TI's smart sensors ideal for automated driving applications

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Introduction

The automotive industry is driving innovation and technology advancements in robotics and machine vision. Automakers are designing new vehicles with a range of diverse technologies to keep up with ever-growing consumer demand. This trend has led to the introduction of the advanced driver assistance system (ADAS), which improves safety, comfort, convenience and energy efficiency.

According to government agencies like the National Highway Traffic Safety Administration, more than 30,000 people in the United States and 1.3 million people worldwide die in road crashes every year; about 94 percent of these crashes are related to human error. An ADAS that helps with warning, breaking, monitoring and steering can assist drivers and potentially reduce errors. Many vehicles today boast features including blind-spot and lane-departure warning, forward collision and rear cross-traffic warning, automatic emergency breaking, lane-keep assist and adaptive cruise control. While these features differentiate brands and are revenue sources for automakers, several countries are now mandating that all vehicles must be equipped with ADAS by 2020.

ADAS—foundation of automated driving

The demand for ADAS is growing rapidly, owing to a rising awareness of safety, an influence of regulations and original equipment manufacturer (OEM) safety ratings. According to the global ADAS market forecast from Research and Markets, around 50 million vehicles equipped with ADAS were shipped in 2016; these shipments should reach 60 million by 2022. Shipments of ADAS components are expected to increase from 218 million units in 2016 to 1.2 billion units in 2025, according to another ADAS market forecast from Research and Markets. A typical ADAS incorporates various sensing technologies along with advanced processing and communication capabilities to automate, adapt and enhance vehicle systems for safety and better driving. Automakers rely on leading semiconductor suppliers to provide automotive electronics ranging from advanced sensing technology and imaging/vision technology to high-performance and low-power processors and in-car networking.

The maturity and advancement of ADAS components will eventually enable semi-autonomous and autonomous vehicles. **Figure 1** on the following page summarizes the six levels of driving automation according to the definitions from SAE International.

An automated driving system is based on many components, including sensors that capture information about a car's surroundings, integrated circuits (ICs) for communication, high-performance processors to analyze sensor data and microcontrollers (MCUs) to activate and control mechanical functions.

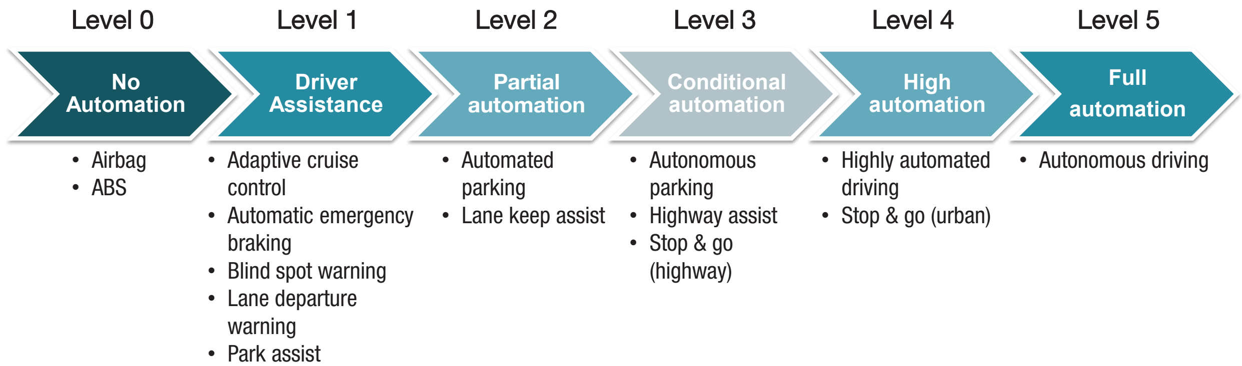

Figure 1. *Levels of automated driving.*

Sensing systems are very critical to ADAS and automated driving since they add intelligence to a vehicle, creating an accurate perception of the surrounding environment. Multiple image sensors in ADAS are becoming standard, but newer sensing technologies such as radar, laser, ultrasonic, infrared and lidar are all enhancing ADAS.

The automotive industry prefers radar sensors, since the sensor penetrates nonmetal objects such as plastic, clothing and glass and is generally unaffected by environmental factors such as fog, rain, snow and bad or dazzling light. Automotive radar systems can be divided into short-, mid- and long-range radars, based on the range of object detection; ultra-short range radar (USRR) is also an emerging ADAS application for park-assist systems. Driver-assist features such as blind spot and lane-departure warning use short-range radar (SRR) systems. These systems, which fall under SAE International Level 1, are expected to report or warn drivers using light-emitting diodes (LEDs) or steering-wheel vibration. While current SRR systems use the 24–29 GHz frequency, according to industry experts, that may well phase out in the future because of regulations around output power at lower frequencies.

Driver-assist features such as adaptive cruise control and automatic emergency braking use long-range radar (LRR) systems. These systems take simple vehicle control actions. While current LRR systems use the 76–77 GHz frequency, as higher levels of automated driving require higher range and resolution, front radar systems will likely use both the 76–77 GHz and 77–81 GHz frequencies for a combination of LRR and newer mid-range radar (MRR) systems. Higher levels will require radar sensors to analyze the complex scenarios by detecting hazards, measuring properties of the hazards (distance and velocity), and categorizing them into objects with distinct properties (distance, velocity, angle, height). Finally, the sensors will need to assist with safe maneuvering.

TI's [AWR1x millimeter wave (mmWave) sensor portfolio] helps developers to create a safer and easier driving experience. Based on the mmWave sensing architecture (**Figure 2**), the AWR1x

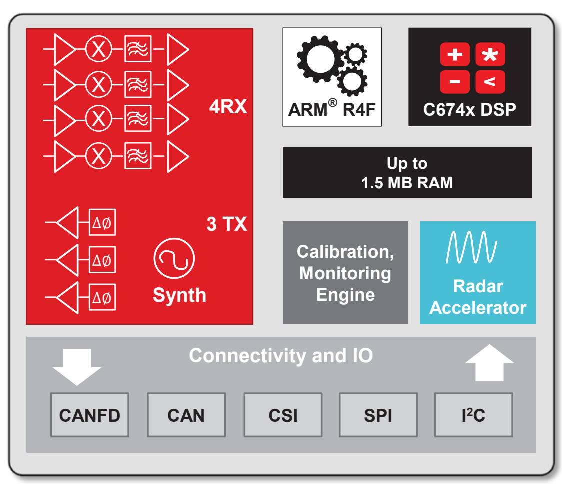

Figure 2. *AWR1xx mmWave sensor block diagram.*

sensor integrates radio-frequency (RF) and analog functionality with digital control capability into a single chip. Using on-chip built-in self-test (BIST) capabilities can help automotive radar system developers to achieve functional safety compliance. In addition, the devices under this portfolio integrate a customer-programmable MCU and radar signal-processing capabilities through a hardware accelerator or DSP. The radar sensor design can be optimized by the level of integration in the AWR1x to reduce size and power.

Precise and ultra-high accuracy to analyze complex, dense urban driving scenarios

The automotive radar sensors use electromagnetic waves in the 76–81 GHz frequency to determine the range, velocity and angle of the objects in the sensors' field of view. While several parameters define a radar system performance for range, velocity and angle, resolution and accuracy are two key parameters. Resolution defines the ability to separate two objects in range, velocity or angle, while the other two variables are the same for those objects. For example, angular resolution defines the ability to separate two vehicles driven at the same speed and at the same distance from the radar sensor. Accuracy defines the accuracy of range or velocity or angle measurement of one object. For SAE International Level 2 and beyond, radar sensors need to have ultra-high accuracy for SRR applications (50 m).

Automotive radar systems often adopt the frequency-modulated continuous waveform (FMCW) technique to measure the range, angle and velocity of remote objects. In FMCW radars, chirp linearity defines the accuracy of an object's range measurement. The traditional implementation of mmWave sensors uses an open-loop voltage-controlled oscillator (VCO)-based chirp generation and causes high chirp nonlinearities, resulting in inaccurate range measurement. The AWR1x mmWave sensor portfolio is also based on the FMCW technique. It uses a closed-loop PLL to enable 0.01 percent linear and precise chirps, resulting in improved range accuracy and higher range resolution. Chirp linearity avoids false detection and ghost objects—artifact or secondary image of an actual target.

Range resolution is a function of RF bandwidth. The AWR1x sensor portfolio supports up to 4-GHz chirp bandwidth in a single sweep, enabling less than a 5 cm range resolution, which is three times more accurate than mmWave solutions on the market today.

Unambiguous velocity defines the ability to separate objects with similar velocity. For a given range resolution and maximum range, a higher maximum velocity needs a higher IF bandwidth. The high-performance radar front end in the AWR1x portfolio supports 15 MHz of IF bandwidth, enabling maximum ranges beyond 250 m and unambiguous velocity up to 300 kph. The combination of IF bandwidth and phase-noise performance enables radar sensors to detect smaller objects in the vicinity of large objects. Further, built-in 20-GHz synchronization capability for phase coherence in the high-performance front end enables you to cascade multiple front ends to achieve <1-degree angular accuracy in dense urban driving situations and better elevation estimation in drive-under conditions such as overhead bridges and tunnels.

Putting it all together, in order to analyze the complex scenarios with highly automated driving, future radar sensors need to be highly accurate. You can leverage the capabilities of the AWR1x portfolio to design highly accurate sensors.

Versatile intelligence to adapt to changing conditions

Automotive sensor manufacturers are beginning to look at multimode radar systems to address SAE International Level 2 and beyond. In a multimode radar system configuration, the sensor is designed to support both MRR and LRR configurations in one sensor module, thus providing a significant cost reduction to automakers since two separate sensor modules are no longer required to support each configuration. A multimode radar system design imposes certain requirements on mmWave technology providers, including ease of use, flexible chirp configurations and monitoring. The AWR1x portfolio integrates a BIST engine to locally control chirp-generation parameters in real time. The engine supports dynamic chirp configuration via non-real-time messaging from a local digital subsystem or external host processor. The BIST engine provides automatic adaptation of the sensor to changing environmental conditions, specifically temperature and aging. This enables self-calibration of drift in RF parameters such as output power and gain. Further, the BIST engine continuously monitors the RF and analog subsystems for key RF performance parameters, thus enhancing safety.

While traditional mmWave sensing technologies used a real baseband architecture, the AWR1x sensors realize system-level and performance benefits through a novel complex baseband architecture. Since the automotive radar sensors are mounted behind the bumper, if the sensors provide an accurate estimation of bumper reflections, they can remember the bumper signature and calibrate during every boot up. The AWR1x portfolio enables more accurate estimation of close objects, using zero-distance magnitude and phase of the bumper reflection, which is nearly impossible with real baseband architecture because of the low frequency of a bumper signature. You can further exploit the complex baseband architecture to monitor the image band, detect interference from other jamming radars without ambiguity over genuine objects, and suppress detected interference, thus enabling a robust radar sensor design.

True single-chip drives the radar sensor to be small and low power

As automated driving becomes a reality, radar sensor requirements will be driven by power, size, cost, distance and accuracy. SAE Level 2 and beyond automated driving systems require many more radar sensors than solutions currently offer. Today's high-end vehicles feature a multichip single radar system. Given the use of multiple discrete components, these radar systems are big and bulky when they need to be smaller, lower power and cost effective. The sensors have to be miniaturized and optimized in order to adapt to future automated driving market demands.

While some current radar systems on the market claim to be a single-chip solution, they are not. Current solutions still require a number of components; they reduce the number of discrete chips from three to one, but then also require a transceiver with an external MCU or DSP to process the radar data.

Thanks to CMOS technology, TI has taken integration to the next level, integrating intelligent radar front ends with MCU and DSP capabilities into the AWR1x single-chip portfolio. Processing is co-located with the front end to reduce the size and form factor of the radar systems by 50 percent. This further enables the efficient mounting of multiple radar systems. CMOS technology and best-in-class power-management techniques enable the AWR1x sensors to be low power, which is critical to the automotive industry's development of energy-efficient electric vehicles. Lower power also leads to a cost advantage because designers can now select more economical and lighter housings. Lower power also enables the AWR1x sensors to withstand higher ambient temperature and increases the reliability of the sensor.

Reliability and volume production

All of these features and capabilities are beneficial to customers only when the solution is offered in a reliable package that enables mass production. The AWR1x mmWave portfolio is offered in an automotive-friendly flip-chip ball-grid array (FC-BGA) package. The FC-BGA package solution delivers reliable electrical, mechanical and thermal performance and eliminates the shielding for emissions and need for underfill, a material that encapsulates the bottom side of the chip to protect the interconnects, thus providing a cost advantage over traditional packages used with mmWave-sensing technology.

The AWR1x mmWave portfolio supports ADAS, body and chassis, and in-cabin applications

TI's AWR1x mmWave portfolio supports highly precise sensing applications across ADAS, body and chassis, and in-cabin applications. The portfolio scales from a high-performance radar front end (the AWR1243) to single-chip radar solutions (AWR1443 and AWR1642). **Table 1** summarizes the key features of each sensor in the AWR1x portfolio.

The portfolio of three devices supports different ADAS radar-sensor configurations ranging from USRR, SRR to MRR, to LRR and imaging. The portfolio further enables a smart sensor architecture, where all of the radar processing occurs at the edge; and a satellite sensor architecture, where the radar sensor sends object data over CAN-FD to a central processor for further processing and sensor fusion.

Device	AWR1243 High-performance Radar front end	AWR1443 Ultra-high-resolution single-chip radar	AWR1642 Small, low-power, single-chip radar
			
Frequency band	76–78 GHz	76–81 GHz	76–81 GHz
Number of receivers	4	4	4
Number of transmitters	3	3	2
RF bandwidth	4 GHz	4 GHz	4 GHz
Max sampling rate	37.5 MSPS	10 MSPS	10 MSPS
IF bandwidth	15 MHz	5 MHz	5 MHz
Processing		ARM® Cortex®-R4F 200 MHz	ARM Cortex-R4F 200 MHz
			C674x DSP 600 MHz
		Radar hardware accelerator—FFT	
Memory		576 KB	1.5 MB
Interfaces	MIPI CSI2 SPI	CAN SPI	CAN-FD CAN SPI

***Table 1**. AWR1x scalable portfolio.*

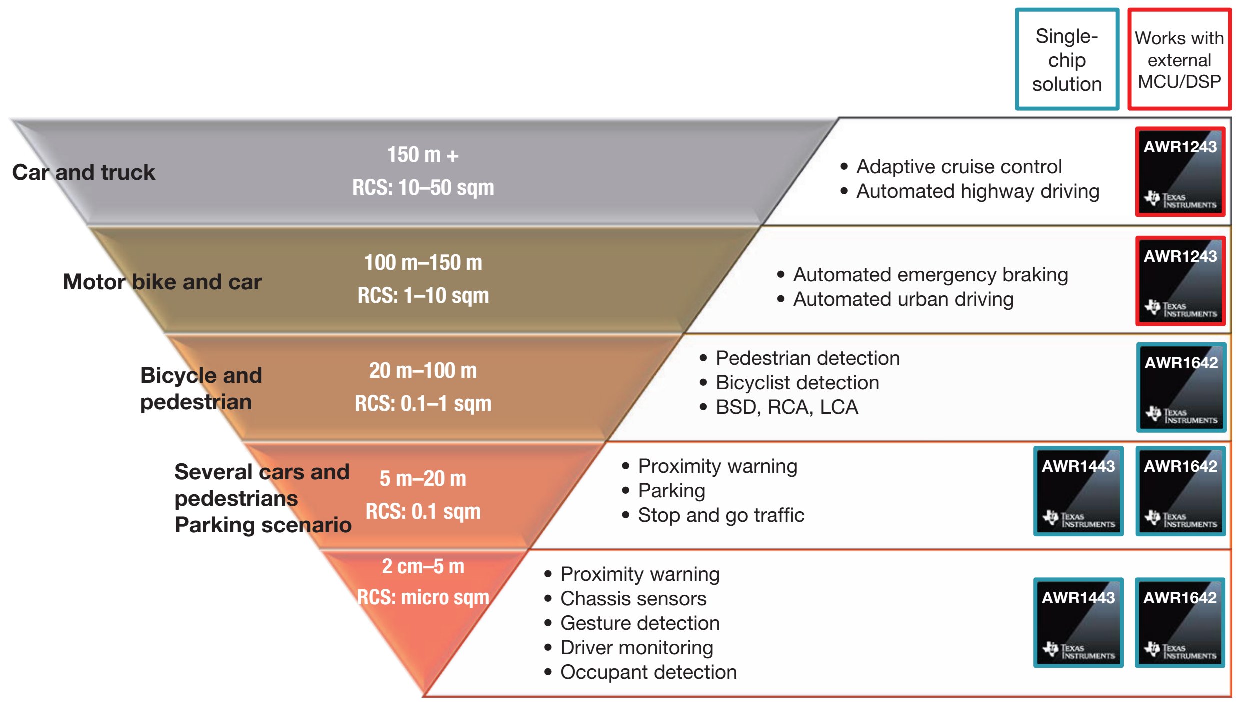

Figure 3. Radar sensor configurations.

Figure 3 maps AWR1x mmWave sensors into different ADAS, body and chassis, and in-cabin applications based on the range and type of the objects to be detected, as defined by radar cross-section (RCS).

Conclusion

The ability for developers to select the right solution for their design needs, makes these sensors extremely unique to the market. The level of integration and small footprint are enabling designers to add new features to existing applications. As the market adapts to ADAS and autonomous vehicles, TI's mmWave AWR1x sensor portfolio will provide the flexibility required.

For more information

To learn more about the portfolio visit:
www.ti.com/mmwave