RF Transceivers Provide Breakthrough SWaP Solutions for Aerospace and Defense

By Wyatt Taylor and David Brown

Next-generation aerospace and defense platforms introduce new challenges that require solutions beyond what can be achieved through individual device optimization. Integrating more software control and cognitive abilities to the radio demands a more frequency and bandwidth flexible RF design. To achieve this goal, static filters need to be removed and replaced with tunable filters. Similarly, the concept of a common platform would allow for shorter development times, reduced manufacturing costs, and provide greater interoperability between systems. The common platform demands that the RF system be capable of providing full performance for applications that traditionally had very different architectures. Finally, future platforms are pushing size and power demands to a new extreme.

Handheld soldier radios are becoming more capable and complex, but simultaneously requiring improved battery efficiency. Small UAVs lack the power generation of large aircraft and every milliwatt that the RF system consumes directly translates to payload battery weight and, thus, reduced flight time. To overcome these challenges and create the next generation of aerospace and defense solutions, a new radio architecture is needed.

Superheterodyne Architecture and Diminishing Returns

Since its inception, the superheterodyne architecture has been the backbone of radio design for aerospace and defense systems. Whether it is a soldier radio, unmanned aerial vehicle (UAV) data link, or a signal intelligence (SIGINT) receiver, the single or dual mixing stage superheterodyne architecture is the common choice. The benefits of this design are clear: proper frequency planning can allow for very low spurious emissions, the channel bandwidth and selectivity can be set by the intermediate frequency (IF) filters, and the gain ditribution across the stages allows for a trade off between optimizing the noise figure and linearity.

For over 100 years of use, there have been significant gains in performance for the superheterodyne across the entire signal chain. Microwave and RF devices have improved their performance while decreasing power consumption. ADCs and DACs have increased the sample rate, linearity, and effective number of bits (ENOB). Processing capability in FPGAs and DSPs has followed Moore's law and increased with time, allowing for more efficient algorithms, digital correction, and further integration. Package technology has shrunk device pin density while simultaneously improving thermal handling.

However, these device specific improvements are beginning to reach the point of diminishing returns. While the RF components have followed a reduced size, weight, and power (SWaP) trend—high performance filters remain physically large and are often custom designs, adding to overall system cost. Additionally, the IF filters set the analog channel bandwidth of the platform, making it difficult to create a common platform design that can be reused across a wide range of systems. For package technology, most manufacturing lines will not go below a 0.65 mm or 0.8 mm ball pitch, meaning there is a limit on how physically small a complex device with many I/O requirements can become.

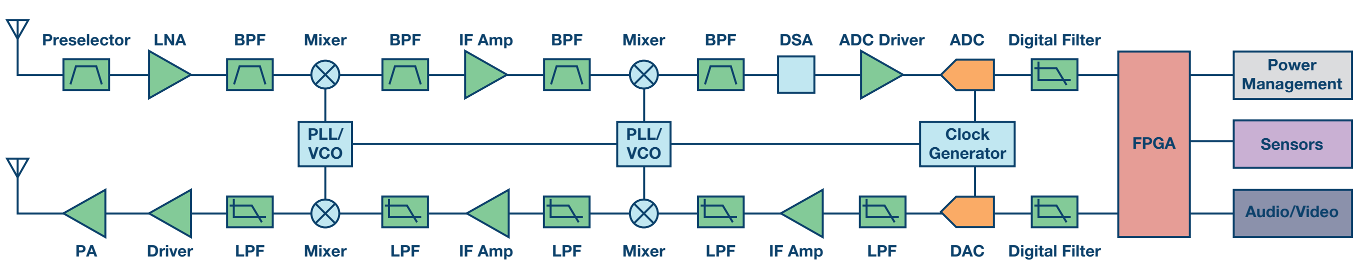

Figure 1. Basic superheterodyne architecture.

Zero-IF Architecture

An alternative to the superheterodyne architecture, which has reemerged as a potential solution in recent years, is the zero-IF (ZIF) architecture. A ZIF receiver utilizes a single frequency mixing stage with the local oscillator (LO) set directly to the frequency band of interest, translating the received signal down to baseband in phase (I) and quadrature (Q) signals. This architecture alleviates the stringent filtering requirements of the superheterodyne since all analog filtering takes place at baseband, where filters are much easier to design and less expensive than custom RF/IF filters. The ADC and DAC are now operating on I/Q data at baseband, so the sample rate relative to the converted bandwidth can be reduced, saving significant power. For many design aspects, ZIF transceivers provide significant SWaP reduction as a result of reduced analog front-end complexity and component count.

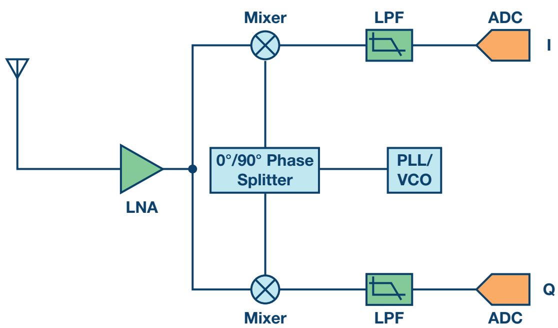

Figure 2. Zero-IF architecture.

However, there are drawbacks to this system architecture that need to be addressed. This direct frequency conversion to baseband introduces a carrier leakage and an image frequency component. Mathematically, the imaginary components of I and Q signals cancel out due to their orthogonality (Figure 3). Due to real-world factors, such as process variation and temperature deltas in the signal chain, it is impossible to maintain a perfect 90° phase offset between the I and Q signals, resulting in degraded image rejection. Additionally, imperfect LO isolation in the mixing stage introduces carrier leakage components. When left uncorrected, the image and carrier leakage can degrade a receiver's sensitivity and create undesirable transmit spectral emissions.

Historically, the I/Q imbalance has limited the range of applications that were appropriate for the ZIF architecture. This was due to two reasons: first, a discrete implementation of the ZIF architecture will suffer from mismatches both in the monolithic devices and also the printed circuit board (PCB). In addition to this, the monolithic devices could pull from different fabrication lots, making exact matching very difficult due to native process variation. A discrete implementation will also have the processor physically separated from the RF components, making a quadrature correction algorithm very difficult to implement across frequency, temperature, and bandwidth.

Integrated Transceivers Provide SWaP Solution

Integrating the ZIF architecture into a monolithic transceiver device provides the path forward for next-generation systems. By having the analog and RF signal chain on a single piece of silicon, process variation will be kept to a minimum. In addition, DSP blocks can be incorporated into the transceiver, removing the boundary between the quadrature calibration algorithm and the signal chain. This approach provides both unparalleled improvements in SWaP and can also match the superheterodyne architecture for performance specifications.

ADI now offers two transceivers to meet the demands of the aerospace and defense market, the AD9361 and AD9371. These devices integrate the full RF, analog, and digital signal chain onto a single CMOS device, and include digital processing to run quadrature and carrier leakage correction in real time across all process, frequency, and temperature variations. The AD9361 focuses on medium performance specifications and very low power, such as UAV data links, handheld and manpack communication systems, and small form factor SIGINT. The AD9371 is optimized for very high performance specifications and medium power. Additionally, this device has an integrated ARM® microprocessor for refined calibration control, as well as an observation receiver for power amplifier (PA) linearization and a sniffer receiver for white space detection. This opens up new design potential for a different suite of applications. Communication platforms using wideband waveforms or occupying noncontiguous spectrum can now be implemented in a much smaller form factor. The high dynamic range and wide bandwidth allows for SIGINT, EW, and phased array radar operation in locations with highly congested RF spectrum.

Next Generation Is Now

100 years of device optimization allowed the superheterodyne to achieve greater and greater performance in continually smaller and lower power platforms. Those improvements are beginning to slow down as physical limitations take hold. Next-generation aerospace and defense platforms will demand a new approach to the RF design, one where several square inches of an existing platform are integrated into a single device, where the boundary between software and hardware is blurred allowing for optimization and integration currently unavailable, and where decreased SWaP no longer means decreased performance.

The combination of the AD9361 and AD9371 provide aerospace and defense designers with the ability to now create systems that, just a few years ago, would have been impossible. The devices share many similarities—tunable filter corners, wideband LO generation, diversity capability, and calibration algorithms. There are key differences, though, that drive each part to be optimized for different applications. The AD9361 is focused on single carrier platforms, where SWaP is a primary driving force. The AD9371 is focused on wideband, discontinuous platforms, where performance specifications are even more difficult to achieve. These two transceivers will be key enablers for next-generation aerospace and defense signal chains.

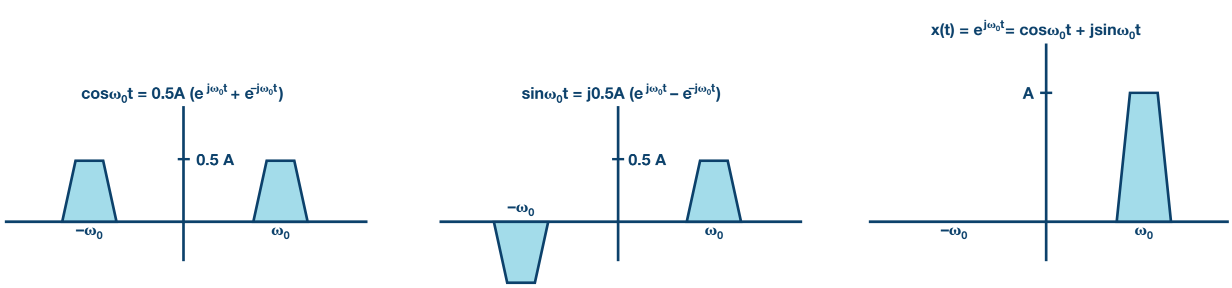

Figure 3. Zero-IF image cancellation.

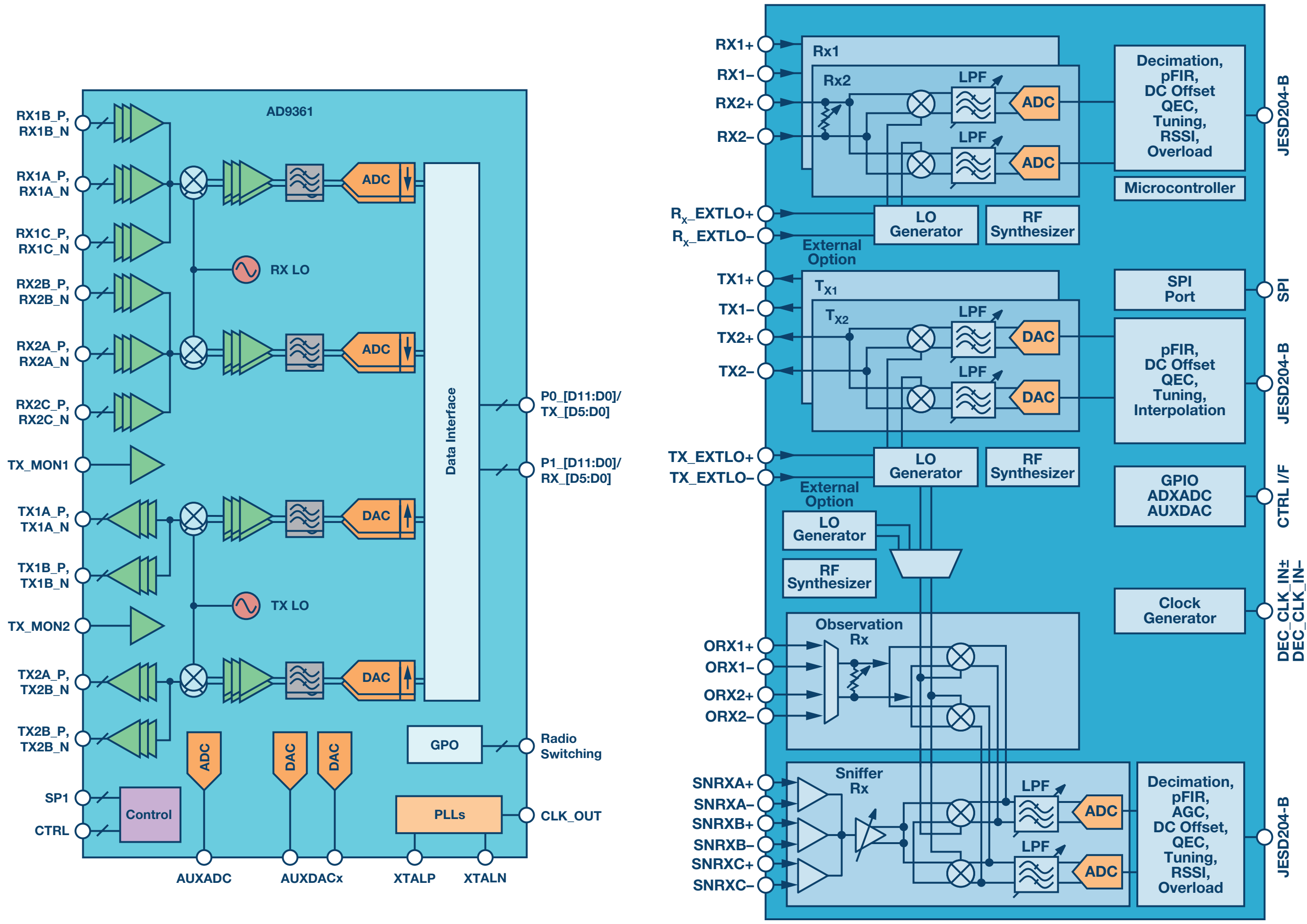

Figure 4. AD9361 and AD9371 block diagrams.

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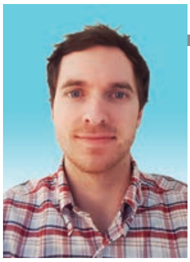

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