4D imaging radar
Addressing the rising complexity and cost of automotive safety

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Contents

Executive summary

From enhancing safety and enabling electrification to achieving automation, the automotive industry is focused on creating the most intelligent vehicles as efficiently and cost-effectively as possible.

As things stand, automakers face three closely related core issues: compliance, complexity, and cost.

Rising safety standards traditionally require the deployment of additional single-function sensors based on technologies which are severely limited in terms of resolution, robustness, affordability, field of view and the ability to maintain privacy.

These additional sensors also increase vehicle complexity. As the modern car becomes crowded with technology, automotive OEMs must grapple with the development risk created by elaborate hardware structures as well as software architectures involving multiple development languages, operating systems and software designs.

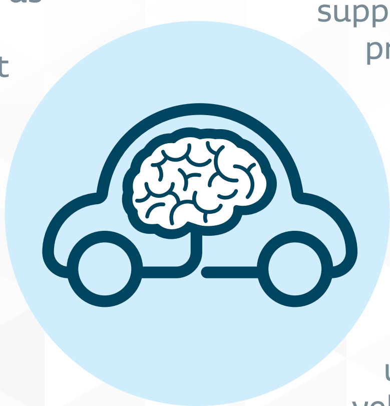
The situation is economically unsustainable. The cost of electronics is projected to rise from 35% to 50% of a vehicle's total cost over the next ten years. As OEMs strive to meet challenging in-cabin and ADAS safety requirements, ever-shrinking profit margins are making high-end safety unattainable for all but high-end models.

This white paper explains why the industry is therefore embracing a new model: multifunctionality on a single-chip platform. Powered by 4D imaging MIMO radar, it features multiple distinct aspects that are instrumental in reducing complexity and cost while enhancing safety.

Key takeaways:

- How this model aligns with the trajectory of automotive safety regulation.
- How the technology reduces complexity and saves automakers money.
- How multifunctionality on a single-chip platform makes high-end safety available for all vehicle models.
- How it lays the foundation for innovation for decades to come.

It also explores the vast range of in-car and ADAS applications the platform supports and features an in-depth primer on 4D imaging radar technology prepared by Vayyar CTO Naftali Chayat.



Above all, you'll discover how your organization can replace dozens of standard sensors with an affordable platform that provides a unified safety ecosystem for vehicles and road users alike.

The global safety challenge

Of all the demands facing the global automotive industry, from electrification to autonomy, safety is the most pressing.

Road Traffic Accidents (RTA) lead to 1.35 million fatalities and up to 50 million serious injuries every year. In fact, RTAs claim the lives of more children and young adults aged 5-29 years than any other cause. What's more, almost half of the survivors develop PTSD, while the total economic cost of RTAs is estimated at $1.8 trillion per annum.

Reducing the death toll, injury rate and overall impact on society is the driving force behind an industry-wide effort to improve safety for both vehicle occupants and other road users.

Going the extra mile to protect lives

Industry efforts to improve safety are driven by a combination of New Car Assessment Programs (NCAP) and regulatory bodies worldwide.

Euro NCAP leads the world in setting automotive safety standards.

Since 1997, the organization has safety tested around 2,000 cars.

Hundreds of thousands more have been saved around the world by legislation directly inspired by Euro NCAP's protocols.

The program's success is borne out by the numbers. Many cars with 5-star Euro NCAP ratings account for fewer than 10 reported road deaths annually[1]. As of 2017, the combination of EU legislation and the Euro NCAP rating system is estimated to have saved around 78,000 lives[2].

For automakers, the business benefits of a high Euro NCAP rating are immense. Safety is the top priority[3] for consumers buying cars, outranking fuel economy and cost, and all online buyer's guides put safety first on their lists of considerations. In fact, all ten of the world's best-selling car models have 5-star safety ratings.

1 https://www.businessinsider.com/20-safest-cars-fatalities-lowest-rates-driver-death-crash-test-2020-6#18-toyota-tundra-crew-max-4wd-3

2 https://etsc.eu/10th-annual-road-safety-performance-index-pin-report/

3 https://www.statista.com/chart/13075/most-important-factors-when-buying-a-car/

Highlights from the 2020–2025 Euro NCAP road map

Inside the cabin, current Euro NCAP requirements stipulate Seat Belt Reminders (SBR)[4] for two seating rows. The program also scores vehicles for mandatory airbag disabling in the front passenger seat and eCall to provide emergency services with vehicle status in the event of a crash.

The standards become even more rigorous with each new set of protocols. Child Presence Detection (CPD) will be scored by Euro NCAP from 2023 to eliminate the risk of hot car incidents and fatalities that have claimed the lives of thousands of infants. Meanwhile, emerging requirements will make two-row SBR a precondition for a new scoring category: Occupant Status (OS).

Outside the cabin, there's a growing emphasis on ADAS and Around-Vehicle Monitoring, with the noticeable addition of a next-generation active safety feature: Autonomous Emergency Braking (AEB). In 2023, the weighted scores will shift toward seven different types of AEB across the Car-to-Car (C2C) and Vulnerable Road Users (VRU) categories. Automatic Emergency Steering (AES) will also be assessed for its ability to protect pedestrians and cyclists and to prevent head-on collisions and C2C rear impacts.

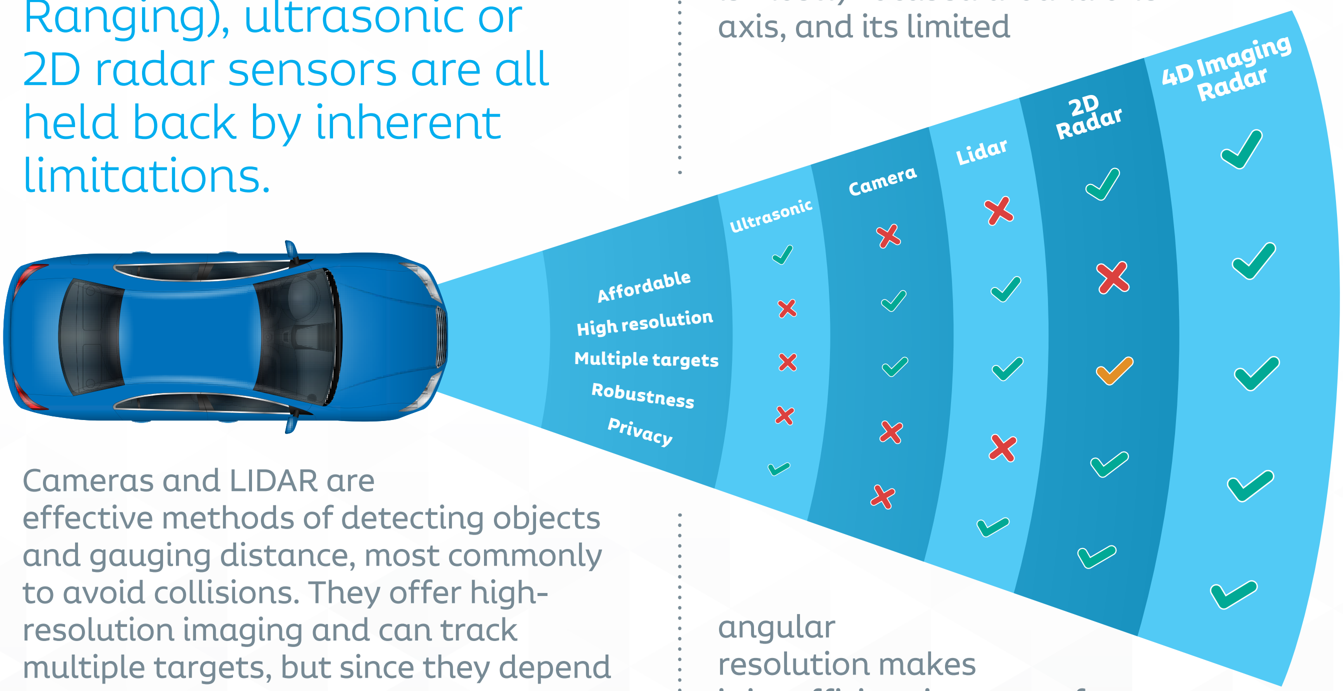
Meeting ever-increasing Euro NCAP standards and satisfying the regulations closely based on them is operationally demanding, technically complex and hugely expensive for automakers.

They therefore need to identify the most efficient, reliable and cost-effective sensor technologies available, considering the relative strengths and weaknesses of the various options on the market.

4 https://etsc.eu/seatbelt-reminders-in-every-seating-position-from-september/

Sensor technologies: A comparison

Over the years, various automotive sensor technologies have emerged to address a range of functions. However, mainstream solutions based on cameras, LIDAR (Light Detection and Ranging), ultrasonic or 2D radar sensors are all held back by inherent limitations.



Cameras and LIDAR are effective methods of detecting objects and gauging distance, most commonly to avoid collisions. They offer high-resolution imaging and can track multiple targets, but since they depend on optics, they are limited by their inability to see through solid objects and can be hindered by adverse weather or lighting conditions. For example, dirt or mud on a lens can severely impact their functionality. They are intrusive of privacy and notoriously expensive[5], putting them at risk of being superseded by more economical technologies.

Ultrasonic sensors are a relatively low-tech, non-robust solution that cannot support imaging or track targets.

2D radar, on the other hand, detects presence, direction, distance and speed and represents a robust, scalable solution that protects privacy. However, since it is based on only a few transmitting antennas and a few receiving antennas, its restricted beam provides only limited coverage over a short range, very low resolution and a narrow field of view, and is unable to generate images. Its limited field of view is mostly focused around one axis, and its limited angular resolution makes it insufficient in terms of differentiating between close targets.

With fatalities from RTAs almost equally divided between vehicle occupants and VRUs, manufacturers must select sensors that will enable them to meet evolving safety requirements designed to protect every life on the road. Only one sensor technology incorporates all the benefits of alternatives and leaves behind the drawbacks.

5 http://www2.cio.com.au/article/658542/self-driving-car-development-stalled-by-chaotic-market-sensor-technology/

Why 4D imaging radar ticks all the boxes

4D imaging radar is the next generation of radar technology that equips vehicles with the necessary instincts required to make lifesaving split-second decisions, while substantially reducing direct and indirect costs to OEMs and Tier 1s.

The technology detects and tracks people and objects in real time, inside and outside a vehicle. Unlike traditional radar solutions, 4D imaging radar leverages a Multiple Input Multiple Output (MIMO) antenna array for high-resolution sensing of its surroundings. It generates 3D imaging that can track multiple targets. The technology combines the 4th dimension, speed, with Doppler analysis of wave distortion caused by movement to create the additional dimension - velocity - enabling it to track movement.

A 4D imaging MIMO radar system measures the time of flight from each transmitting (Tx) antenna to a target and back to each receiving (Rx) antenna, processing data from the numerous ellipsoids formed. The point at which the ellipsoids intersect – known as a hot spot - reveals the exact position of the target at any given moment.

The technology's three core strengths can be summed up as follows:

Resolution

A large antenna array enables accurate detection and tracking of multiple static and/or dynamic targets simultaneously. Inside the cabin, this technology detects occupants, classifies children and adults, monitors vital signs and detects posture and position. Outside, it detects and tracks other vehicles, obstacles and VRUs.

Robustness

There are no optics involved, so this technology is robust in all lighting and weather conditions. 4D imaging radar does not require line of sight with targets to reliably monitor them, such as inside the cabin. It can also detect targets behind walls and other objects, enabling visibility around street corners. This gives the technology a critical advantage in terms of ADAS and around-vehicle safety applications such as collision avoidance at intersections, valet parking in underground lots and intruder detection in dark alleyways.

Privacy

4D imaging radar also maintains privacy at all times, an increasingly important concern across the automotive industry, especially for vehicles such as taxis or public transportation, where vehicle occupants constantly change. Leading automakers are committed to the Automotive Consumer Privacy Principles[6], making in-cabin cameras a sub-optimal option.

These attributes make 4D imaging radar the ideal technology for enhancing automotive safety by providing vehicles with a heightened sense of awareness and by better protecting vehicle occupants.

An in-depth explanation of this technology can be found in ***Appendix B.***

6 https://autoalliance.org/connected-cars/automotive-privacy/#:~:text=Under%20the%20automotive%20Privacy%20Principles,-committed%20to%20protecting%20this%20data.

4D imaging radar: Reimagining in-cabin sensing

The need for smarter in-cabin sensing, based on reliable technologies like 4D imaging radar, is clear. Thousands of children worldwide have died from vehicular heatstroke after being left behind by their parents or caregivers.

As part of a global drive to prevent hot car incidents, Child Presence Detection (CPD) will be scored by Euro NCAP from 2023[7]. Legislative bodies worldwide are also developing regulation to prevent these tragedies.

To the majority of motorists, in-cabin safety also means seat belts and airbags. Seat belts are estimated to have saved almost 330,000 lives between 1960 and 2012[8], and airbags are said to have saved 50,547 lives[9] from 1987 to 2017.

However, drivers who sit closer to the steering wheel are at greater risk of suffering airbag impact injuries because airbag deployment traditionally does not account for size or posture. For the same reason, 90% of airbag-related fatalities between 1990 and 2008 were children, testament to the fact that differentiating occupants according to dimensions is vital when it comes to protecting life in the cabin. Many internal injuries can also be directly attributed to "seat belt syndrome[10]," indicating that the mission of protecting life within the cabin still has a long way to go.

Apart from incremental improvements such as depowered airbags, the space has remained largely unchanged for decades. Current weight-based seat belt sensors often trigger false alarms because they cannot distinguish between humans and heavy objects, while automatic airbag disabling is also weight-based and notoriously unreliable. Motorists and their passengers deserve a higher standard of safety, which can be achieved with better occupant data that accounts for size and posture.

7 https://europe.autonews.com/automakers/child-detection-safety-technology-may-get-mandate

8 https://www.nhtsa.gov/seat-belts/seat-belts-save-lives#:~:text=A%20NHTSA%20study%20of%20lives,assemblies%2C%20and%20electronic%20stability%20control

9 https://www.nhtsa.gov/equipment/air-bags#:~:text=From%201987%20to%202017%2C%20frontal,your%20first%20line%20of%20defense

10 https://www.sciencedirect.com/science/article/pii/S2210261216000262

Current CPD is mostly confined to indirect sensing systems[11], which are prone to false positives and, even worse, false negatives. Like legacy SBR systems, low-end CPD solutions are not supported by reliable, real-time occupant data. Some cover only the second row of the vehicle and increase the risk of drivers ignoring alerts in the event of an emergency, after experiencing previous false alarms. These low-end solutions earn automakers just 0.5-1.5 out of a possible 4 points in this Euro NCAP category.

Delivering an enhanced level of CPD and passenger safety has led to a reassessment of the in-car ecosystem. Instead of considering seat belts, airbags and other features as separate components, automakers are now seeing them as elements of a centralized safety setup, with CPD front and center.

The next generation of in-cabin sensing supports a wide range of additional applications central to a safer in-car environment, including:

Child Presence Detection (CPD)

Direct sensing-based detection of a child left alone anywhere in the cabin, using precise classification facilitated by real-time occupant data.

Enhanced Seat Belt Reminders (SBR)

Differentiation between occupants sitting close to each other, with no false positives triggered by heavy bags or Child Restraint Systems (CRS).

Optimized airbag deployment and dynamic disabling

Identifying the position, dimension and posture of each occupant and adjusting the level of inflation accordingly. Injuries caused by a front-seat passenger having their feet up on the dashboard[12] can also be avoided by Out-of-Position (OOP) detection capability.

Pre-tensioner optimization

Using precise location and dimension data to reduce forward force in the event of a collision. Minimizing the amount of pressure on the occupant's chest through enhanced load limiter functioning.

eCall support

Alerting emergency services after an accident, providing data about number of occupants, classification, respiration and movement.

Intruder detection

A low-power consumption solution that senses the movement of potentially hostile actors around the perimeter of the vehicle.

But the in-cabin environment is only one aspect of the holistic safety picture. Protecting pedestrians and cyclists, as well as avoiding collisions with other vehicles, is critical to the industry's mission, and it's another area where 4D imaging radar is leading the way.

11 https://www.consumerreports.org/car-safety/auto-industry-agrees-to-put-rear-seat-reminder-systems-in-most-new-cars-by-2025/

12 https://www.autoblog.com/2020/01/27/x-ray-injuries-feet-on-car-dashboard/?guccounter=1#:~:text=If%20you%20ride%20with%20your,So%3A%20Seatbelt%20on.&text=of%20their%20car.,Airbags%20deploy%20between%20100%20%26%20220%20MPH.,knees%20through%20your%20eye%20sockets.

ADAS and ARAS: Enhancing safety from every angle

Advanced Driver Assistance Systems (ADAS) are at the forefront of automotive development, but their predecessors — cruise control and anti-lock braking (ABS) — have been around for decades.

These applications, along with others like Blind Spot Detection (BSD), Lane Change Assist (LCA), traction control and Electronic Stability Program (ESP), all share the same goal: improving road safety by minimizing or eliminating human error. And they've proved their worth over the years. Cars equipped with ESP are 25% less likely[13] to be involved in a fatal crash than those without the technology.

Currently, ADAS is widely seen as a stepping-stone to fully autonomous vehicles. However, ADAS solutions alone are predicted[14] to prevent 40 percent of all passenger-vehicle crashes, 37 percent of injuries that occur in passenger-vehicle crashes and 29 percent of deaths in crashes that involve passenger vehicles.

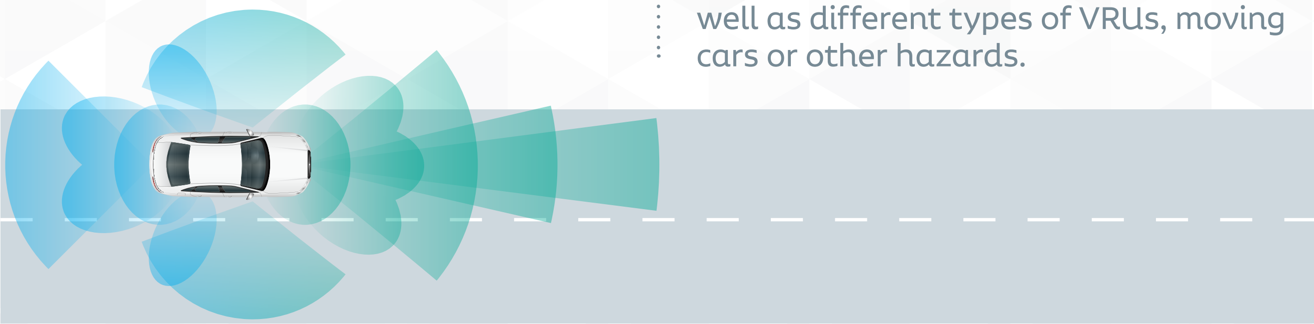
ADAS applications based on 4D imaging radar currently fall into four categories:

- uSRR (Ultra Short-Range Radar) for parking lots
- SRR (Short-Range Radar) for parking lots and low-speed city driving
- MRR (Mid-Range Radar) for higher speed city driving
- LRR (Long-Range Radar) for highway and freeway driving

To provide the required performance across all these scenarios, ADAS sensors must cover a very wide field of view, both horizontally and vertically. The elevation component is vital for depth perception, as well as for the vehicle's ability to detect height obstacles and overhead signage.

Another requirement is high resolution: the ability to detect VRUs as they approach the vehicle, especially in urban neighborhoods and crowded parking lots where pedestrians suddenly emerge from between vehicles and scooters lurk in the vehicle's blind spots.

Beyond accurate detection, optimal ADAS functionality requires the sensor to differentiate static obstacles such as dividers, curbs and parked vehicles as well as different types of VRUs, moving cars or other hazards.



13 https://ec.europa.eu/transport/road_safety/specialist/knowledge/esave/esafety_measures_known_safety_effects/electronic_stability_control_en

14 https://aaafoundation.org/potential-reduction-in-crashes-injuries-and-deaths-from-large-scale-deployment-of-advanced-driver-assistance-systems/

Standard 2D radar is inadequate for these complicated scenarios which require high angular resolution. More advanced LIDAR sensors are capable of addressing resolution requirements, but their limitations in darkness and adverse weather conditions severely impact their overall robustness. What's more, they aren't always scalable due to their high price point, making LIDAR-based safety unrealistic for economy vehicle models.

4D imaging radar supports uSRR, SRR, MRR and LRR applications. It helps drivers both at low speeds – providing advanced parking assistance, for example – and at high speeds with Blind Spot Detection (BSD), Automatic Emergency Braking (AEB), Forward and Rear Collision Warnings (FCW & RCW) and Forward and Rear Cross-traffic Alerts (FCTA & RCTA).

The technology is also ideally suited to two-wheel vehicles, good news for motorcyclists who represent a uniquely high-risk group of road users. According to the NHTSA, motorcycles are five times more likely than cars to be involved in a fatal accident. To protect motorcyclists, Advanced Rider Assistance Systems (ARAS) are focused on three core categories:

Frontal collision warning

When there is a clear risk of an imminent collision, this application is designed both to detect the obstacle and to assess the potential severity of the impact. It calculates the required safe distance and path in order to provide an instant warning that enables deceleration and evasive action.

Intersection support

To protect motorcyclists from side-impact collisions at junctions and to safeguard pedestrians at crosswalks, lateral-facing sensors operate in conjunction with a frontal sensor to detect targets which could come into contact with the motorcycle. These sensors also facilitate Cross Traffic Alerts (CTA) and cover accident blackspots such as narrow sections of road and tunnel entrances.

Lane change support

Lane changes are among the most dangerous maneuvers for any vehicle due to blind spots. To enable safer lane changes, a rear-facing sensor tracks the speed and position of any other vehicles in proximity to the motorcycle to assess the risk and alert the rider.

All the functions described above are fully supported by 4D imaging radar, thanks to its high resolution and wide FoV, eliminating the need for ADAS and ARAS engineers to rely on expensive technologies and complicated infrastructures.

Saving as many lives as possible means equipping the maximum number of vehicles with reliable sensors. However, the legacy industry approach of simply fitting additional sensors to support each new application is impractical, uneconomical and unsustainable.

The cost of compliance and complexity

The average car is currently laden with over 100 single-function sensors and ECUs that support safety features, a figure expected to double by 2030.

This is fueled in part by the exponential rise[15] in the use of scooters and other two-wheelers, which increases the risk of collisions between cars and VRUs and creates the need for new safety protocols.

Within 10 years, electronics will make up 50% of vehicle cost, up from around 30% currently[16]. As a result, profit margins for OEMs and Tier 1s are expected to drop by half[17], making it uneconomical to provide budget models with anything beyond a baseline standard of safety.

Compliance

The total cost of meeting rising safety standards already accounts for up to 20% of a vehicle's value, factoring in the price of each designated sensor, along with the associated wiring, ECUs and power consumption.

Automakers, most of which now operate according to global-vehicle strategies, must also consider the cost incurred from divergence in safety regulations, calculated[18] at over $4 billion for all vehicles sold in both the US and the EU.

Complexity

A larger number of interrelated systems also increases design complexity. And like any machine, more moving parts means greater potential for malfunction. The growing intricacy of the modern car's electronic ecosystem increases the risk of launch delays, unexpected costs and even failure to meet the specs.

Start of Production (SOP) programs are a particular area of concern. Creating and overseeing new-integration SOPs is enormously time-consuming and expensive. And when multiple vendors are involved in complex integrations, the chance of crossed wires – both literal and figurative – grows exponentially.

The traditional paradigm of "one sensor per application" exacerbates these problems and is no longer sustainable, causing automakers to seek out fresh strategies to ensure compliance while cutting complexity and reducing costs.

15 https://www.bloomberg.com/news/articles/2020-08-27/how-big-was-2019-s-scooter-boom-and-what-s-next#:~:text=Scooter%20ridership%20increased%20from%2038.5,36.5%20million%20to%2040%20million

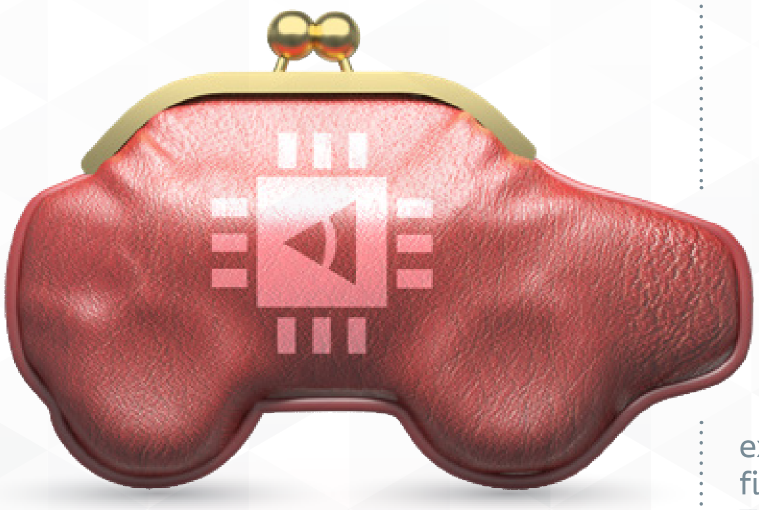
16 https://www.statista.com/statistics/277931/automotive-electronics-cost-as-a-share-of-total-car-cost-worldwide/

17 https://www.automotivemanufacturingsolutions.com/suppliers/tearing-profits-apart-how-tier-1-automotive-suppliers-can-mitigate-shrinking-margins/39815.article

18 https://www.cargroup.org/wp-content/uploads/2017/02/Potential-Cost-Savings-and-Additional-Benefits-of-Convergence-of-Safety-Regulations-between-the-United-States-and-the-European-Union.pdf

A new approach

There is a growing number of 4D imaging radar solutions on the market, all promising high performance and reliability. Many 3D/4D imaging radar solutions require chip concatenation, which demands additional hardware, a heavy external processor and a large form factor, offering a limited field of view, and carrying a hefty price tag. One supplier, Vayyar, offers another crucial benefit: the ability to do far more with just one RFIC and less complexity at a much lower cost.



The platform offers a number of key advantages for OEMs and Tier 1 suppliers, including:

Cost-efficiency:
Vayyar's 4D imaging Radar-on-Chip costs around the same as a 2D radar sensor solution, but with immense added value: richer data, higher accuracy and more functionality, while offering an optimal price-performance balance, lowering overall development costs, reducing associated risks and shortening TTM.

Scalability:
Vayyar enables automakers to rapidly develop and deploy new applications over point cloud to meet new safety requirements, without the need for additional SOP programs.

Highly integrated technology:
With a DSP and MCU on board, all software is embedded on-chip, and processing and computing are performed at the edge, including execution of advanced radar algo. This allows automakers to focus more on image processing and machine learning, and less on low-level radar algo development.

Beyond these benefits, Vayyar offers a truly unique capability. It is the world's only provider of multifunctionality on a single-chip platform. One sensor simultaneously supports numerous applications, made possible by exceptional resolution and an ultra-wide field of view over rich point cloud imaging. The platform dramatically reduces the overall number of sensors and associated SOP programs, cutting direct and indirect costs while supporting a wide range of cutting-edge safety features.

Vayyar: Industry-first multifunctionality on a single-chip platform

Vayyar's 4D imaging Radar-on-Chip (RoC) is the only full-stack software-hardware solution that delivers multifunctionality on a single-chip platform both in and out of the cabin, reliably addressing many of the industry's most stringent emerging standards.

Vayyar offers an affordable and comprehensive answer to the challenges of compliance, reliability, complexity and cost. The global leader in 4D imaging radar is the only supplier to offer multifunctionality on a single-chip platform that detects, computes, processes, tracks and images multiple targets in real time, both in and out of the cabin.

The platform model is a central aspect of multifunctionality, which incorporates advanced software as well as leading-edge hardware. In addition to reducing the amount of hardware, Vayyar's approach allows automakers to tackle numerous software challenges ranging from increased complexity to reduced flexibility with a mature, full-stack solution that addresses all aspects of the development and integration processes. With new electrical/electronic (E/E) architectures allowing OEMs to streamline the software aspect, Vayyar enables OEMs to embrace the multifunctional platform model on the system level as well.

In the safety domain, Vayyar's unique offering of multifunctionality on a single-chip platform has three distinct aspects:

1. Reducing the number of sensors required for each application.
2. Supporting multiple applications simultaneously on a single chip.
3. Giving automakers the flexibility to scale to future safety applications without the need for new hardware and/or software.

This cuts complexity: less hardware, software, wiring, power consumption and integration efforts, along with fewer ECUs. It also lowers development risk, reduces the number of new SOP programs, shortens TTM and ensures an economical BOM.

Most alternative technologies require multiple chips to achieve a rich data output and high resolution. Vayyar's multifunctional platform, on the other hand, can achieve this level of granularity with just one powerful RFIC that combines resolution with performance, for utmost efficiency.

Multifunctionality on a single-chip platform is the gold standard of automotive technology, a complete software-hardware solution that enables OEMs and Tier 1s to seamlessly develop multiple advanced applications independently. Reduced complexity leads to dramatic cost savings, while the platform's OTA (over the air) software update capabilities effectively future-proof any vehicle.

Multilayered in-cabin monitoring: Combo and beyond

When it comes to meeting crucial upcoming Euro NCAP standards, Vayyar is leading the way.

The company provides an industry-first in-cabin ‘combo’ solution that addresses two key safety requirements: two-row SBR and the upcoming CPD (effective 2023). Powered by a single sensor, it’s designed to prevent both hot car incidents and the countless deaths and injuries caused by vehicle occupants neglecting to wear seat belts.

Vayyar’s comprehensive CPD solution is based on direct sensing, making any vehicle eligible for the full 4 points awarded by Euro NCAP for this criterion. Powered by rich, high-resolution data, it counts the number of occupants, distinguishes between adults and children (including infants), prevents false alarms and supports escalated automatic intervention by the vehicle.

The single-sensor platform is the only 60 GHz solution that monitors the entire cabin, covering three complete seating rows and detecting the presence of eight occupants across several safety applications simultaneously. It classifies adults and children based on their dimensions to prevent false positives. Furthermore, the sensor can identify a baby in a Child Restraint System (CRS) hidden under a blanket or even a child in any of the footwells.

But this CPD + SBR combo is just one component of Vayyar’s truly intelligent, centralized in-cabin ecosystem. Thanks to multifunctionality on a single-chip platform, automakers are able to replace numerous existing in-car sensors. Beyond the lifesaving flagship combo, Vayyar’s end-to-end, multilayered software-hardware platform also provides rich point cloud data captured by the sensor. This enables OEMs and Tier 1s to seamlessly develop multiple advanced applications independently over the point cloud layer, without requiring additional sensors.

These applications — such as driver monitoring (DMS), Occupant Status Monitoring (OSM), optimized airbag deployment and dynamic disabling, seat belt pre-tensioning, eCall and even intruder detection — can be introduced early in the development cycle, or at a later date by OTA.

[Watch the in-cabin real-time demo.]

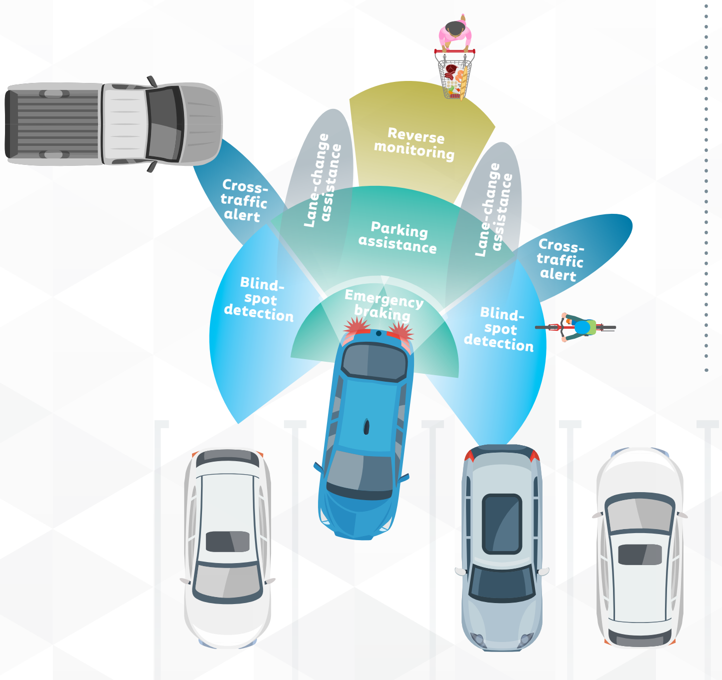
In addition to enabling vehicles to earn the full 4 safety points that Euro NCAP will award for Child Presence Detection (CPD) starting in 2023, the platform also supports front and rear Seat Belt Reminders (SBR) and the three additional Occupant Status (OS) points that Euro NCAP will award. Automatic airbag disabling, meanwhile, will be worth two points, with eCall functionality earning a vehicle one extra point. Vayyar’s solution enables vehicles to pick up these crucial 10 safety points, while enhancing user experience by minimizing false alarms. In fact, just one Vayyar sensor replaces seven or more in-car sensors.

Accelerating ADAS innovation

On the outside of the vehicle, Vayyar's integrated 76-81GHz software-hardware platform also serves as an ADAS solution, delivering better resolution and robustness than alternatives, at a lower cost, supporting all uSRR, SRR, MRR (and in the future, LRR) applications simultaneously with a single chip.

It's the only platform that supports a zero-minimum distance from its targets, no dead zones and an ultra-wide azimuth-elevation field of view for rich elevation perception.

Watch the ADAS real-time demo.



The platform also provides a range of data outputs tailored to various ADAS and AV architectures:

Edge computing
Processing-on-chip enables smart object clustering and tracking, significantly reducing ECU costs.

Raw 4D point cloud data streaming
For native AV sensor fusion and synergy with centralized computing systems.

Hybrid configurations
For powerful signal processing embedded on chip at the sensor level, enabling transmission of compressed high-resolution point cloud even over serial low bit rate protocols such as CAN.

As few as two Vayyar sensors perform the function of up to 20 standard ADAS sensors, enabling automakers to earn up to 33 Euro NCAP points per vehicle. To address the VRU protocol, the platform supports four types of AEB to protect pedestrians, cyclists and motorcyclists, earning 24 out of the 33 points. It also meets four crucial standards set out in the Safety Assist protocol that aim to prevent C2C collisions, earning the vehicle an additional 9 points.

Offering 10 in-car points and 33 ADAS points overall, Vayyar enables a vehicle to score 43 out of 170 Euro NCAP safety points (from 2023). This amounts to 60% of the 70 sensor-based points awarded across all protocols.

*For a full breakdown of the points that Vayyar sensors can provide any vehicle with, please refer to **Appendix C.***

Under the hood of Vayyar's platform

As a Tier 2 supplier, Vayyar provides a broader and deeper offering than just a radar RFIC and development board. The company offers a complete "prototype to mass production" solution that minimizes the potential for delays, while yielding significant cost savings.

Automotive Grade and HVM readiness

Vayyar's AEC-Q100 qualified and ASIL-B compliant chip is the most powerful and mature RoC of its kind. The global leader in 4D imaging radar is the only supplier that has validated its solutions against real humans from newborns to large adults. With leading-edge mechanical and thermal design engineering, the RF has been exhaustively performance-tested across Power vs. Time and in high-coverage factory scenarios.

Tens of thousands of recording sessions have been conducted, producing millions of samples to validate the technology and its application-readiness. A validated, automotive-grade reference design and BOM ensures HW design readiness for high volume manufacturing now. It's also compliant with ETSI and JP 60 GHz and is in the process of receiving FCC approval across the 60-64 GHz bands, making it the first globally regulated in-car mmWave solution. The technology is compliant with Human Safety (SAR) for safe use in the cabin.

Unprecedented resolution

With the most advanced RFIC of its kind, Vayyar's solution features the industry's largest MIMO antenna array. Alternative solutions usually rely on 6-8 transceivers, whereas Vayyar's sensor supports up to 48, maintaining efficient performance while delivering exceptionally high resolution. This enables comprehensive tracking of multiple targets inside and outside the vehicle with pinpoint accuracy, addressing the industry's most exacting safety requirements.

All-in-one RFIC

With all digital and analog RF components, including a DSP and MCU, Vayyar provides a full end-to-end Radar-on-Chip solution. The platform includes a highly integrated RFIC, fully tested reference design and the entire embedded SW stack. It's a complete System-on-Chip, optimized across all layers.

Software/point cloud

Vayyar's SW architecture features a universal API compatible with a wide range of partner SW. The rich data collected by the platform is processed on-chip, generating proprietary 4D point cloud VOXEL imaging that automakers can leverage to develop advanced image-processing or machine learning applications without needing specialist RF algo resources. Vayyar's partners can add more features through the software embedded on the chip, without the need to add ECUs. The software also enables the transfer of high-resolution point cloud data to a central unit for fusion purposes.

Firing on all cylinders

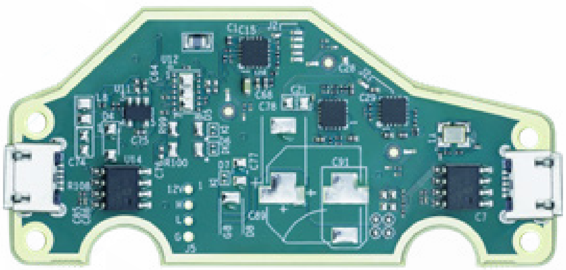
Combining its unprecedented resolution with an ultra-wide field of view, Vayyar's 4D imaging radar provides true multifunctionality on a single-chip platform. This enables automakers to shift from the "one sensor per application" model to a cross-functional approach that enables more with less. OEMs can significantly reduce the number of sensors vehicles require, while maintaining cost-efficiency and developing more applications on the same hardware-software architecture. Tier 1 suppliers can provide safety solutions based on a single sensor, which acts as a foundation for more features and unique added value.

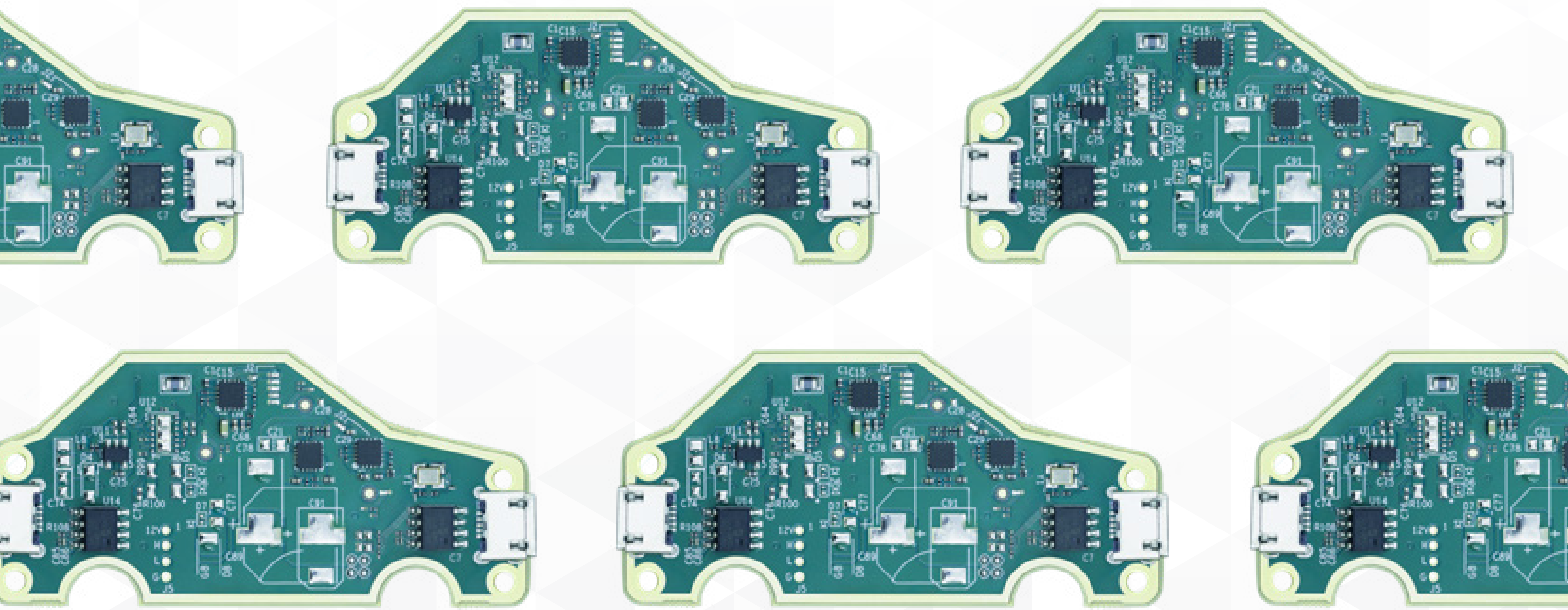
Road-ready and future-proofed technology

When it comes to meeting the specs, Vayyar's offering ticks all the boxes, including all hardware, software and resource elements to mitigate the inherent risk of deploying complex, multi-component technology.

Fully tested and validated against real humans (from newborns to large adults), with complete end-to-end reference design and fully developed radar algo, the platform eliminates the need for OEMs and Tier 1s to acquire in-house imaging radar expertise.

With the accelerating pace of safety requirements and innovation, Vayyar also supports OTA software updates that enable OEMs and Tier 1 suppliers to stay ahead of the game, even after vehicles hit the road. As industry needs evolve, applications can be updated remotely, delivering continued multifunctionality throughout the car's lifetime.





Conclusion

Safety ratings not only protect lives; they drive sales. But the bar is getting higher all the time.

The traditional industry approach to new safety standards has been reactive: introducing new applications and stop-gap solutions supported by single-functional sensors. This methodology has served only to increase the number of sensors and ECUs, and the amount of wiring, pushing up direct hardware costs as well as indirect resource expenses. The net result is that exceptional safety has come to be regarded as a feature of only high-end models, leaving the vast majority of the world's motorists — as well as other road users — exposed to the danger of Road Traffic Accidents.

Just one Vayyar in-car sensor and as few as two ADAS sensors enable automakers to earn 43 Euro NCAP points in 2023 and beyond by addressing the most challenging current and upcoming safety requirements. In fact, Vayyar's solution can supply 60% of all sensor-based safety points awarded by the Euro NCAP.

With a price point similar to low-end radar sensors, Vayyar's 4D imaging sensors offer the lowest cost-per-safety-point ratio in the whole industry, while ensuring shorter time to market, lower risk, fewer SOP programs, and substantial savings.

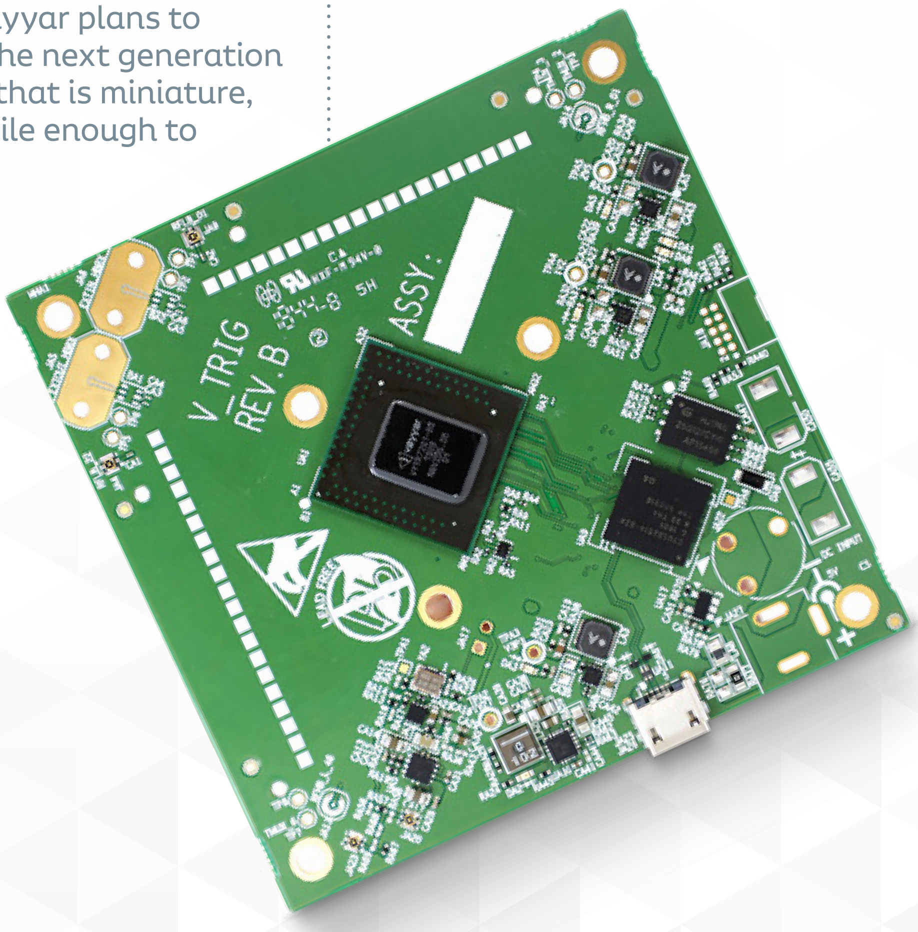
In a period of unprecedented global change, Vayyar's flagship offering of multifunctionality on a single-chip platform reduces complexity and costs, equipping all vehicles with uncompromising safety. This lifesaving approach protects all road users, both in the here and now and in a near future that will be increasingly defined by autonomous and electric mobility.

Chat with Vayyar's 4D imaging radar experts to learn more.

About Vayyar

Vayyar's automotive sensors create holistic safety opportunities for in-cabin and ADAS, using automotive-grade 4D imaging radar technology.

At the core of these sensors is a high-performance Radar-on-Chip that supports up to 48 transceivers for exceptional resolution. With an ultra-wide field of view, Vayyar's 60 GHz and 79 GHz single-chip radar modules provide robust detection in and around the vehicle, in all road conditions, while protecting user privacy. The 4D imaging radar-based platform is cost-efficient and available now. Vayyar plans to continue developing the next generation of sensor technology that is miniature, affordable and versatile enough to enable a safer world.



Appendix A: Glossary of Terms

Acronym	Explication
ABS	Anti-lock Braking System
ADAS	Advanced Driver Assistance Systems
AEB	Autonomous Emergency Braking
AES	Autonomous Emergency Steering
AOP	Adult Occupant Protection
ARAS	Advanced Rider Assistance Systems
BSD	Blind Spot Detection
C2C	Car-to-Car
CCR	Car to Car Rear-end
COP	Child Occupant Protection
CPD	Child Presence Detection
CRS	Child Restraint System
CTA	Cross Traffic Alert
DMS	Driver Monitoring System
ESP	Electronic Stability Program
ETSI	European Telecommunications Standards Institute
Euro NCAP	European New Car Assessment Program
FCW	Front Collision Warning
JA	Junction Assist

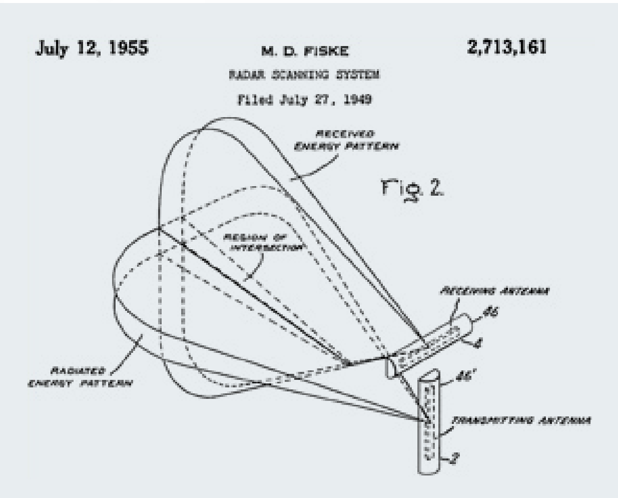
Acronym	Explication
LCA	Lane Change Assist
LIDAR	Light Detection and Ranging
LRR	Long-Range Radar
MIMO	Multiple Input Multiple Output
mmWave	Millimeter Wave
MRR	Mid-Range Radar
NHTSA	National Highway Traffic Safety Administration
OS(M)	Occupant Status (Monitoring)
PTW	Powered Two Wheeler
RCW	Rear Collision Warning
RoC	Radar-on-Chip
RTA	Road Traffic Accident
SA	Safety Assist
SAR	Specific Absorption Rate
SBR	Seat Belt Reminders
SoC	System-on-Chip
SOP	Start of Production
SRR	Short-Range Radar
uSRR	Ultra Short-Range Radar
VRU	Vulnerable Road User

Appendix B: Millimeter-wave 4D imaging radar sensors for automotive safety applications

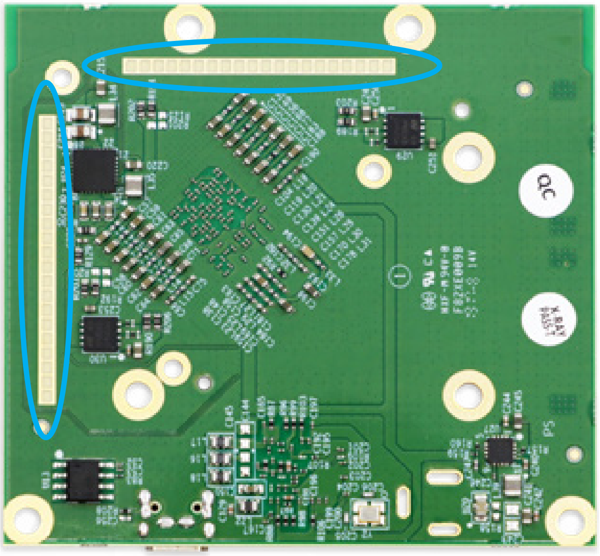
Naftali Chayat, CTO Vayyar Imaging

MIMO Radar Technology

MIMO radar has advanced since the 1990s, but the underlying principles are apparent, for example, in a 1949 patent that proposes to achieve az-el resolution by combining horizontal fan beams on transmission (for elevation resolution) with vertical fan beams upon reception (for azimuth resolution). The intersection of transmit and receive beams yields that az-el direction.



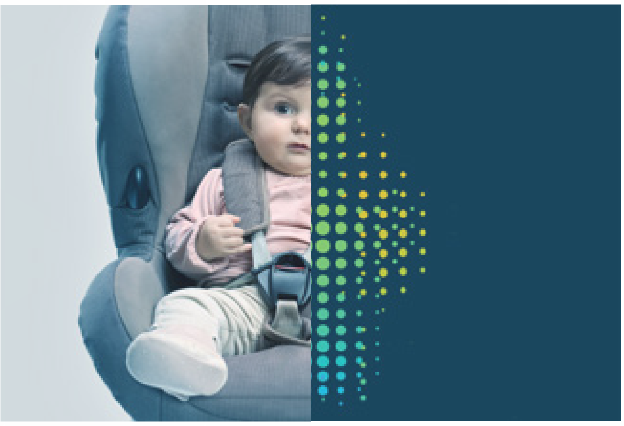
MIMO radars generalize this principle with arrays of transmit elements and receive elements and by taking into account a "virtual array" of transmit-receive element combinations. The system benefits from the spatial resolution of the virtual array, while retaining the square-root complexity of two smaller arrays. "Virtual array" is a convolution of the transmit array and the receive array. For example, two linear arrays (vertical and horizontal) yield a square virtual array (though from the receive sensitivity standpoint, the effective aperture is that of the line, not of the square).



The antenna side of Vayyar's "vTrig" PCB with an "L-shaped" antenna array: 48 antennas.

Resolution aspects

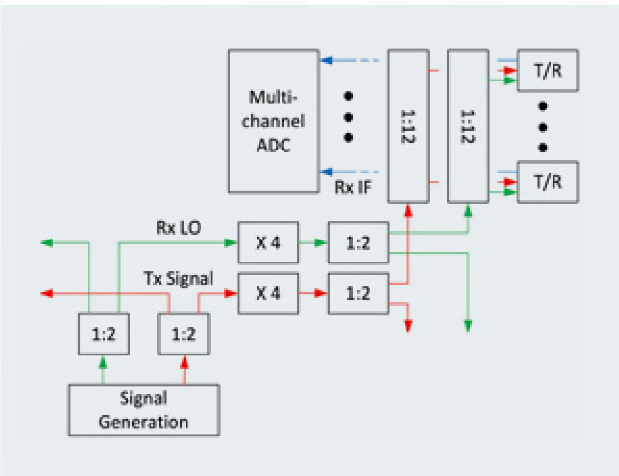
The spatial resolution is determined by antenna array size and by the bandwidth. The azimuth and elevation resolutions are determined by the number of elements in the transmit and the receive antenna arrays. By having 20 antenna elements in the elevation direction and 20 in the azimuth direction, the system can discern 400 spatial directions. The distance resolution derives from the bandwidth as $\frac{c}{2BW}$ – e.g. sub-7cm for 3Ghz bandwidth. These scales of resolution allow visualizing silhouettes of people, as seen below. The angular resolution plays a crucial role in assessing the locations of car occupants and surrounding pedestrians, with the ability to differentiate between objects, adults and children, even when close together.



For in-car applications, object displacement causes a phase shift of $(2\varpi*2d)/\lambda$. Operating at 60 GHz (5 mm wavelength) enables the detection of sub-mm displacements. These values facilitate the recording of respiration and heart rate patterns, data that can be used to differentiate between adjacent living and inanimate targets.

Multichannel transceiver and processing SoC

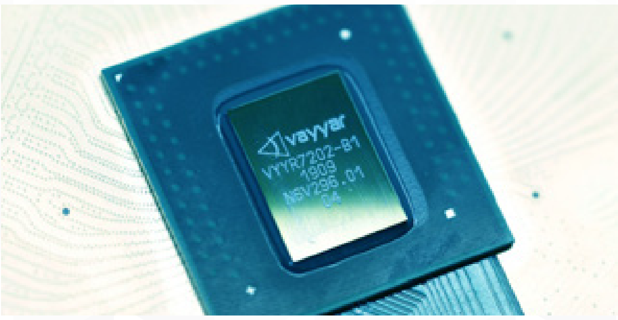
Vayyar's VYYR7203 and VYYR7204 "Centipede" Radar-on-Chips (ROC) comprise 48 millimeter-wave transceivers. The RoCs combine circuitry to generate a variety of radar signals within the 60-64Ghz and 76-81 GHz bands respectively (LFM, stepped frequency etc.), transmitting them from multiple antenna elements and simultaneously recording 24 coherently received signals.



The signal-generation circuitry combines fractional synthesis and quadrature modulation techniques to provide flexible signal generation, allowing complex sequences of chirp and frequency-stepped waveforms in the Ku-band. The signals are quadrupled into the millimeter wave band. The broadband quadruplers embed compact high-order interstage filtering to reduce the spurious signal content.

The 48 transceivers are grouped into four clusters of 12. Each transceiver gets a signal for transmission and a 'receive' LO, producing a 'receive' IF signal. The transceivers incorporate phase and gain control. The use of common transmit and receive LO signals in all the T/R modules, and simultaneous sampling by the multichannel ADC, facilitate coherent processing of the signals to extract directional information.

The RF subsystem of the RoC is supplemented by memory – to collect and process the received data – and by a powerful on-chip DSP processor. The on-chip processing of the radar data compresses it into target and event information that can be conveyed over the vehicular data network to the car's computers without consuming precious computational resources.

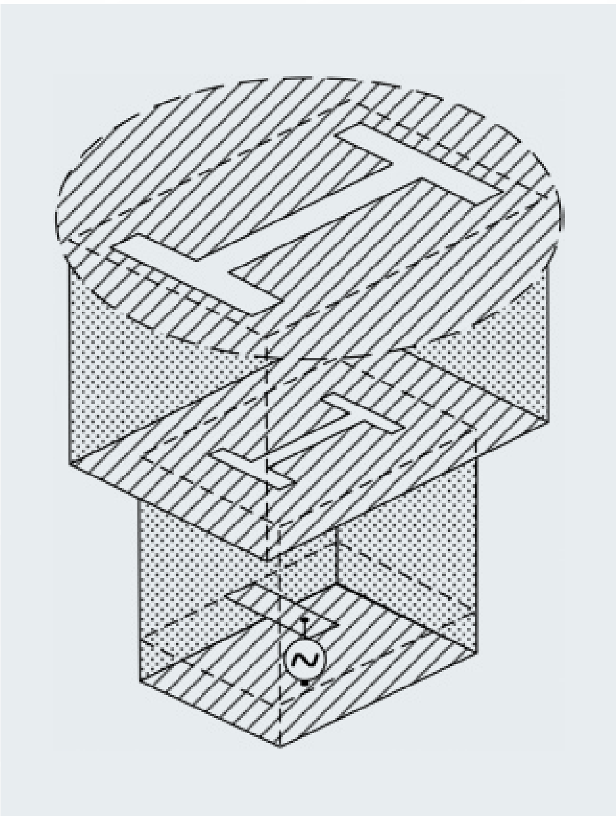


Vayyar's Centipede RoC + flip-chip BGA package.

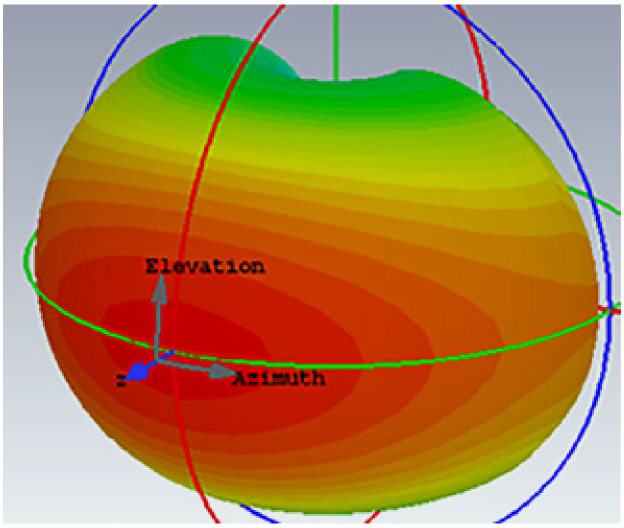
The 8*10 mm RoC is fabricated in a stable and depreciated automotive-grade CMOS process, and is housed in a 20*20 mm flip-chip BGA package. The chip and the package are able to contain the huge number of RF channels, while maintaining performance.

Wide-FoV antenna array technology

Typical applications of imaging radar sensors call for a very wide field of view – a room monitoring device is often wall-mounted while an in-car monitoring device is often ceiling-mounted. Detecting all the occupants of a room or car requires nearly hemispherical coverage. To address this need Vayyar's patented antennas are based on cavity-backed slot technology, having a dipole-like pattern with nearly +/- 90-degree E-plane beam-width. The antenna uses in-PCB stacked cavities for broadband match, using filter-like concepts of coupled resonators. The linear arrays of elements are densely packed to avoid grating lobes, while avoiding excessive mutual coupling.



The large number of elements in the antenna arrays favorably affects the link budget of the radar, a crucial element of current transmission profiles. This also allows the use of common low-cost PCB materials and production processes, reducing the system cost.



Signal processing technology

Each signal acquisition sequence produces vast amounts of data – scanning over elevation (transmit channels), over azimuth (receive channels) and over distance (frequencies) – sometimes denoted as a "data cube." This signal data is processed to recover the spatial data that is further processed over time to measure the velocity profile in each location. This 4D data is then processed to extract the safety-related features of objects in the arena. The Doppler data is indicative of velocity, while phase variations are indicative of minute displacements.

Super-resolution and micro-Doppler analysis techniques provide additional improvements in resolution and classification accuracy over the native resolution of the radar. Vayyar employs these techniques to take full advantage of the superior native resolution of its micro-radars.

Substantial signal complexity, which often goes unnoticed, goes into system calibration. Factors such as the length of the traces between each port and its antenna element, leakage effects and temperature effects have a significant impact on performance. It is well known that misbalance between array elements hits side lobe level performance before a substantial degradation of gain is experienced. Side lobe level impacts the ability to detect weak targets in the presence of stronger targets and calibration algorithms come to the rescue.

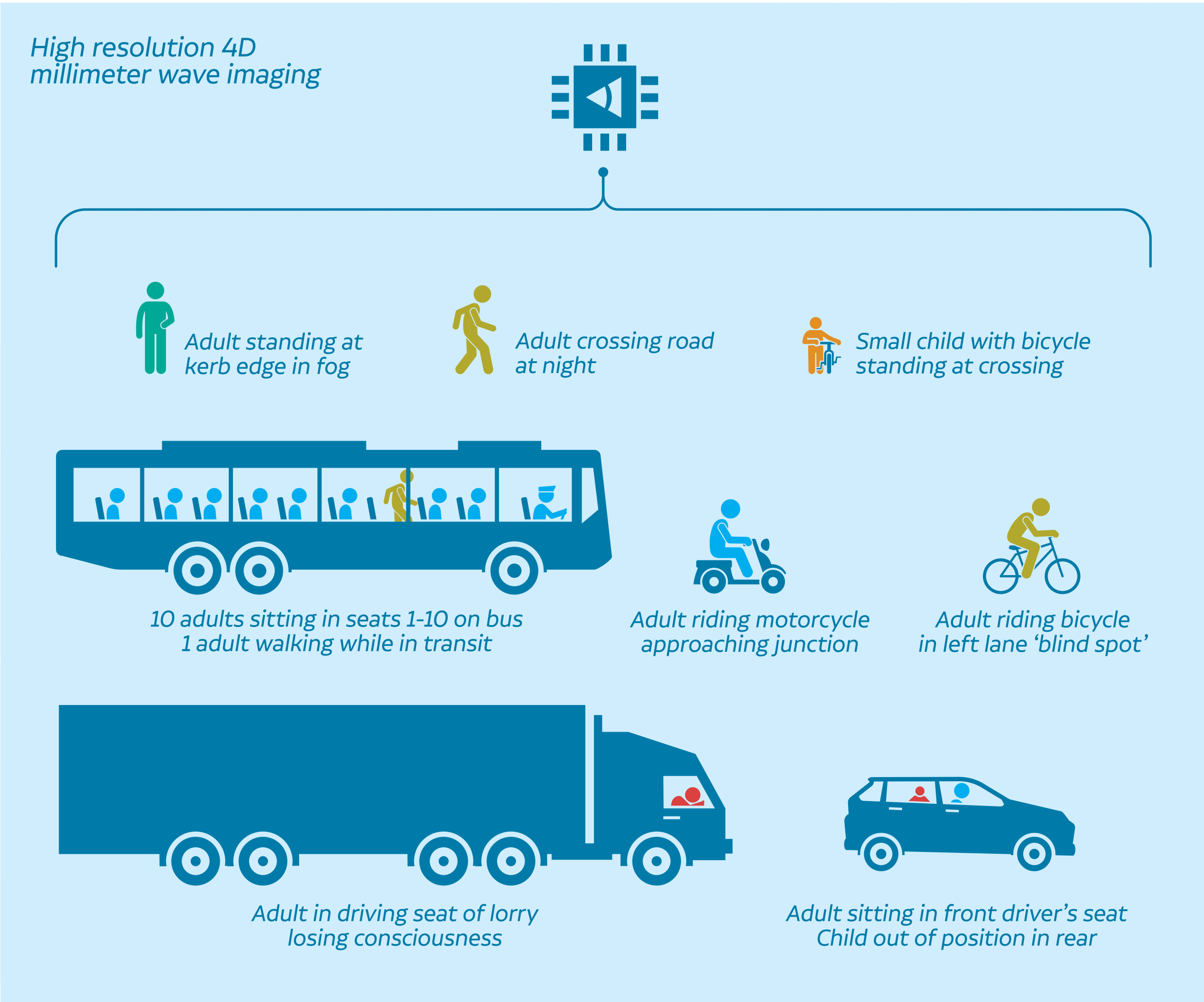
Artificial Intelligence Techniques

Advances in the fields of Machine Learning and Artificial Intelligence have transformed the field of image and video processing, and now these techniques are helping to transform the field of imaging radar. The versatility of the imaging radar system stems from its ability to segment a scene into objects, assess their positions, sizes, postures and motion patterns. The complexity and variety of possible scenarios make these tasks natural candidates for benefitting from advanced ML and AI algorithms.

Summary

Using high-resolution 4D millimeter wave imaging, radar sensors can facilitate accurate detection and classification of multiple static and/or dynamic targets in and out of the car. The unique technological advances in millimeter wave multichannel ASICs, in antenna technology and in signal processing algorithms create solutions with a wide field of view that provide a new level of safety to all road users, while answering even the toughest regulatory demands.

Go back to document section ***4D Imaging Radar.***



Appendix C: Breakdown of EU NCAP in-car and out-of-car points enabled by Vayyar (by protocol)

In-car:

Protocol	Requirement	Potential Points
Adult Occupant Protection	eCall	1
Child Occupant Protection	Child Presence Detection	4
Safety Assist	Occupant Status	3
	Airbag Disabling	2
Total		**10**

ADAS:

Protocol	Requirement	Potential Points
Vulnerable Road User	AEB JA PTW	6
	AEB/AES Pedestrian	7
	AEB Reverse Pedestrian	2
	AEB/AES Cyclist	9
Safety Assist	AEB/AES Head-on	3
	AEB/AES CCR	3
	AEB JA C2C	3
Total		**33**

Overall:

EU NCAP total possible points per vehicle	**170**
EU NCAP total possible sensor points per vehicle	**70**
Total points possible with Vayyar sensors	**43**
Percentage of total sensor points possible with Vayyar sensors	**60%**
Weighted percentage of a 5-star safety rating facilitated by full Vayyar system implementation (One in-car sensor and two to four ADAS sensors)	**36%**

Get in touch with Vayyar's 4D imaging radar experts to find out more.