RADAR for Autonomous Driving Cars

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TEXAS INSTRUMENT FMCW RADAR

Texas Instruments (TI) Frequency Modulated Continuous Wave (FMCW) radar operates by sending out a continuous signal that changes frequency over time. By comparing the frequency of the transmitted signal to the received one, the radar can calculate the distance and speed of objects. This method allows for precise measurements, making FMCW radar highly effective.

Signal Transmission

The radar system continuously transmits a signal. Unlike pulsed radar systems that send out short bursts of energy, FMCW radar emits a continuous wave. This wave is modulated in frequency, meaning that its frequency changes in a known pattern over time. Typically, the frequency increases linearly over a period, then ramps back down, forming a sawtooth or triangular wave pattern. This modulation is what allows the radar to measure distances and velocities with high precision.

Frequency Modulation

The transmitted signal’s frequency varies over time in a controlled manner. This modulation is essential because it creates a unique signature that can be compared against the received signal. The frequency of the signal at any point in time is known and controlled by the radar’s internal systems, allowing for precise calculations when the signal returns.

Signal Reception

When the transmitted signal hits an object, it reflects back to the radar. The radar system then receives this reflected signal. Due to the time delay caused by the distance the signal has traveled, the received signal will have a different frequency compared to the transmitted signal at that instant.

Frequency Comparison

The core of FMCW radar’s operation is the comparison between the transmitted and received signals. The radar mixes these two signals, and the difference in their frequencies (known as the beat frequency) is directly proportional to the distance of the object. This is because the time delay (and thus the frequency difference) increases with the distance the signal travels.

Calculating Distance

By analyzing the beat frequency, the radar system can determine the round-trip time of the signal. Since the speed of the signal is known (the speed of light), this time can be converted into a distance measurement. The formula used is:

$$\text{Distance} = \frac{\text{speed of light X Beat frequency}}{\text{2Xfrequency modulation rate}}$$

This calculation gives a precise measurement of how far away the object is from the radar.

Measuring Speed

In addition to distance, FMCW radar can measure the relative speed of an object. If the object is moving, the frequency of the reflected signal will be shifted due to the Doppler effect. By analyzing this frequency shift, the radar can determine how fast the object is moving toward or away from it. The Doppler shift adds another component to the beat frequency, which can be isolated and measured to determine velocity.

Advantages of FMCW Radar

FMCW radar offers several advantages:

- **High Precision**: The continuous nature of the signal and the detailed frequency analysis allow for very precise measurements of both distance and speed.
- **Robust Performance**: FMCW radar systems are less affected by noise and interference, making them reliable in various environmental conditions.
- **Real-Time Data**: The continuous wave and frequency modulation allow for real-time processing and quick response times, essential for applications like autonomous driving and industrial automation.

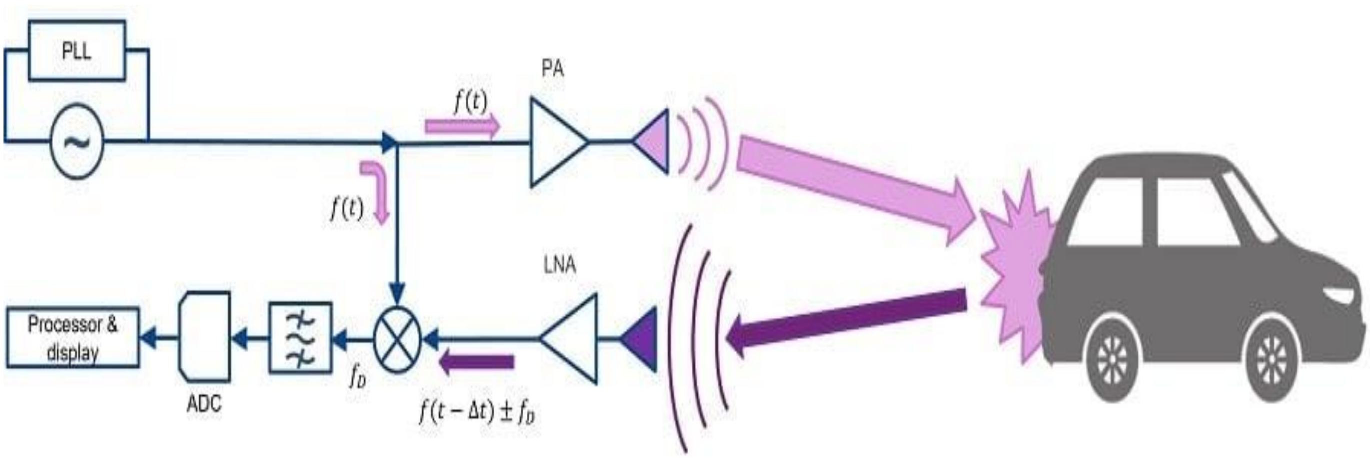

Figure 1. FMCW automotive radar – Principle and building blocks

The operation of TI’s FMCW radar involves sending out a continuously varying frequency signal, receiving the reflected signal, and comparing the two to measure distance and speed. This technology’s ability to provide accurate, real-time measurements makes it highly effective for a wide range of applications, from automotive safety to industrial monitoring

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AWR1642

The TI AWR1642 is a highly integrated, single-chip radar sensor designed for automotive use. Operating in the 76-81 GHz frequency range, it is built using TI’s 45-nm RFCMOS technology, which allows for a compact and low-power design. This chip includes:

- **2 Transmitters and 4 Receivers**: For detailed and accurate radar sensing.
- **Integrated Signal Processing**: With a high-performance DSP for processing radar signals.
- **ARM Processor**: Manages the radar's configuration, control, and calibration.

The AWR1642 supports flexible sensor configurations (short, mid, long range) and dynamic reconfiguration for multimode sensing. It comes with comprehensive support including reference designs, software drivers, sample configurations, and documentation, making it easier for developers to implement advanced radar systems in vehicles.

Features:

- **Compact Design**: Small form factor ideal for integration into automotive systems.
- **High Integration**: Combines multiple radar components into a single chip.
- **Flexible Sensing**: Can be programmed for different range requirements and reconfigured dynamically.
- **Complete Platform**: Provides all necessary tools and documentation for implementation.

The TI AWR1642 is a single-chip FMCW radar sensor designed for automotive applications, operating in the 76-81 GHz band. Built on TI's 45-nm RFCMOS process, it integrates 2 transmitters, 4 receivers, a high-performance DSP for radar signal processing, and an ARM processor for control and calibration. This compact, low-power chip supports various sensing configurations (short, mid, long range) and dynamic reconfiguration. It comes with comprehensive support including reference designs, software drivers, and documentation for easy implementation.

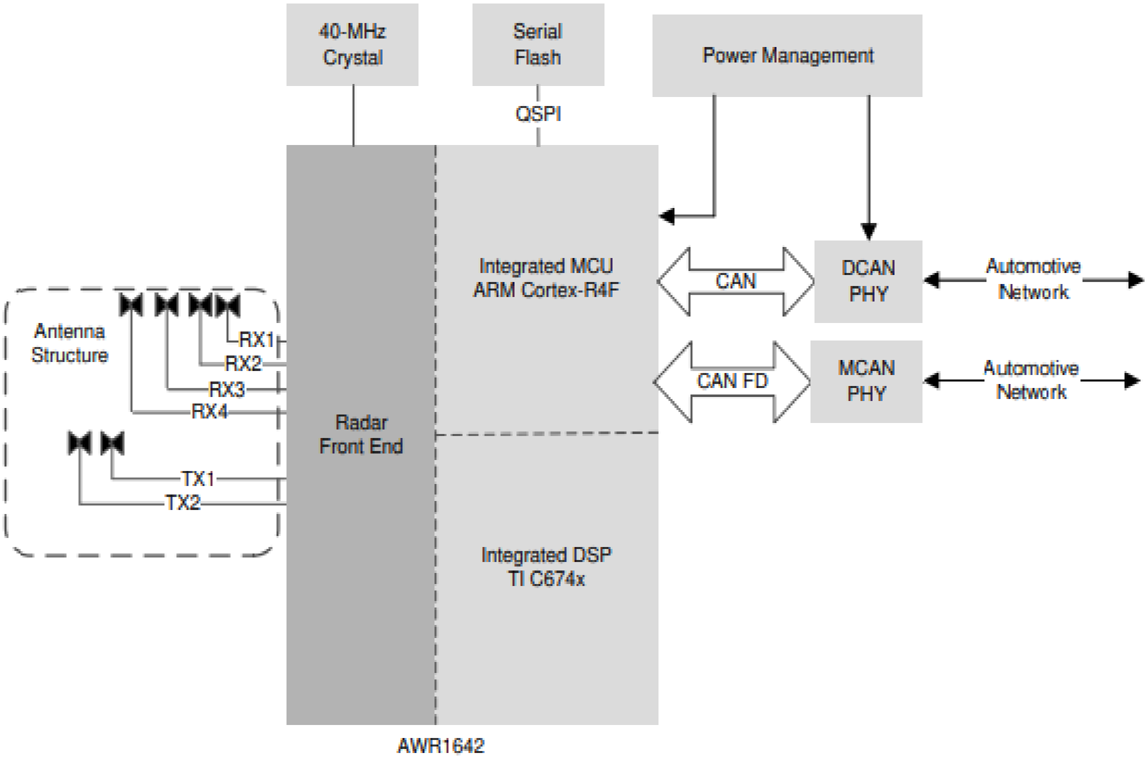

Figure 2-1. Autonomous Radar Sensor For Automotive Applications

The AWR1642 is a single-chip 77- and 79-GHz frequency-modulated continuous-wave (FMCW) radar sensor developed by Texas Instruments. Here are the main aspects of the AWR1642:

Key Features:

1. **FMCW Transceiver:**
   - Integrated Phase-Locked Loop (PLL), transmitter, receiver, baseband, and Analog-to-Digital Converter (ADC).
   - Operates in the 76-81 GHz band with 4 GHz available bandwidth.
   - Four receive channels and two transmit channels.
   - Ultra-accurate chirp (timing) engine based on fractional-N PLL.
   - Transmit power: 12 dBm.
   - Receive noise figure: 14 dB (76-77 GHz), 15 dB (77-81 GHz).
   - Phase noise at 1 MHz offset: -95 dBc/Hz (76-77 GHz), -93 dBc/Hz (77-81 GHz).
2. **Integrated Systems:**
   - ARM Cortex-R4F-based radio control system.
   - Built-in firmware and self-calibrating system across process and temperature.
   - C674x Digital Signal Processor (DSP) for FMCW signal processing.
   - On-chip memory: 1.5MB.
3. **Peripheral Interfaces:**
   - Host interfaces: CAN and CAN-FD.
   - Additional interfaces: up to 6 ADC channels, 2 SPI channels, 2 UARTs, I2C, GPIOs, and 2-lane LVDS interface for raw ADC data and debug instrumentation.
4. **Device Security:**
   - Secure authenticated and encrypted boot support.
   - Customer programmable root keys and cryptographic software accelerators.

5. **Functional Safety:**
    - Developed for functional safety applications, with documentation available for ISO 26262 functional safety system design up to ASIL-D.
    - ISO 26262 certified up to ASIL B by TUV SUD.
    - AEC-Q100 qualified.
6. **Power Management:**
    - Built-in LDO network for enhanced Power Supply Rejection Ratio (PSRR).
    - I/Os support dual voltage 3.3 V/1.8 V.
7. **Hardware Design:**
    - Compact 0.65-mm pitch, 161-pin 10.4 mm × 10.4 mm flip-chip BGA package.
    - Operating temperature range: –40°C to 125°C.

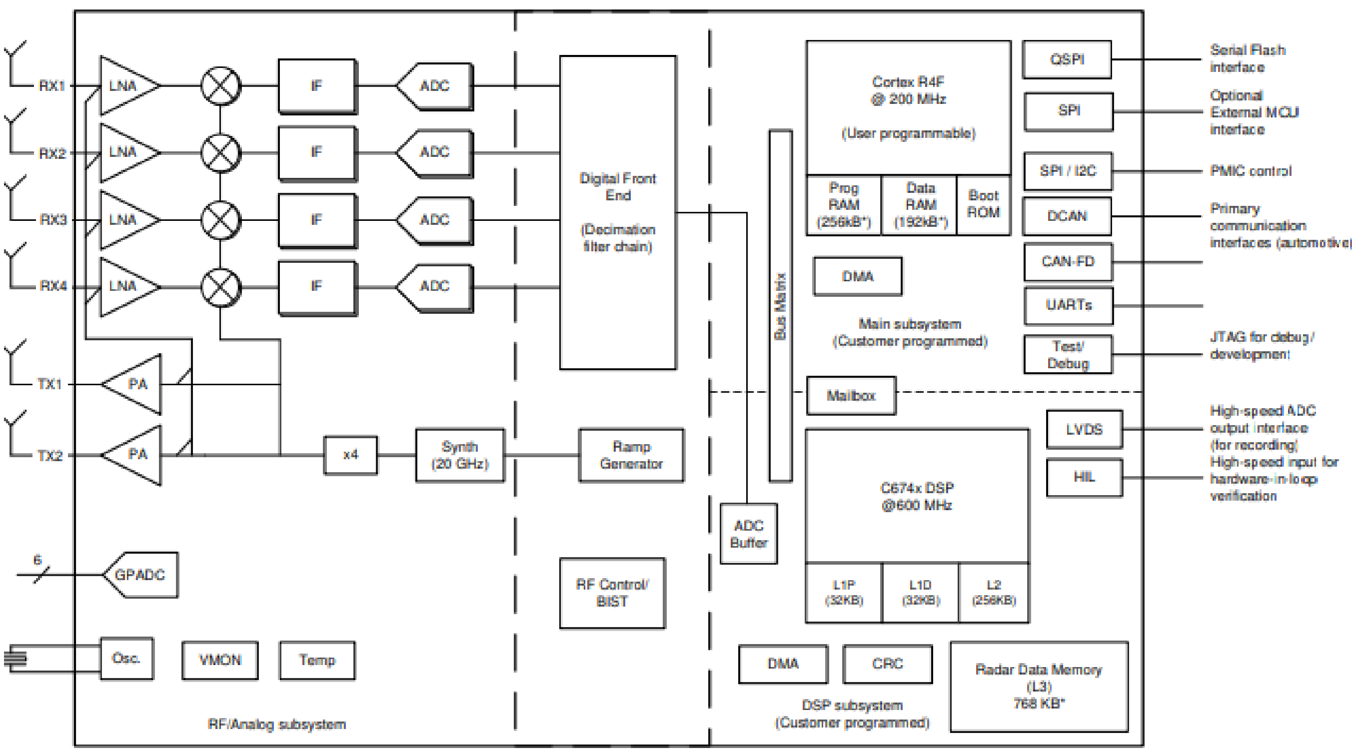

Figure-Functional Block Diagram

RF/Analog Subsystem:

- **RX1 to RX4 (Receiver Channels):**
    - **LNA (Low Noise Amplifier):** Amplifies the received RF signals with minimal added noise.
    - **IF (Intermediate Frequency):** Converts the amplified signals to an intermediate frequency.
    - **ADC (Analog-to-Digital Converter):** Converts the analog IF signals to digital signals for processing.
- **TX1 and TX2 (Transmitter Channels):**
    - **PA (Power Amplifier):** Amplifies the RF signals for transmission.
- **Synth (Synthesizer):** Generates the LO (Local Oscillator) signals needed for frequency conversion.
- **Ramp Generator:** Generates the frequency-modulated signals (chirps) used in FMCW radar.
- **GPADC (General-Purpose ADC):** Used for auxiliary measurements (e.g., monitoring power supply voltages).

- **Osc (Oscillator):** Provides the reference clock signal for the synthesizer.
- **VMON (Voltage Monitor) and Temp (Temperature Sensor):** Monitor the operational environment of the chip.

Digital Front End:

- Processes the digitized signals from the ADCs. Includes a decimation filter chain to reduce the data rate and improve signal-to-noise ratio.

Main Subsystem:

- **ARM Cortex-R4F (200 MHz):**
  - **Prog RAM (256 KB):** Program memory for storing the code executed by the Cortex-R4F.
  - **Data RAM (192 KB):** Data memory for storing variables and intermediate data.
  - **Boot ROM:** Contains the firmware that runs at startup.
  - **DMA (Direct Memory Access):** Allows efficient data transfer without CPU intervention.
- **Mailbox:** Communication interface between the ARM Cortex-R4F and the DSP subsystem.

DSP Subsystem:

- **C674x DSP (600 MHz):**
  - **L1P (32 KB):** Level 1 program cache.
  - **L1D (32 KB):** Level 1 data cache.
  - **L2 (256 KB):** Level 2 cache/shared memory.
  - **Radar Data Memory (L3 - 768 KB):** Large memory space for radar data storage and processing.
- **DMA:** Direct Memory Access for efficient data transfer within the DSP subsystem.
- **CRC (Cyclic Redundancy Check):** Ensures data integrity during transfers.

Interfaces:

- **GSPI (General Serial Peripheral Interface):** For serial communication.
- **SPI (Serial Peripheral Interface):** For communication with peripheral devices.
- **DCAN and CAN-FD (Controller Area Network - Flexible Data rate):** For automotive communication.
- **I2C:** For communication with low-speed peripherals.
- **UARTs:** Universal Asynchronous Receiver-Transmitters for serial communication.
- **Test/Debug:** JTAG interface for debugging and development.
- **LVDS (Low Voltage Differential Signaling):** High-speed data output for raw ADC data and debug.
- **HIL (Hardware in Loop):** For real-time hardware testing and validation.

Additional Features:

- **RF Control/BIST (Built-In Self-Test):** Controls the RF subsystem and provides self-test capabilities.
- **PMIC (Power Management IC) Control:** Manages power supplies.
- **Primary Communication Interface:** Main communication interface for automotive applications.
- **High-Speed ADC Output Interface:** Outputs high-speed ADC data for external processing.

TRANSMITTER

Components and Functions:

1. **PCB (Printed Circuit Board):**
   - The interface where the transmit subsystem is mounted, connecting the chip to the external components.
2. **Package:**
   - The physical housing of the chip that contains the transmit subsystem circuitry.
3. **12 dBm @ 50 Ω:**
   - This indicates the output power and impedance matching of the transmit signal. The subsystem outputs a signal at 12 dBm power and 50 ohms impedance.
4. **Loopback Path:**
   - A feedback path used for self-test purposes. This allows the system to verify the functionality of the transmit subsystem by routing the transmitted signal back to the receiver.
5. **Fine Phase Shifter:**
   - Controls the phase of the transmitted signal with high precision. It receives a control signal (6 bits) to adjust the phase and an input from the timing engine that can switch the phase by 0 or 180 degrees.
6. **LO (Local Oscillator):**
   - Provides the reference frequency signal for the transmit subsystem. This signal is modulated to create the desired transmit signal.

Signal Path:

1. **Input Path:**
   - The input RF signal from the LO is first routed through a phase shifter that allows fine control of the signal phase.
   - The phase shifter receives phase control signals that adjust the phase of the LO signal precisely.
2. **Amplification:**
   - The phase-shifted signal is then amplified by a series of amplifiers (shown as multiple amplifier stages) to achieve the desired output power level (12 dBm).
3. **Output Path:**
   - The amplified signal is then transmitted out of the chip, through the package, and onto the PCB to the antenna or other external components.
4. **Self-Test:**
   - The loopback path is used to reroute the transmitted signal back into the system for testing purposes. This helps in verifying the integrity and functionality of the transmit path.
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- The transmit subsystem of the AWR1642 is responsible for generating and transmitting the radar signal.
- It includes components for precise phase control, amplification, and self-test capabilities.
- The fine phase shifter ensures accurate signal modulation, while the loopback path allows for functional testing of the transmit subsystem

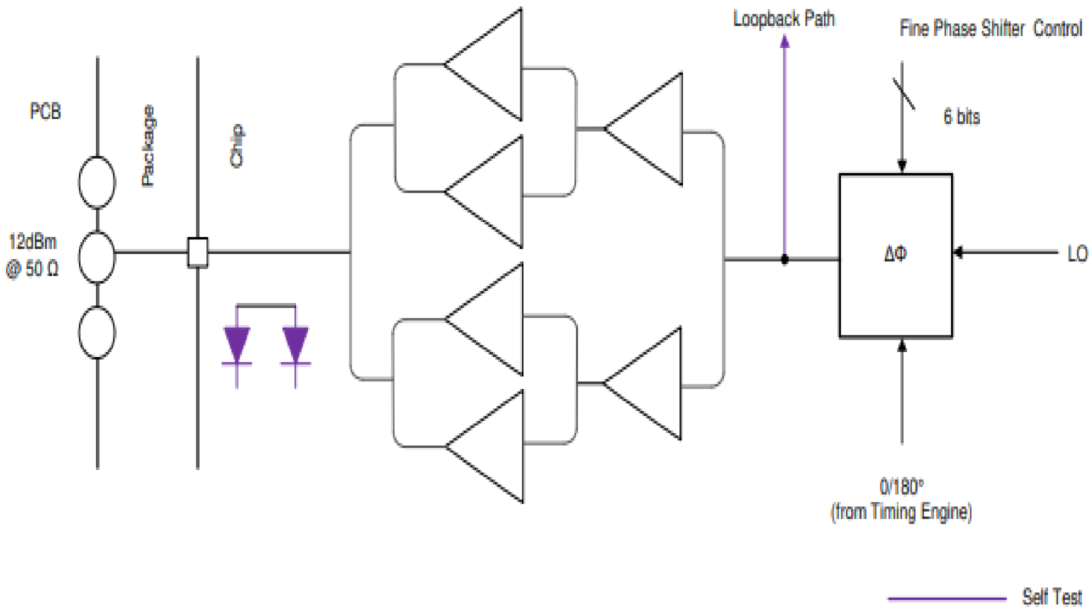

Figure-Transmitter Block Diagram

1. The receive subsystem of the AWR1642 is responsible for capturing and processing the radar signals received by the antenna. It includes components for amplification, frequency conversion, digital conversion, and signal correction.
2. The loopback path and DAC allow for self-test capabilities to ensure the proper functionality of the receive path.
3. This subsystem ensures accurate and reliable reception of radar signals, which is critical for various automotive radar applications.

RECEIVER

Components and Functions:

1. **PCB (Printed Circuit Board):**
   - The interface where the receive subsystem is mounted, connecting the chip to external components such as antennas.
2. **Package:**
   - The physical housing of the chip that contains the receive subsystem circuitry.
3. **50 Ω GSG (Ground-Signal-Ground):**
   - Indicates the impedance and the type of transmission line used for the signal path.
4. **Loopback Path:**
   - Used for self-test purposes, routing a known signal through the receive path to verify functionality.
5. **LNA (Low Noise Amplifier):**
   - Amplifies the received RF signal with minimal added noise.
6. **Mixer:**
   - Converts the amplified RF signal to baseband by mixing it with the local oscillator (LO) signal, producing in-phase (I) and quadrature (Q) components.
7. **DAC (Digital-to-Analog Converter):**
   - Used in the feedback path for self-test, generating test signals.

8. **ΔΣM (Delta-Sigma Modulator):**
   - Converts the analog baseband signals to a digital format with high resolution.
9. **Saturation Detect:**
   - Monitors the signal levels to detect and handle saturation conditions.
10. **Decimation:**
    - Reduces the sampling rate of the digital signals, lowering the data rate and improving the signal-to-noise ratio.
11. **IQ Correction:**
    - Corrects any imbalances between the I and Q components to ensure accurate signal representation.
12. **RSSI (Received Signal Strength Indicator):**
    - Measures the strength of the received signal for further processing or feedback.
13. **Image Rejection:**
    - Filters out unwanted mirror frequencies that may interfere with the desired signal.
14. **ADC Buffer:**
    - Temporarily stores the processed digital signals before further processing or transmission to the main subsystem.

Signal Path:

1. **Input Path:**
   - The received RF signal from the antenna enters the chip and is first amplified by the LNA.
   - The amplified signal is then mixed with the LO signal to produce I and Q baseband components.
2. **Digital Conversion:**
   - The I and Q signals are digitized by the Delta-Sigma Modulators (ΔΣM), converting them to high-resolution digital signals.
   - The DAC generates test signals for self-test purposes.
3. **Processing:**
   - The digital signals undergo decimation to reduce the data rate.
   - IQ correction adjusts for any imbalances between the I and Q signals.
   - RSSI measures the strength of the received signals.
   - Image rejection filters out unwanted frequencies.
4. **Output Path:**
   - The processed digital signals are stored in the ADC buffer before being sent to the main subsystem for further processing or analysis.

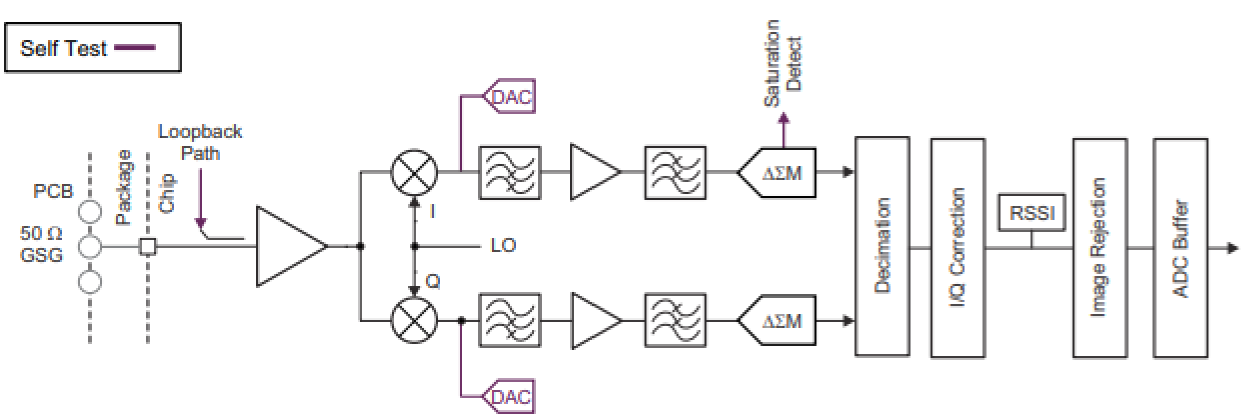

Figure-Receiver Block Diagram

• The receive subsystem of the AWR1642 is responsible for capturing and processing the radar signals received by the antenna.

• It includes components for amplification, frequency conversion, digital conversion, and signal correction.

• The loopback path and DAC allow for self-test capabilities to ensure the proper functionality of the receive path.

• This subsystem ensures accurate and reliable reception of radar signals, which is critical for various automotive radar applications.

PROCESSING SYSTEM

DSP Subsystem:

- **DSP (Digital Signal Processor):**
  - **L1P (32KB):** Level 1 program cache.
  - **L1D (32KB):** Level 1 data cache.
  - **L2 (128KB x 2):** Unified level 2 cache and RAM.
- **EDMA (Enhanced Direct Memory Access):**
  - Facilitates efficient data transfer within the DSP subsystem without CPU intervention.
- **HIL (Hardware-in-Loop):**
  - Enables real-time hardware testing and validation.
- **DSP Interconnect:**
  - A 128-bit bus running at 200 MHz that connects various DSP components, enabling high-speed data transfer.
- **ADC Buffer (32KB Ping-Pong):**
  - Temporarily stores the data from the ADC before it is processed by the DSP.
- **L3 Memory (768KB):**
  - Shared static memory for data storage, accessible by both the DSP and RF subsystems.
- **Data Handshake Memory (32KB):**
  - Facilitates data transfer and synchronization between different processing units.
- **CRC (Cyclic Redundancy Check):**
  - Ensures data integrity by checking for errors during data transfer.
- **LVDS (Low Voltage Differential Signaling):**
  - High-speed interface for transferring raw ADC data and other high-speed data.

Main Subsystem:

- **Main R4F:**
  - **ROM:** Read-only memory for boot and firmware storage.
  - **TCM A (256KB):** Tightly coupled memory A for high-speed access.
  - **TCM B (192KB):** Tightly coupled memory B for high-speed access.
- **MSS DMA (Microcontroller Subsystem Direct Memory Access):**
  - Facilitates efficient data transfer within the main subsystem.
- **Mailbox:**
  - Communication interface between the main microcontroller and the DSP subsystem.
- **BSS Interconnect:**
  - Bridge subsystem interconnect for communication between the main subsystem and other parts of the chip (not detailed in this diagram).
- **Main Interconnect:**
  - A bus system that connects various components of the main subsystem, facilitating data transfer and communication.

Interfaces:

- **SPI (Serial Peripheral Interface):**
  - For communication with peripheral devices.
- **UART (Universal Asynchronous Receiver-Transmitter):**
  - For serial communication.
- **I2C (Inter-Integrated Circuit):**
  - For communication with low-speed peripherals.
- **QSPI (Quad Serial Peripheral Interface):**
  - For high-speed serial communication.
- **CAN FD (Controller Area Network - Flexible Data rate):**
  - For automotive communication.
- **CAN:**
  - Standard CAN interface for automotive communication.
- **PWM (Pulse Width Modulation):**
  - For generating precise timing pulses.
- **PMC (Power Management Control):**
  - For managing power supply to the various components.
- **CLK (Clock):**
  - For synchronizing operations of the different subsystems.

Debug and Test:

- **JTAG:**
  - For debugging and development.
- **CRC (Cyclic Redundancy Check):**
  - For data integrity verification.
- **HIL (Hardware-in-Loop):**
  - For real-time hardware testing and validation.

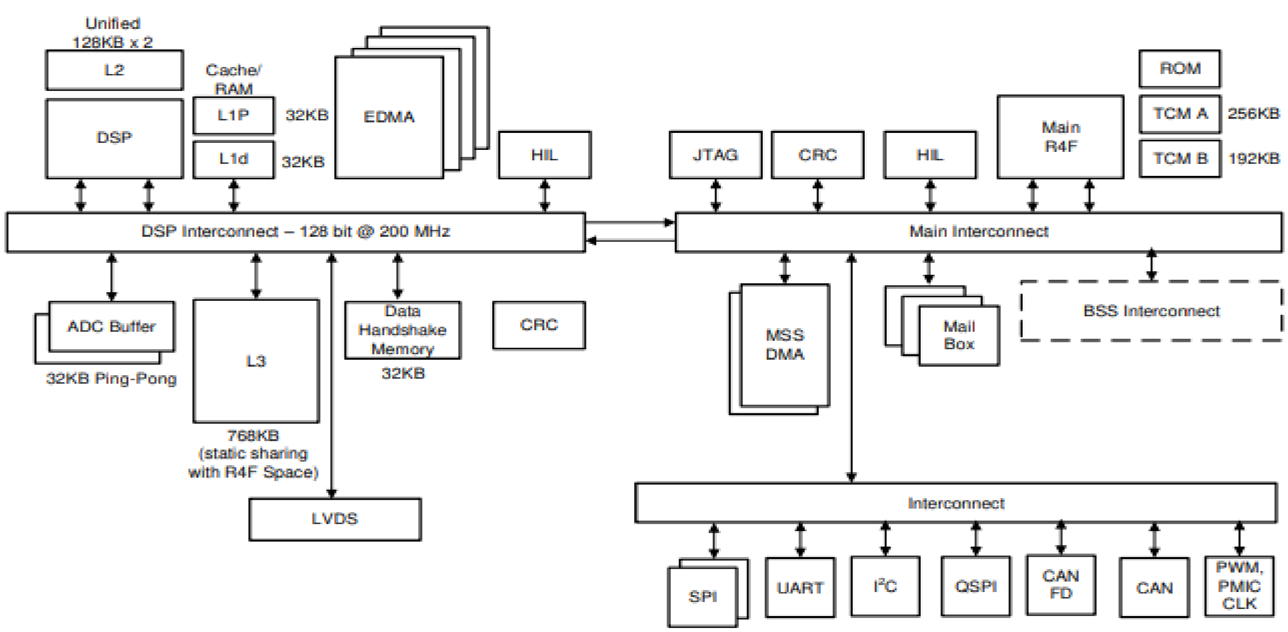

Figure-Processing system Block Diagram

APPLICATIONS

Automotive Applications:

1. **Adaptive Cruise Control (ACC):**
   - Monitors the distance and relative speed of vehicles ahead to maintain a safe following distance by automatically adjusting the vehicle's speed.
2. **Automatic Emergency Braking (AEB):**
   - Detects imminent collisions with vehicles or obstacles and applies the brakes automatically to prevent or mitigate accidents.
3. **Blind Spot Detection (BSD):**
   - Monitors adjacent lanes and areas behind the vehicle to alert the driver about vehicles in their blind spots.
4. **Lane Change Assist (LCA):**
   - Helps in detecting vehicles in adjacent lanes and provides warnings when it is unsafe to change lanes.
5. **Parking Assistance:**
   - Detects obstacles around the vehicle to facilitate safer parking maneuvers and avoid collisions.
6. **Pedestrian Detection:**
   - Identifies pedestrians around the vehicle, enhancing safety by preventing accidents involving pedestrians.

Industrial Applications:

1. **Building Security:**
   - Used for perimeter monitoring and intrusion detection in security systems to enhance building security.
2. **Industrial Automation:**
   - Detects objects and humans in industrial environments, ensuring safety and improving automation processes.
3. **Level Sensing:**
   - Measures the level of materials in tanks or silos, providing accurate real-time data for inventory management.
4. **Traffic Monitoring:**
   - Monitors traffic flow and vehicle speed, contributing to traffic management and safety systems.
5. **Drones and Robotics:**
   - Provides obstacle detection and navigation capabilities for drones and autonomous robots, enabling safer and more efficient operations.

Healthcare Applications:

1. **Elderly Care:**
   - Monitors movements and detects falls in elderly care facilities, ensuring timely assistance and enhancing the safety of elderly individuals.
2. **Patient Monitoring:**
   - Enables non-contact monitoring of vital signs, such as heart rate and respiration rate, providing continuous health monitoring.

Smart Home Applications:

1. **Intrusion Detection:**
    - Part of home security systems, detecting unauthorized entry and alerting homeowners.
2. **Occupancy Sensing:**
    - Detects the presence of people in rooms to optimize heating, cooling, and lighting systems, enhancing energy efficiency and comfort.

The AWR1642 radar sensor's high precision, reliability, and adaptability make it suitable for a wide range of applications. Its ability to provide accurate distance, speed, and angle measurements in challenging environments makes it an essential component in enhancing safety, automation, and efficiency across automotive, industrial, healthcare, and smart home sectors.

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