikes the silicon, it displace an electron from the thin layer of silicon. The displaced electron is captured in the pixel. The more photons strike the silicon, the more electrons are captured.

Video compression

Nearby objects identification is one of the main pilar of autonomous vehicle, crucial features are outlined and separated from background scene… in real time to take a decision.

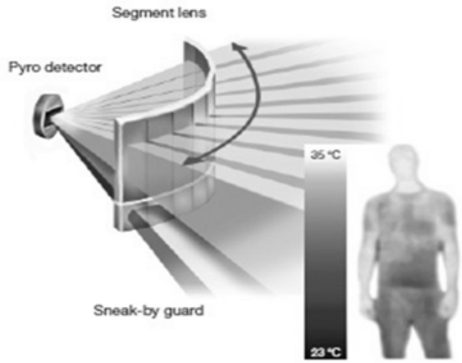
To decrease network traffic and data computation, cameras output flow is compressed. Compression algorithm belong on fact that each point in an image are not completely independent of the others.

Even if it’s better way to to take on the shelf an already known compression format, it essential to study strength and drawback because available algorithm was optimized to « cancel » information that are unnecessary for human eye.

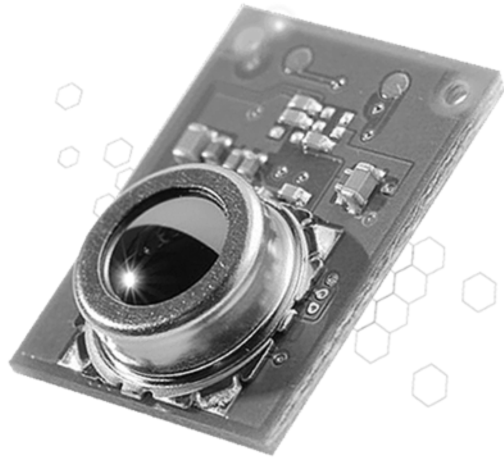
Compression basic principles :

- Spatial & Temporal redundancy,
- Quantization, inter/intra frame compression
- Entropy coding & Motion Compensation

Lossless video coding can vary from ~50 to 75%.



Infrared Detection



Passive System (PIR) :

The principle is to use emitted heat to « generate » an image, sensor doesn’t sent any radiation

Active system :

The active Infrared system detection send I.R waves, scattered signal are detected by the camera,

Max range : >200m

Camera

Camera Types

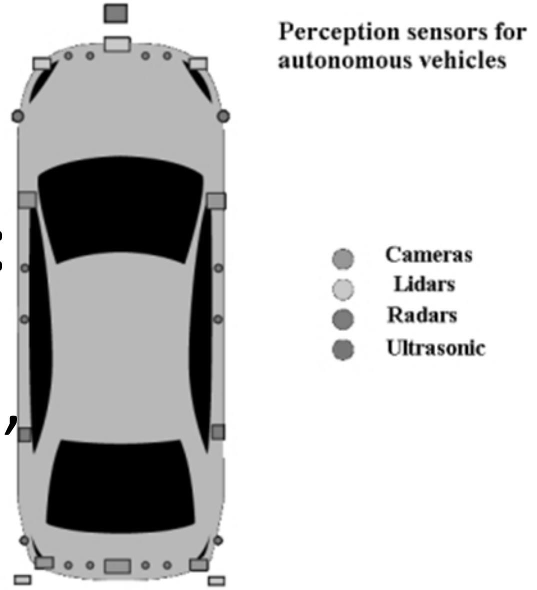
	Visible Ray	Near IR	Far IR
Principle	Ambiant reflected light	Use active IR source	Reflected target temperature
Day	++	+	+
Night	--	+	++
Bad weather	--	-	+

Due to weather and light condition (Night vs Day), Pedestrian detection range rate is between 70 to >90%.
Most of the pedestrian detection algorithms follow two major steps which are region of interest (ROI) generation and pedestrian classification. In some cases, a tracking and refinement step is also added to improve the detection rate.

Detection

Pedestrian detection is a complex challenge:

- Huge variability (Children, adults, short/high,...),
- Moving and chaotic target,

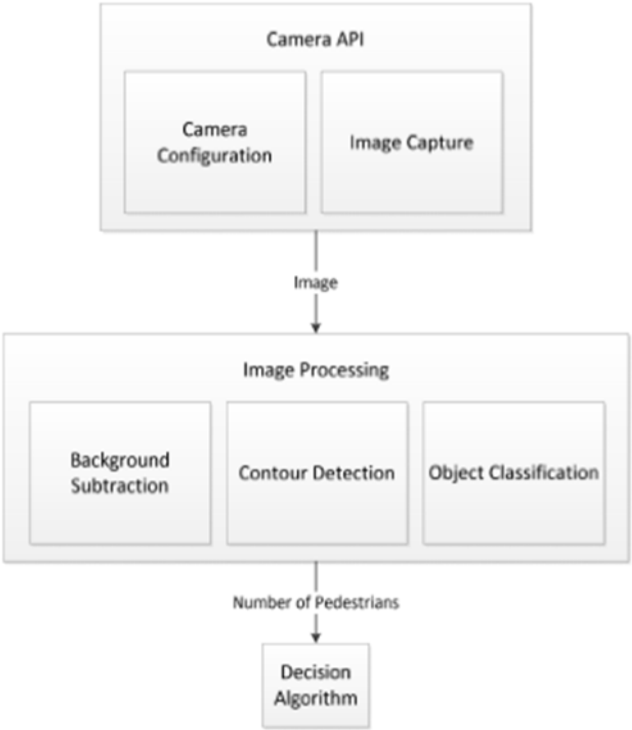


On the road conditions, it’s necessary to detect other vehicles, whatever weather conditions.

To insure exhaustive scan of the environment, it’s necessary to associate several detection technology.

Detection

Software architecture diagram



After detecting the objects, it is needed to classify them. The simplest and fastest way is to observe the objects dimensions. After detecting the contour and bounding (height &width) of the object, the CPU can estimate object class with a library/data base comparison.

2D detection information :

- ✓ Speed Limits. Stop Signs.
- ✓ General signs (triangular, rectangular).
- ✓ Vehicle lights / traffic lights.
- ✓ Object classification (machine learning).
- ✓ Lane markings.

Sensors Comparison

Actives sensors : Radar, Ultrasonic, Laser

Passives sensors: Infrared et video

	Range	Weather conditions sensibility	Computing needs (CPU / Asic)	Cost
Ultrasonic	< 10m			
Infrared	>200m			
Camera	20 to 60m			
Laser	>150m			
Radar	>150m			

Sensors Comparison

Technology	Range (day/ clear)	Range (night/ obscured)	Resolution /Detection	Eye-safe	Price
Radar	Long (200m+)	Excellent	Limited	Yes	$
Optical camera	Short -medium (<50m)	Poor	Good	Yes	$
LiDAR 905nm	Medium (<200m)	Good	Excellent	???	$$
LiDAR 1550nm	Long (200m+)	Good	Excellent	Yes	$$$

Range => ~200m : Best case

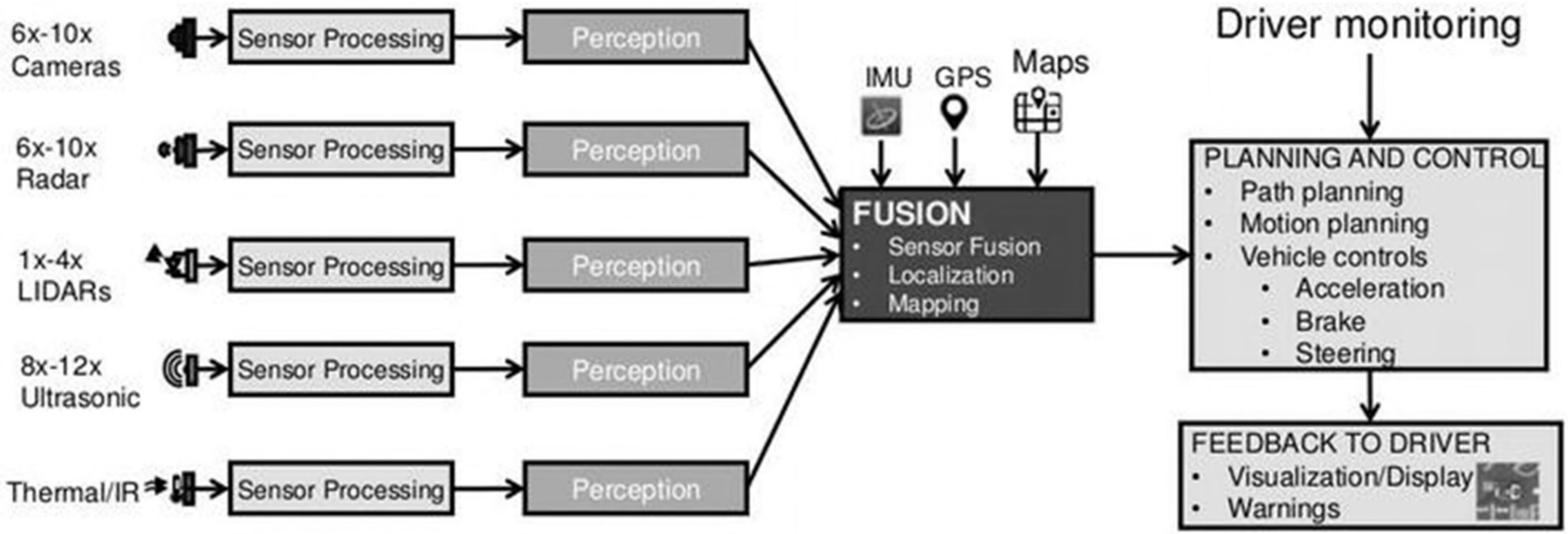
Sensor	Physical Size (cm^3)	Power Consumption (W)
Camera	25 - 200	3 - 5
Radar	100 - 500	5 - 15
LiDAR	300 - 1800	8 - 30

Table 1: Size and Power Consumption vs Performance for Selected Automotive LiDARs
Patience Consulting LLC

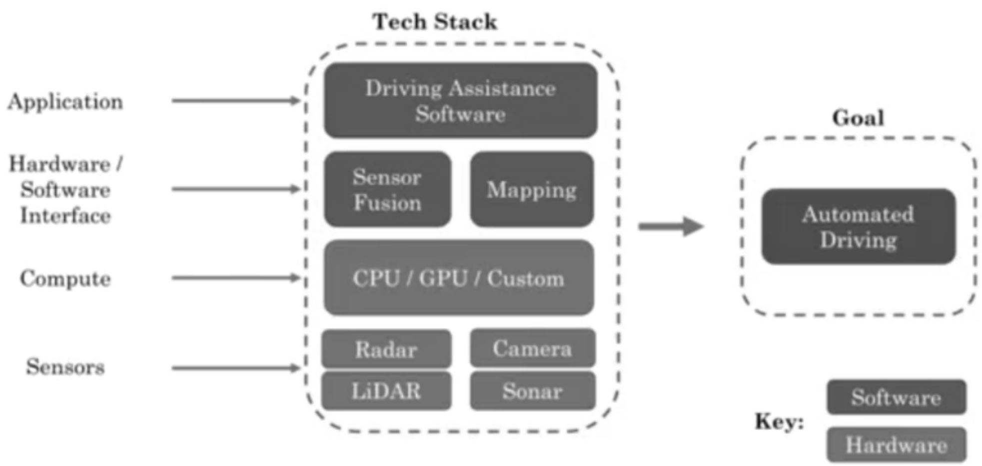
Sensor Type	Data per sensor
Radar	0.1 - 15 Mbit/s
Lidar	20-100 Mbit/s
Camera	500-3500 Mbit/s
Ultrasonic	<0.01 Mbit/s
Vehicle data	<0.1 Mbit/s

https://intellias.com/

Let's summarize



Automated Driving Stack



Sensor fusion is a key

Most likely used fusion solution in future — Good — Fair — Poor

	Camera	Radar	LiDAR	Ultrasonic	LiDAR+Radar+ Camera
Object detection	Fair	Good	Good	Good	Good
Object classification	Good	Poor	Fair	Poor	Good
Distance estimation	Fair	Good	Good	Good	Good
Object edge precision	Good	Poor	Good	Good	Good
Lane tracking	Good	Poor	Poor	Poor	Good
Range of visibility	Fair	Good	Fair	Poor	Good
Functionality in bad weather	Poor	Good	Fair	Good	Good
Functionality in poor lighting	Fair	Good	Good	Good	Good