Compact millimeter-wave sensors with integrated CAN modules are suitable for advanced driver assistance systems (ADAS). Texas Instruments (TI) has introduced the mm-wave family, which includes the CAN-connectable AWR1642.

Millimeter-wave sensors are not new. In the past, they were all discrete – with the transmitters, receivers, and the processing components as separate circuits. This made the design process of such sensor complex and the solution big and bulky.

As the number of radar sensors in vehicles climbs to at least 10 (front, rear, and corners), space constraints dictate that each sensor becomes smaller, consumes less power, and is more cost-effective. Some current radar systems under development will push the integration of the transmitter, receiver, clock, and baseband functionality into a single chip, which will reduce the number of front-end chips from four to one.

TI has taken integration to the next level, leveraging complementary metal-oxide semiconductor (CMOS) technology to integrate intelligent radar front ends with embedded micro-controllers (MCUs) and digital signal processing (DSP) capabilities. Processing is co-located with the front end to minimize radar system size, power, form factor and cost, further enabling the mounting of multiple radar systems in vehicles. Classical advantages of CMOS technology include higher transistor density and lower power consumption. Digital scaling in CMOS decreases the power and size and increases performance at every node. Driven by these digital transistor improvements, the speed of CMOS continues to increase and is now sufficient for 79-GHz ADAS applications. The 79-GHz band offers the 4-GHz bandwidth essential for higher-range resolution. Future radar systems will also need support for short range, with better angular resolution translating to more antennas in the radar systems. TI's sensors in CMOS technology can support this scalability to high-volume mass production.

By bucking the trend of traditional SiGe-based sensor technology, TI's RFCMOS-based radar sensors bring in a high-level of digital and analog integration to enable high-output power, low-power consumption (50 percent less compared to existing solutions in market) and low-phase noise, in turn resulting in accurate and ultra-high resolution.

TI's sensor family works on frequency modulated continuous waveform (FMCW) technique in the 76- to 81-GHz band. It has the following features:

- Closed-loop PLL (phase locked loop) enables linear and highly precise chirps, which helps with increased range accuracy;
- Ability to sweep the complete 4-GHz chirp bandwidth, which enables detection of objects spaced less than 5 cm apart;
- A complex receiver architecture that enables jamming or interference detection in a dense sensor environment;
- An intelligent self-monitoring system that self-calibrates across voltages and temperatures.
The AWR1642 comprises two transmitter and four receiver antennas targeted toward short-range and ultra-short-range applications like blind-spot detection, lane-change assistance, cross-traffic alert and stop and go. It comes with an on-chip ISO CAN FD module and SPI interfaces. The integrated circuit (IC) features 1.5 MiB of RAM, one Cortex-R4F processor, and one C674x DSP. The supplier has published a "short range radar reference design" document.

The presence of a hardware-in-loop (HIL) interface enables feeding of raw analog-to-digital converter (ADC) data collected in the field back to the sensor, which enables the analysis of the data path and algorithmic development. A crypto accelerator encrypts object/raw data sent to the engine control unit (ECU) through the ISO CAN FD interface.

Figure 1: Functions in the AWR1642 mm-wave sensor IC includes CAN connectivity (Photo: TI)

Dedicated for low-range applications

According to the Eno Center for Transportation, about 90 percent of car accidents are due to human error; many of the accidents caused by driver distraction. Cameras, 24-GHz radars, and ultrasonic sensors exist on the market to help address these problems, but the products may not be the best fit. The AWR1642 77-GHz single-mm-wave sensor with an integrated DSP (digital signal processor) (DSP) can work under any environmental condition like day, night, snow, rain, fog, and dust. It offers the below advantages compared to a 24-GHz sensor:

- 33 percent smaller form factor
- 50 percent less power consumption
- 10 times more range accuracy
- Cost-optimized bill of materials (BOM)

Figure 1: Functions in the AWR1642 mm-wave sensor IC includes CAN connectivity (Photo: TI)
The Cortex-R4F can run Autosar middleware clustering and tracking algorithms. For signal processing-intensive applications like FFT (Fast Fourier Transform) and object detection, the DSP can perform both fixed- and floating-point operations.

**Fundamentals of millimeter-wave sensors**

Millimeter-wave is a special class of radar technology that uses short wavelength electromagnetic waves. Radar systems transmit electromagnetic wave signals that objects

**Advanced driver assistance systems (ADAS) save lives**

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 as well as 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.

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 will eventually enable semi-autonomous and autonomous vehicles. 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 simple vehicle control actions. While current long-range radar (LRR) systems use the 76- to 77-GHz frequency, as higher levels of automated driving require higher range and resolution, front radar systems will likely use both the 76- to 77-GHz and 77- to 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 mm-wave sensor portfolio helps developers to create a safer and an emerging ADAS application for park-assist easier driving experience. Driver-assist features such as blind-spot and lane-departure warning use short-range radar (SRR) systems. These systems are expected to report or warn drivers using light-emitting diodes (LEDs) or steering-wheel vibration. While current SRR systems use the 24- to 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 LRR systems.

(Source: TI’s smart sensors designed for automated driving applications by Sneha Narnakaje. Texas Instruments, 2017)
in their path then reflect. By capturing the reflected signal, a radar system can determine the range, velocity, and angle of the objects. They transmit signals with a wavelength that is in the millimeter range. Indeed, the size of system components such as the antennas required to process mm-wave signals is small. Another advantage of short wavelengths is the high accuracy. An mm-wave system operating at 76 GHz to 81 GHz (with a corresponding wavelength of about 4 mm), has the ability to detect movements that are as small as a fraction of a millimeter.

A complete mm-wave radar system includes transmit (TX) and receive (RX) radio frequency (RF) components; analog components such as clocking; and digital components such as ADCs, MCUs, and DSPs. TI products implement a special class of mm-wave technology called FMCW. As the name implies, FMCW radars transmit a frequency-modulated signal continuously in order to measure range as well as angle and velocity. This differs from traditional pulsed-radar systems, which transmit short pulses periodically.

The fundamental concept in radar systems is the transmission of an electromagnetic signal that objects reflect in its path. In the signal used in FMCW radars, the frequency increases linearly with time. This type of signal is called a chirp. Figure 2 shows a representation of the chirp signal with magnitude (amplitude) as a function of time on the right. On the left, Figure 2 displays the same chirp signal with frequency as a function of time. The chirp is characterized by a start frequency \( f_c \), bandwidth \( B \), and duration \( T_c \). An FMCW radar system transmits a chirp signal and captures the signals reflected by objects in its path. Figure 3 represents a simplified block diagram of the main RF components of the FMCW radar; Figure 4 shows IF frequency.

Cesar Iovescu from TI describes in detail in his white paper “The fundamentals of millimeter sensors”, how the radars operate:

- The synthesizer (synth) generates the chirp signal;
- The transmit antenna (TX ant.) sends the chirp signal;
- The reflection of the chirp signal by an object generates the reflected chirp signal captured by the receive antenna (RX ant.);
- The “mixer” combines the RX and TX signals to produce an intermediate frequency (IF) signal.

Kvaser Delivers Custom Solutions for the CAN industry

In its simplest form, Kvaser’s OEM service is a private label, but it can be specific variants of drivers and firmware, PCB, casing, leads and connectors.
The frequency mixer is an electronic component that combines two signals to create a new signal with a new frequency. The operation of the frequency mixer can also be understood graphically by looking at TX and RX chirp frequency representation as a function of time (Figure 4). The upper diagram shows TX and RX chirps as a function of time for a single object detected. Notice that the RX chirp is a time-delay version of the TX chirp. To obtain the frequency representation as a function of time of the IF signal at the output of the frequency mixer, subtract the two lines presented in the upper section of the figure. The distance between the two lines is fixed, which means that the IF signal consists of a tone with a constant frequency. The IF signal is only valid in the time interval, in which both the TC chirp and the RX chirp overlap. The mixer output signal as a magnitude function of time is a sine wave, since it has a constant frequency.

When multiple objects are detected, each chirp is delayed by a different amount of time proportional to the distance to that object. The different RX chirps translate to multiple IF tones, each with a constant frequency. Using a Fourier transforms, this IF signal (consisting of multiple tones) can be processed. This separates the tones and results in a frequency spectrum that has separate peaks for the different tones.

When two objects move closer, at some point, a radar system is not able to distinguish them as separate objects. Fourier transform theory states that you can increase the resolution by increasing the length of the IF signal. To do so, the bandwidth needs to be increased proportionally. Thus the FMCW radar with a chirp bandwidth of a few GHz has a range resolution of some centimeter (e.g. a 4-GHz bandwidth translates to a range resolution of 3.75 cm).

In order to measure velocity, the FMCW radar exploits phase change across chirps separated in time. The FMCW radar transmits a set of N equi-spaced chirps called a frame. Each reflected chirp is processed by a first FFT, called range-FFT, to detect the range of the object. A second FFT, called doppler-FFT, is performed to determine the velocity. Velocity resolution defines the ability to distinguish between two different speeds. The shorter the frame length, the higher the velocity resolution. Since velocity is computed based on phase change, there is an ambiguity. Maximum velocity that can be unambiguously measured is inversely proportional to the time Tc between consecutive chirps.

An FMCW radar can also estimate the angle of a reflected signal with the horizontal plan. This angle is called angle of arrival (AoA). Angular estimation is based on the observation that a small change in the distance results in a phase change in the peak of the range-FFT or Doppler-FFT. Using two RX antennas, you can measure the differential distance from the object to each of the antennas. The phase change enables you to estimate the AoA.

To summarize, an FMCW sensor is able to determine the range, velocity, and angle of nearby objects using a combination of RF, analog, and digital electronic components. The block diagram of TI's single-chip mm-wave sensor shows the necessary components. The sensor is able to store 512 chirps with four profiles before a frame starts. This capability allows the product to be easily configured with multiple configurations to maximize the amount of useful data extracted from a scene. Individual chirps and the processing back-end can be tailored "on-the-fly" for real-time application needs such as higher range, higher velocities, higher resolution, or specific processing algorithms.

Of course, the AWR1642 is not only suitable for applications in passenger cars, but also in commercial vehicles including mobile machinery and in other self-moving systems including service robots and automatic guided vehicles. For low-volume applications, a standardized CANopen or J1939 profile would simplify system integration.

Author

Holger Zeltwanger
CAN Newsletter
pr@can-cia.org
www.can-newsletter.org
HY-TTC 32 - Compact Control Unit for Cost-Sensitive Applications, Smaller Machines and Implements

Flexibility and User Friendliness
- Extensive I/O set (30 Inputs / Outputs with various options for configurability by software)
- CAN with automatic baud-rate detection
- Programmable in C/C++ or CODESYS® including support for CANopen® master
- 1 x CAN bus termination configurable via connector pin

Safety
- Certified according to EN ISO 13849 PL c
- CANopen safety protocol (CiA 304) according to EN 50325-5

Robustness and Availability
- Aluminum die-cast housing for extremely rough work conditions
- Maximum current up to 24 A

Connectivity
- 2 x CAN 125 kbit/s up to 1 MB/s
- CANopen conformity

Performance
- Infineon XC22xx CPU running at 80 MHz
- 768 kByte int. Flash, 82 kByte int. RAM, 8 kByte EEPROM

www.ttcontrol.com/HY-TTC-32-ECU