

mmWave radar: Enabling greater intelligent autonomy at the edge



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Sensing at the edge is not new in concept or practice. Today it is commonplace for sensors to detect presence and take actions such as automatically opening doors, alerting drivers to obstacles behind them, or turning lights on or off.

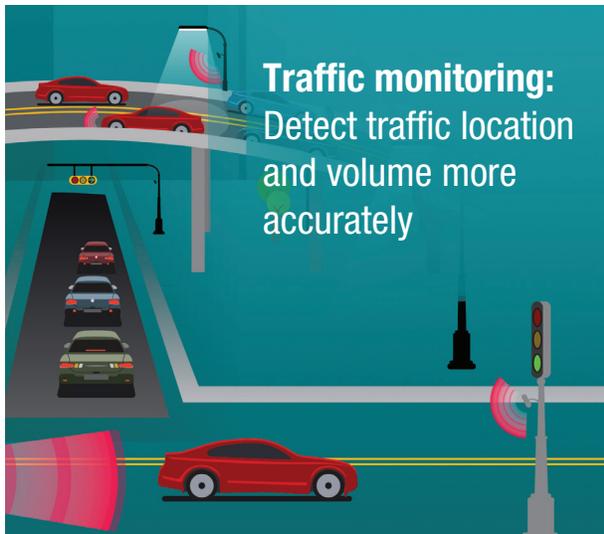
Traditionally, though, there have been limits to the effectiveness of these sensing applications. Think about how often an automatic door opens when somebody moves nearby but is not approaching to pass through, or even stays stuck open when a shopping cart is sitting just within range of the sensor. The sensor detects something bulky within a few feet of the door, then wastes power opening the door and letting conditioned air from inside escape—with no useful result.

Suppose the door would open not only because it senses proximity, but also because someone approaching has changed speed, indicating an intention to enter. An extreme instance would be when an excited child runs directly at the door. Proximity sensing alone cannot react quickly enough, but a sensor that also detects the speed and angle of movement can trigger the door to open just in time, promoting safety and letting only the minimum air escape. The sensor is also clever enough to spot individual people and common objects, so that it can provide useful information to the building network, such as giving a store a count of customers or notifying managers when shopping carts need to be brought in from the parking lot. Considering the vast number of automatic doors in use, widespread installation of such sensors could bring considerable energy savings, as well as contributing to security, safety and convenience as a part of building automation.

Today, this kind of improvement to ordinary applications is becoming a reality with the adoption of millimeter wave (mmWave) radar sensing. Based



on integrated circuits that are optimized for size, power and cost, mmWave sensors are available in single-chip solutions that fit readily into even the most space-constrained systems. mmWave radar sensing is best known for its use in advanced driver assistance systems (ADAS) and self-driving features in cars such as adaptive cruise control



(ACC). However, as the example of the door opener shows, the same technology can be used effectively in a wide variety of ways in other market segments beyond the vehicle. For example, mmWave radar sensing can improve:

- Timing of traffic lights and flow at intersections and freeway on-ramps;
- Operation of construction and farming equipment;
- Tracking of people and objects in safety and security systems;
- Automated lighting and comfort systems; and
- Guidance for industrial robots and drones.

In its many applications, mmWave radar sensing is enabling intelligent autonomy for decision-making at the edge. Remote systems with effective sensing functionality can respond immediately and efficiently to local situations, instead of having to report data and receive instructions from a control center or via the internet.

Bringing the benefits of mmWave radar sensing to so many applications requires expertise in a variety of semiconductor technologies: radio, other radar and sensing technologies, high-frequency design, analog signal chain functions, low-power microcontroller hardware and software, advanced

signal processing, and system and network communications, among others. To design and manufacture high-performance mmWave radar sensing solutions that are small and affordable for such wide-ranging systems requires expertise in the integration, packaging and qualification of these and other functions. Texas Instruments (TI), an industry leader across all of these areas of semiconductor technology, is driving innovation to bring greater performance and more power-efficient operations through mmWave radar sensing.

How mmWave radar sensing enables intelligent autonomy at the edge

Like all radar solutions, mmWave radar works by transmitting electromagnetic signals that are reflected by objects, including people and animals. Upon reaching the originating point, these reflections (returned signals) are used to calculate the range, velocity and angle of the detected object. What sets mmWave technology apart is that it employs radar in the millimeter waveband from 30 to 300 gigahertz (GHz), an area of the electromagnetic spectrum with several industrial, scientific and medical (ISM) sub-bands that are open for commercial use.

Use of mmWave emissions permits the use of very small antennas, enabling integration within the sensing unit and greater system miniaturization. As a result, compact mmWave sensors can be easily mounted where they are needed—behind a plastic car bumper, within a security camera housing, inside a robotic or drone housing, beside an environmental or traffic control unit and so on. In addition, mmWave radar technology operates in conditions that can hamper cameras and optical-based sensors such as LIDAR. Darkness, dazzling sunlight, rain, haze, fog and smoke do not interfere with mmWave operation. Radar sensing technology can also penetrate barriers such as glass,

plexiglass, opaque plastic sheets, and thin layers of drywall and plywood. This capability not only makes mmWave radar robust in adverse environmental conditions, but also allows the sensors to be mounted inconspicuously behind surfaces and used in many locations that do not provide a clear line of sight.

Most mmWave sensors employ a [frequency-modulated continuous-wave \(FMCW\) scheme](#),



meaning that they emit a frequency-modulated signal continuously, rather than the traditional radar pulses or “bleeps.” FMCW offers certain advantages, including its usefulness in measuring range precisely. Another feature of mmWave transmission is the ability to encode a unique signature in the signal, so that numerous units can operate in the same area without interference. Transmitters can also be cascaded with different times or phases in order to improve resolution and, with signal processing, identify objects such as pedestrians, pets or animals, vehicles, shopping carts, traffic cones, and other details of the landscape, instead of simply identifying presence or movement.

Delivering high accuracy, image clarity and range

mmWave radar sensing is highly accurate over a wide range, from a distance just over an inch up to the length of a stadium. Tests have shown that at one meter’s distance, a sensor can detect objects as fine as the edge of a quarter. At distances that are typical of traffic flow and people movement, sensors can spot large objects such as cars and trucks up to and beyond 200 meters.

Because a mmWave system can detect movements that are as small as a fraction of a millimeter, the technology can detect very fine motions, such as a pulse rate or batting an eye, that are typical of a person sitting still. Perception of such fine movements can be useful in office buildings, where workers are frequently left in the dark because room sensors that detect only large movements turn out the lights when someone is sitting relatively still at a desk. mmWave sensors, by contrast, leave the lights on because they can detect small motions such as typing or moving the head slightly.

mmWave range measurements are both highly accurate and provide high resolution. For a task such as measuring the liquid in a large storage tank or the grain in a silo, accuracy means that the sensor can identify exactly the level of the contained material, while resolution can tell almost to the last drop or kernel when the material is about to run out (**Figure 1**).

In a basement or storage area, a sensor can detect leaks from containers and pipes long before spilled materials can create a hazard.

Among the technologies employed for detecting remote objects, mmWave radar sensing fills a unique niche, so that it may be used alone or along with other sensing technologies, depending on application requirements. mmWave radar sensing is exceptional in its ability to track the speeds and angles of multiple moving objects, and the sensor’s

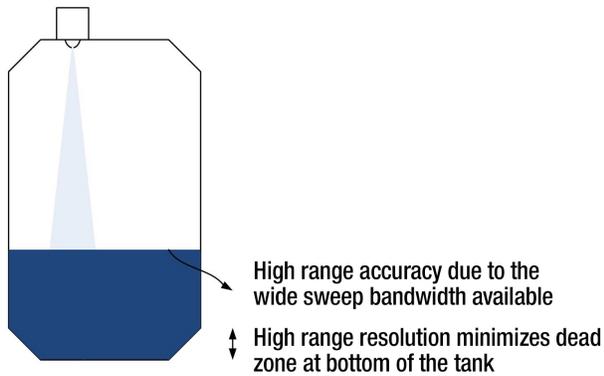


Figure 1. High resolution 77 GHz radar improves performance for industrial level sensing.

field of view can focus within a narrow angle. With these features, the technology enables smart traffic control, such as timing a signal light via a small sensor in the unit housing, instead of by a large inductive coil that is buried under concrete in the street and must be dug up and replaced periodically (**Figure 2**). In a smart city, sensors at key points along a street or freeway can monitor vehicle movement and make immediate decisions such as shutting down a ramp if traffic is not flowing, while simultaneously communicating this action to a control center for responders to be dispatched.

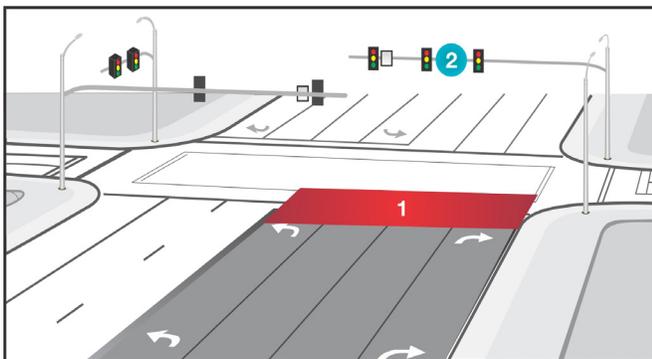


Figure 2. An intersection where traffic radar sensors can be positioned at the stop bar (1) or on the traffic pole (2). Sensors on the traffic pole do not require installation in the road's surface.

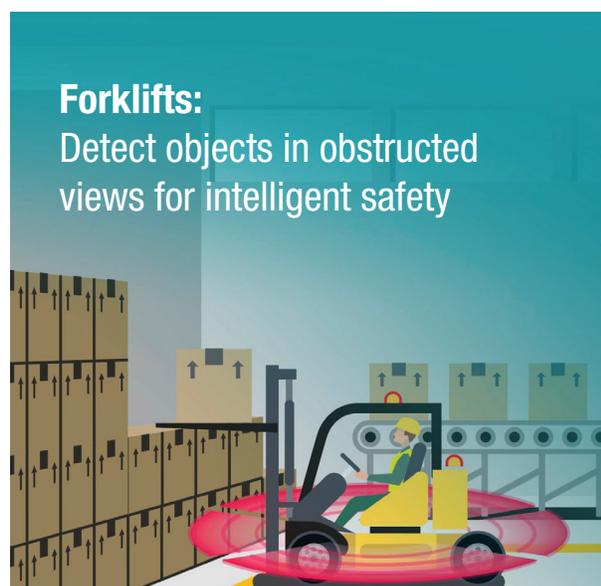
In safety applications related to building entry and occupancy, which can be critical during fires and other emergencies, mmWave sensors can keep track of people on the premises, even those who would not be directly visible to cameras. Because mmWave radar sensors are not dependent on visual images to make decisions, they can help provide security and safety in areas such as restrooms and locker rooms, where cameras are not permitted because of privacy concerns. For routine security, mmWave radar sensing can cut down on the false alerts issued by video-only systems, saving the time and expense required to check these unnecessary interruptions.

Enhancing intelligence for mobile and motion systems in vehicles

In vehicles, mmWave radar sensing supports ADAS and the steady development of automatic operation. ADAS features include adaptive cruise control (ACC), automatic braking, backup object detection, blind-spot detection, lane-change assist, and cross-traffic alert, among others. These systems use the radar to detect the presence of objects, pedestrians and other vehicles and track their distances, speeds and trajectories. Because cars and trucks operate in a complex, dynamic environment, several types of sensing are used to create as complete a picture of the roadway as possible. mmWave radar sensors work along with video cameras, ultrasound and LIDAR, with each type of sensor contributing its strength to complement the others. Radar's unique ability to "see" at night and through poor environmental conditions make mmWave a key component of the vehicle's overall sensing complex. mmWave radar sensing has a role to play within the cabin, too. Fine motion detection by a sensor can monitor breathing and heart rate to help determine

whether the driver is awake, providing an essential measure of safety as automated driving—and the tendency to nod off—become more common. Safety is also at issue if a baby becomes locked inside a hot car; an mmWave sensor could detect the child and issue an alert to the car’s alarm system. Radar sensing can also identify passengers and help provide more satisfying climate control, or warn about dinging the door of a neighboring car in a parking lot. In future innovations with head-up displays, radar sensing may serve to determine the driver’s eye level in order to locate the display where it needs to be for proper viewing.

mmWave technology, originally driven by the automotive market, is finding wide use in other mobile systems. For instance, work, construction and farming vehicles also benefit from radar guidance. mmWave radar sensors can provide information to trucks and forklifts about how close they are to loading docks and other structures. Heavy equipment such as bulldozers, backhoes and agricultural combines can rely on the technology to help avoid both static and dynamic obstacles and perform construction and crop- and soil-related tasks more effectively.

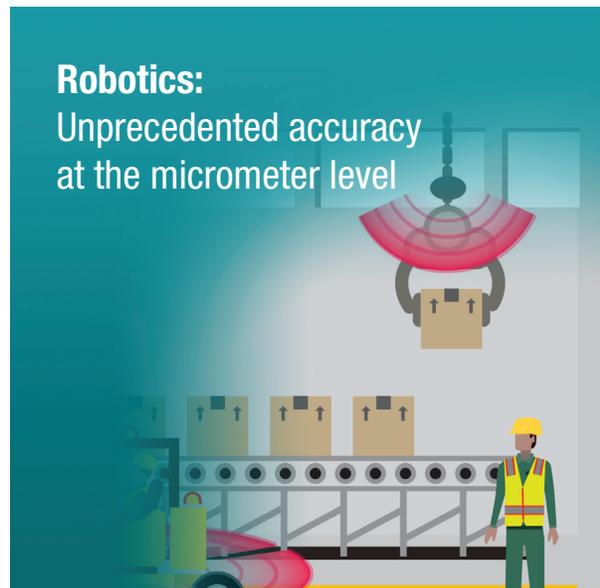


Because vehicle motion sensing is independent of wheel slippage, mmWave can also ensure the uniform distribution of seeds.

Smaller systems that are in motion, and even airborne, need ADAS-type guidance too. Drones are starting to aid farmers in spraying crops and may also eventually be used to make deliveries. For navigation and tasks such as surface observation and surveying, drones can make abundant use of mmWave radar sensing. Logistics robots are making an impact in large warehouses, where they store, fetch and deliver items. The more sophisticated the guidance and movement control, the less fixed the floor layout has to be, and the greater the number of robots that can be used in the same space. For a fulfillment operation, for example, using mmWave guidance can help increase robot usage and flexibility within the space, enabling more and faster deliveries from the same building.

Robots used on assembly lines and for other factory tasks such as testing are often fixed in place but have arms with a large range of motion. Increasingly, factory robots are being designed to work in the same space with humans. Optical sensing (LIDAR or 3D time-of-flight sensing), which is commonly used in these robots, directs tasks and protects employees and equipment from collisions as it guides the robot’s motions. mmWave radar sensing can provide additional task information and extend machine capabilities by, for example, helping the robot discriminate among materials. In addition, factory conditions are continually changing, and safety may demand more than one type of sensing. mmWave radar can identify employees as they approach an area and also take over as the “eyes” of the robot if the air becomes dusty or otherwise visually obstructive.

Such additional sensing information can help enable robots to operate more efficiently at a range of speeds, depending on work flow and environmental conditions, rather than being limited to one or two operating speeds, as is common today.

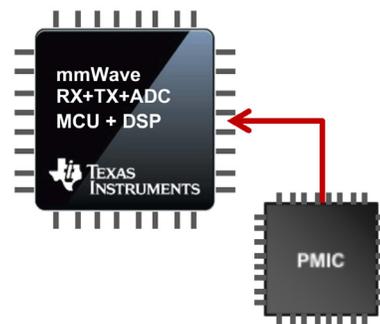


Solving the challenges of mmWave design

There is already a wide range of mmWave radar sensing applications, and new uses are continually being discovered. Semiconductor solutions designed to serve the needs of these diverse areas must integrate a variety of functions, including radio frequency (RF) transceivers, analog functions such as clocking, analog-to-digital converters (ADCs), high-speed processing, and connectivity. Depending on the application need, the processing may include hardware acceleration or a programmable digital signal processor (DSP), as well as a microcontroller (MCU), and the connectivity may include network communications as well as standard system interfaces.

High frequencies and diverse functions make mmWave radar sensor design complicated when using discrete components, so single-chip

integration saves considerable effort for system developers (**Figure 3**). Since there are several mmWave ISM frequency sub-bands, with a degree of variation internationally, semiconductor solutions must offer RF flexibility that adapts transceivers for different requirements. Other factors that aid developers include system miniaturization and low power consumption, since the sensors must often be placed in small spaces and may at times require battery-powered operation. Designing mmWave antennas can also be complex, and the software required for a specific application often demands signal-processing expertise, so development support in these areas is important.



TI single-chip mmWave sensors

- Smaller in size
- Simpler design
- Built in monitoring and calibration (SIL)
- High resolution, fewer false positives
- Programmable core
- Lower power

Figure 3. TI's single-chip mmWave sensor.

Given the many challenges involved in implementing mmWave radar sensing applications, system developers need optimized offerings with greater integration, ultimately eliminating as many design challenges as possible. Responding to these

needs, TI creates mmWave radar technologies with the hardware, software and tools that sensing application that developers need. TI introduced the industry's first single-chip mmWave complementary metal oxide semiconductor (CMOS) sensor to minimize design complexity, space and power requirements. CMOS-based RF expertise enables TI to adapt transmissions to market requirements and tailor different sensing solutions for the processing needs of various automotive and industrial markets. mmWave radar devices also include standard I/O ports and industrial network connections such as CAN. TI's in-depth network expertise allows further integration if applications demand.

Complete solutions include in-depth support with evaluation modules (EVMs) and reference designs for a large number of applications, along with downloadable source software to accelerate product development and revenues. [Online labs and experiments](#), with source code and test information included, showcase the many innovative uses of radar sensing, including people tracking, storage tank liquid measurement, automatic doors, robotics, and traffic monitoring, among others. For additional support, customers can take advantage of an ecosystem of co-developers who specialize in designs, software and development tools to help implement mmWave technology.

mmWave radar sensing is at the base of its ascent into multidimensional application space, and TI is innovating to grow its products and support along with the market. In addition to tailoring more devices to more applications by integrating functions and creating software, TI technology advancements

across a range of areas will help make new types of radar applications possible, giving greater power to system developers to realize their visions. Areas of potential development are simplification in antenna design, cascading sensors to bring greater resolution, hyperspectral imaging, algorithms for advanced functions, and many others.

Through new developments, TI is pushing mmWave radar technology to new levels of resolution, utility, efficiency and adoption. Predicting the full range of uses for mmWave sensing in the years ahead is an impossible task, but the one certainty is that the universe of applications is expected to keep growing. With a unique combination of innovation and technology leadership across multiple engineering disciplines, TI plays a significant role in fostering the growth of mmWave radar sensing, bringing more efficient operation and intelligent autonomy to the edge.

For more information:

- Learn about our [mmWave radar sensor portfolio](#), including the [AWR1642](#) and [IWR1642](#) devices
- Review our reference designs:
 - o [Vehicle Occupant Detection Reference Design](#)
 - o [People Counting and Tracking Reference Design Using mmWave Radar Sensor](#)
 - o [Traffic Monitoring Object Detection and Tracking Reference Design Using mmWave Radar Sensor](#)
- Read our blog: [mmWave sensors offer unprecedented accuracy for automotive, industrial applications](#)

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