ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

HIGH PERFORMANCE INTEGRATED 24GHz FMCW RADAR TRANSCEIVER CHIPSET FOR AUTO AND INDUSTRIAL SENSOR APPLICATIONS

John Morrissey and
Patrick Walsh
Analog Devices Inc.

24 GHz Radar Technology Enable Next Generation Sensors

24 GHz Radar based Millimeter Wave Sensors are increasingly being used in automotive, industrial and consumer applications to provide users critical real time information such as presence, movement, velocity and distance. Up until recently Radar transceivers supporting these high frequency sensor applications were realized with complex and costly discrete chip and wire technology limiting broad market adoption. Now fully monolithic 24 GHz radar transceivers chips from Analog Devices are available that provide the performance, size, cost and ease of use that system designers demand for their next generation sensor products. Analog Devices has developed a multi-channel transceiver chip sets supporting the expanding MMW sensor market. Narrowband 24 GHz ISM band applications are supported, such as complex FMCW based Advanced Driver Assistance Systems with full AECQ100 certification, Traffic Monitoring & Lighting down to simpler Doppler Radar based Motion and Occupancy Detection systems. In addition applications such as Tank Gauging and

Process Automation are supported with these innovative chipsets.

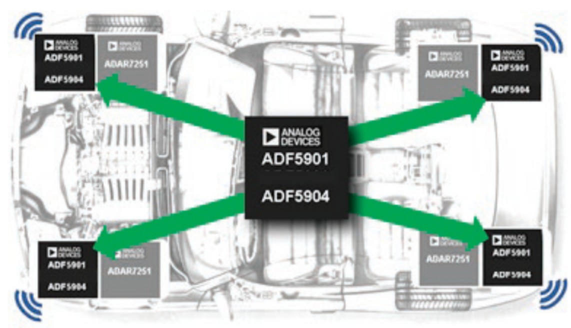

Figure 1. ADI's 24 GHz ISM Band Multi-channel radar chipset enables auto & industrial radar sensors

ADF5904, four-channel, 24-GHz Receiver MMIC

The ADF5904 is 4-channel 24-GHz Rx MMIC where the four RF channels are down converted in frequency to differential baseband signals which can then drive directly into a specialized multi-channel A/D converter to digitize the incoming analog receiver signals. These digital signals can be interrogated using Fast Fourier transforms or FFT's and other sophisticated radar detection software algorithms running on a system microprocessor to enable the detection of targets that appear in front of the radar sensor system and enable the calculation of the target speed, distance and position.

The ADF5904 down converts the receiver signals using the local oscillator input signal or LO source that is generated on the transmitter companion IC, called the ADF5901. All the RF inputs on the ADF5904 are simple single-ended inputs, and these are internally connected to the integrated baluns used to convert the Rx signals to differential signals achieving higher performance amplification and down conversion processing. The single-ended RF interface connections eases the PCB design task considerably in designing the RF port connections of the IC to the printed circuit board (PCB) antennas where 50-Ω PCB line traces are only required without the need for external matching passive components, saving considerable board space. One of many of the ADF5904's technical highlights is that it achieves world-class Rx to Rx channel isolation performance of 30 dB even with this high level of integration in a low-cost plastic package. Careful RF layout around the Rx input pins is required to maintain this excellent 30-dB Rx to Rx isolation performance.

Each of the four Rx signal paths contains a low noise amplifier (LNA) followed by a low noise mixer and a differential output amplifier. The four channels share the LO signal generated from the ADF5901 chip. The overall Rx chain has a fixed gain of 22 dB with a P1 dB of -10 dBm, and the low-noise design yields a noise figure of 10 dB for the Rx signal chain, while achieving a very low power consumption figure of 550 mW even with all four Rx channels powered-on together and powered from a single 3.3 v supply. Of course, with power-on duty cycling of the system, the overall power consumption can be reduced even further and unused Rx channels can be powered down individually to allow for even more power consumption and thermal management savings. The ADF5904 contains an on-chip temperature sensor which is connected as an analog voltage to the Atest pin allowing monitoring of the system temperature. The ADF5904 offer simple control over a four- wire SPI with the DOUT pin allowing for read-back of the registers to check for correct write operation to the chips control registers.

ADF5901, two-channel, 24-GHz Transmit MMIC

The ADF5901 is a 24-GHz Tx MMIC with on-chip 24-GHz VCO spanning the 250-MHz ISM band from 24 GHz to 24.25 GHz connected to two Tx PAs that can deliver 8 dBm output power, an LO output to drive the Rx MMIC ADF5904 and differential auxiliary outputs to allow for close-loop control with the ADF4159 ramp generation PLL. When combined together the chipset completes an RF signal chain for a 24-GHz ISM radar system.

The on-chip VCO that drives the Tx outputs on the part is frequency- and power-calibrated to ensure operation within the ISM band and maintain the optimum VCO power levels to ensure superior phase noise performance @ -108 dBc/Hz @ 1-MHz offset. The part also contains Tx output power calibration circuits to calibrate the Tx output power to ensure power remains within the allowed power level limits. The calibration circuits run from an external reference clock supplied to the part on REF_{IN} pin; the same reference clock can be shared with the reference input on the ADF4159 PLL.

To accommodate the power calibration there are on-chip power detectors on the TX outputs to measure the power at the Tx output pins. The power detectors are used as part of the calibration engine to control the output power. The output power calibration is accurate over temperature and supply.

The VCO frequency calibration is performed using the on chip R (Reference) and N (RF) divider-counters which are used to compare the divided-down RF signal to a known frequency signal from the reference clock.

This N counter block can also be used to feed the MUOUT pin to allow for operation of the chip in open loop frequency discriminator systems. This then requires extra external monitoring circuits to measure the divided-down VCO frequency and a D/A converter to adjust the Vtune pin of the part to ensure that itis operating within the ISM band. Also, temperature variations must be taken into account when using this open loop method to ensure the frequency does not drift outside the ISM band. All of this will require intervention from the DSP to carry out the calibration. The closed-loop system using the ADF4159 eliminates this extra DSP workload as the closed-loop PLL ensures that the frequency is correct and has no temperature or supply voltage variation effects, which makes this device more robust and easy to use.

The two Tx outputs on the ADF5901 are controlled individually to allow for virtual antenna and MIMO operation of the radar sensor.

The Tx and LO outputs on the ADF5901 are single-ended outputs to ease in the RF interface to the part and reduce the PCB design task with only 50-Ω PCB traces required.

The LO output on the ADF5901 delivers a fixed output power which is used to drive the LO input on the ADF5904 RX chip. The power level is sufficient to allow it to drive multiple ADF5904 receiver parts with the need for external components to allow for scalable systems with higher Rx channel count.

The differential auxiliary outputs allow for divide by two or divide by four outputs from the fundamental VCO frequency so either 12-GHz or 6-GHz outputs are available which allow either the ADF4158 or ADF4159 ramp-generation PLL's to be used in the feedback path to lock the ADF5901 VCO and generate the highly linear FMCW modulation ramps required.

Additionally, the ADF5901 contains an on-chip temperature sensor which allow both analog output on ATEST pin or to be digitalized using an on-chip 8 bit ADC and then the resultant digital word can be readback on DOUT digital pin. The DOUT pin can also be used to readback the registers to check for correct write operation to the chip's control registers. The part is powered off a single 3.3-V supply with draws 700 mW at 100 percent duty cycle – with duty cycling in the system reducing overall power consumption.

ADF4159 – 13GHz Frac-N FMCW ramp generation PLL

The ADF4159 PLL offer the best-in-class phase-noise performance (normalized phase noise FOM of -224 dBc/Hz) with flexible ramp modulation schemes for FMCW operation. With maximum PFD frequency of 110 MHz this allows the part to support both slow ramps (1 ms -10 ms) and fast ramp (20 us – 1 ms) concepts. With maximum RF input frequency of 13 GHz it allow for easy interface to the transmitter IC ADF5901 auxiliary outputs to complete a closed loop FMCW generation. The ADF4159 flexible ramp generation engine support various triangular and sawtooth ramp profiles with flexible time and frequency deviations. It also supports fast ramp profiles that minimize the over/under shoot in the re-trace period of the ramp that maximize the RF bandwidth sweep frequency allowing for fine range resolution in a radar system. No external passive components are require to interface between the ADF5901 and ADF5904, eliminating the need for expensive high frequency caps. On the auxiliary signals between the ADF5901 and ADF4159 no coupling capacitor are needed. All three IC's offer excellent ESD performance and are fully qualified to AECQ100 standard to ensure an even more robust sensor design.

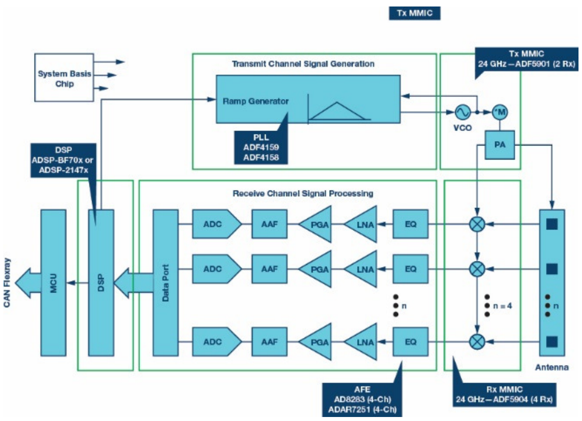

Figure 2. ADI's 24 GHz full signal chain product offering.

Radar System Benefits:

The combined high-performance specifications that the RF chipset offers while connected to ADI's companion radar baseband AFE-ADC products (AD8283 or ADAR7251), as seen in block diagram 2, are important when used to build a full signal chain radar sensor actuator where every dB in improved receiver sensitivity and detection range matters. Many IC-based radar systems are transmitter (phase noise) and receiver-noise limited, resulting in limited overall receiver signal-to-noise ratios (SNR). This generally results in a radar system limitation in detection of smaller objects or targets while in the presence or near larger objects. In practical radar applications busy or cluttered target scenarios including ground clutter exist, which all cumulatively increase system phase noise and can desensitize the radar receiver. Higher system noise masks or hides small targets and prevents detection which potentially can cause a sensor safety issue, for example, if used in an automotive detection application, where better small target detection in the presence of large targets is required, i.e. a child or small pole in the presence of a very large target such as a reflecting wall, or a parked vehicle obscuring a child.

The combination of performance and power offered by the ADF5904's excellent low noise figure (3 dB better than competition) coupled with the companion ICs, transmitter ADF5901 chips and ADF4159 PLL, high performance phase noise, output power, and high speed ramping capability, this device offers lower noise floor performance for the sensor.

Higher receiver system SNR can be achieved and offers more reliable and dependable detection with faster resulting parameter estimation. The high performance of the integrated chipset gives the radar system designer at least 2× improvement in sensitivity and up to 1.5× better detection range with much lower overall power consumption, resulting in more robust, consistent performance from a small sized sensor that is easy to design.