TECHNICAL ARTICLE

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

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ADF5904, 4-Channel, 24 GHz Receiver Downconverter MMIC

The ADF5904 is a highly integrated, 4-channel, 24 GHz receiver downconverter MMIC with the industry's best combination of low noise performance, high linearity, and low power consumption. The ADF5904 integrated, multichannel receiver downconverter achieves a 10 dB noise figure that is 3 dB better than competing devices. While using 50% less power, it is assembled in a small, cost-effective 5 mm × 5 mm LFCSP plastic package. Each of the device's four on-chip receive channels use a simple, single-ended connection to four individual antennas, which simplifies RF transmission line design and PCB layout, and reduces board size. The receiver downconverter simultaneously amplifies and translates four 24 GHz receive signals directly to produce a high quality, high amplitude baseband or lower frequency signal that easily connects to ADI 4-channel analog-to-digital converters or analog front ends (AFE). The ADF5904 also provides an integrated temperature sensor that eliminates the need for discrete sensing components that otherwise can require additional time and resources to calibrate during system assembly and test.

The ADF5904 is designed for multichannel receiver, high frequency applications that use digital beamforming, such as automotive ADAS radar, microwave radar sensors, and industrial radar system environments where energy efficiency is becoming a more important system-level design consideration. The ADF5904 24 GHz receiver enables these and other sensor applications by offering best-in-class receiver sensitivity while using less overall power than competing RF IC technologies.

Key Features

- Four receive channels, receiver channel gain: 22 dB
- Noise figure: 10 dB, P1dB: –10 dBm
- Power consumption: 0.5 mW (all four channels powered on)
- LO input range: –8 dBm to +5 dBm
- Receiver to IF isolation: 30 dB
- RF signal bandwidth: 250 MHz
- On-chip temperature sensor with analog output: ±5°

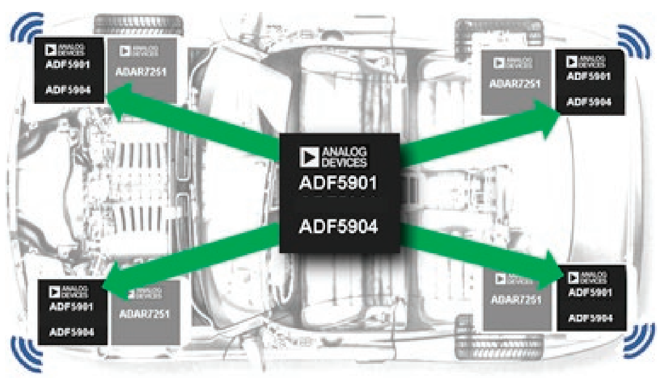

Figure 1. ADF5904, four-channel, 24 GHz receiver downconverter MMIC.

Technical Details

The ADF5904 is a 4-channel, 24 GHz receiver MMIC where the four RF channels are downconverted in frequency to differential baseband signals, which can then drive directly into a specialized multichannel ADC to digitize the incoming analog receiver signals. These digital signals can be interrogated using fast Fourier transforms (FFTs) 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 downconverts 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 receiver signals to differential signals achieving higher performance amplification and downconversion processing. The single-ended RF interface connections ease 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 receiver-to-receiver channel isolation performance of 30 dB even with this high level of integration in a low cost plastic package. Careful RF layout around the receiver input pins is required to maintain this excellent 30 dB receiver-to-receiver isolation performance.

Each of the four receiver 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 receiver chain has a fixed gain of 22 dB with a P1dB of –10 dBm, and the low noise design yields a noise figure of 10 dB for the receiver signal chain, while achieving a very low power consumption figure of 550 mW even with all four receiver channels powered-on together and powered from a single 3.3 V supply. With power-on duty cycling of the system, the overall power consumption can be reduced even further and unused receiver 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 A test pin and allows monitoring of the system temperature. The ADF5904 offer simple control over a 4-wire SPI with the D_{OUT} pin allowing for readback of the registers to check for correct write operation to the chips control registers.

ADF5901, 2-Channel, 24 GHz Transmit MMIC

The ADF5901 is a 24 GHz transmitter MMIC with on-chip 24 GHz VCO spanning the 250 MHz ISM band from 24 GHz to 24.25 GHz connected to two transmitter PAs that can deliver 8 dBm output power, an LO output to drive the receiver MMIC ADF5904, and differential auxiliary outputs to allow for closed-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 part's transmitter outputs is frequency and power calibrated to ensure operation within the ISM band and maintain the optimum VCO power levels to ensure a superior phase noise performance of –108 dBc/Hz @ 1 MHz offset. The part also contains transmitter output power calibration circuits to calibrate the transmitter 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 transmitter outputs to measure the power at the transmitter 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 MU_{OUT} 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 DAC converter to adjust the V_{TUNE} pin of the part to ensure that it is 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 because 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 transmitter outputs on the ADF5901 are controlled individually to allow for virtual antenna and MIMO operation of the radar sensor.

The transmitter 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 receiver 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 receiver 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 allows the ADF4158 or ADF4159 ramp generation PLLs 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 that allows for an analog output on the ATEST pin. Alternately, the sensor signal can be digitalized using an on-chip 8-bit ADC, with the resulting digital word readback on the D_{OUT} digital pin. The D_{OUT} pin can also be used to read back the registers to check for correct write operation to the chip's control registers. When the part is powered off, a single 3.3 V supply withdraws 700 mW at 100% duty cycle—with duty cycling in the system, reducing overall power consumption.

ADF4159—13 GHz Fractional-N FMCW Ramp Generation PLL

The ADF4159 PLL offers the best-in-class phase noise performance (normalized phase noise FOM of –224 dBc/Hz) with flexible ramp modulation schemes for FMCW operation. With a maximum PFD frequency of 110 MHz, the part supports both slow ramp (1 ms to 10 ms) and fast ramp (20 ms to 1 ms) concepts. With a maximum RF input frequency of 13 GHz, the ADF4159 allows for easy interface to the transmitter IC ADF5901 auxiliary outputs to complete a closed-loop FMCW generation. The ADF4159 flexible ramp generation engine supports 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 retrace period of the ramp that maximizes the RF bandwidth sweep frequency allowing for fine range resolution in a radar system. No external passive components are required to interface between the ADF5901 and ADF5904, eliminating the need for expensive high frequency capacitors. On the auxiliary signals between the ADF5901 and ADF4159 no coupling capacitor is needed. All three ICs offer excellent ESD performance and are fully qualified to the AEC-Q100 standard to ensure an even more robust sensor design.

Radar System Benefits

The combined high performance specifications that the chipset offers, as seen in Figure 3, are important when used to build a 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 (SNRs). This generally results in a radar system limitation in detecting 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.

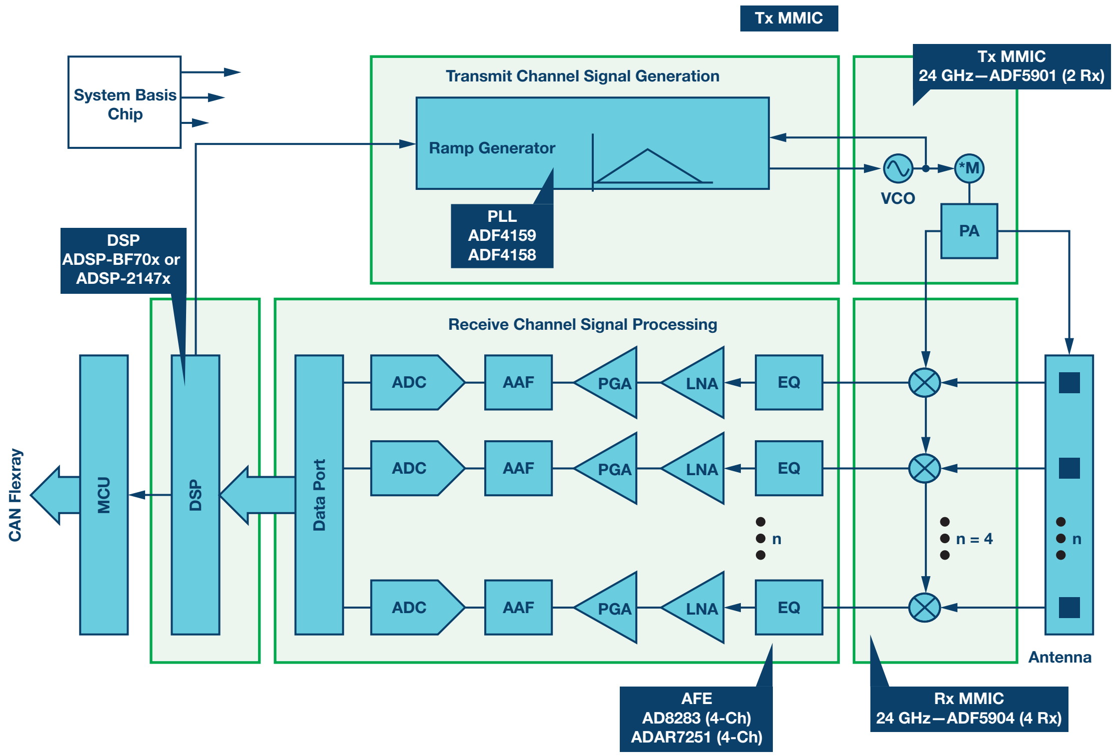

Figure 3. ADI's 24 GHz full signal chain product offering.

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 (such as a child or small pole) in the presence of a very large target, like 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.

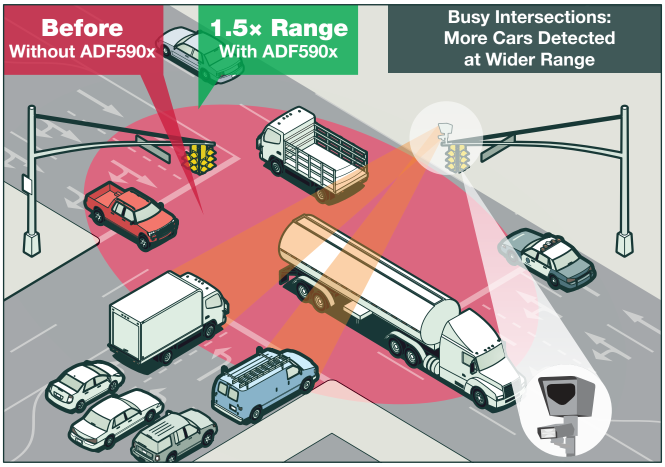

Figure 2. Intelligent traffic light radar sensor. 3D object tracking.

About the Author

John Morrissey joined Analog Devices in 1984, graduating with a bachelor's degree in electronic engineering (BENG) from University of Limerick, Ireland. From 1984 to 1998, he worked as an Analog IC designer, on DAC, ADC, and mixed-signal analog circuits for new product developments for industrial and communication applications. From 1999 to 2007 he expanded his design skills and work interests in RF and microwave design for communications products at Analog Devices. Since 2007, he has held many senior technical engineering and business management roles at Analog Devices including design and marketing. He currently holds the position of Product Line Director in the RF and Microwave Group (RFMG) at Analog Devices, and supports ADI's automotive and Industrial radar business as well as many others.

Patrick Walsh joined Analog Devices in 1998 after graduating with a bachelor's degree in electrical/electronic engineering from Dublin Institute of Technology, Ireland. From 1998 to 2001 he worked as a design engineer working on RF PLL synthesizers. Since 2011 he has been an application engineer supporting RF and microwave parts and 24 GHz MMICs for automotive and industrial radar.

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