ANALOG DEVICES

High Dynamic Range IF Receiver Simplifies Design of Next-Generation µW Point-to-Point Modems

by Paul Hendriks, applications engineer, Analog Devices, Inc.

Microwave point-to-point links are an integral part of a cellular mobile network, providing backhaul capability between cell sites (BTS/NodeBs) and the radio controllers (BSC/RNCs) in over 50% of global deployments where fiber links are not cost effective to deploy. The recent explosion in mobile network traffic driven by the market shift to smartphones has intensified data demands, such as streaming video, and puts pressure on the existing microwave backhaul equipment capacity. In order to scale the data throughput of the backhaul network to the needs of LTE and LTE-Advanced, the next generation microwave links will need to:

- Move to increasingly higher order digital modulation from today's QAM256 to as high as QAM4096 in the future, thus providing a 50% increase in capacity within a fixed channel assignment.
- Support channel assignments from 56 MHz today to 112 MHz in the traditional 6 GHz to 42 GHz band. Every doubling of channel bandwidth provides a proportional increase in the data throughput rate capability if the carrier-to-noise ratio (CNR) remains constant.
- Employ techniques such as polarization diversity, channel aggregation, and N × N line of sight MIMO.

As is typically the case in communication system design, this increase in throughput capability does come at a price. To support combinations of higher QAM levels and channel bandwidth, the microwave link must have a more dynamic range capability to support the required minimum EVM performance, especially since receiver sensitivity is reduced by 3 dB for every doubling in QAM size or bandwidth. Since the microwave equipment must remain flexible, additional consideration is required to support all possible operating scenarios while still simplifying the receiver filtering and AGC requirements for improved performance and cost reduction.

An additional industry trend is the emergence of full outdoor units (ODU), in which the full radio modem and transceiver are combined with the switching/multiplexing units and traffic interface in a self contained box mounted on a tower or equivalent structure. This trend is driven by CAPEX/OPEX at new sites, and space constraints at existing sites. Traditional split indoor (IDU)/outdoor (ODU) systems host the μ W/RF section in the ODU with a coaxial cable connecting to the rest of the system housed in an equipment shelter (IDU). The coaxial cable can be up to 300 meters in length and carries bidirectional traffic with a diplexer being used to separate the receiver IF signal centered at 140 MHz from the transmitter IF signal being centered in the 340 MHz to 400 MHz range.

While this is a notable trend, the majority of µW equipment shipped today and in the foreseeable future is the legacy split IDU/ODU system. It would be beneficial to leverage one back-end modem transceiver architecture for design reuse purposes that supports both the legacy system and the next generation ODU platforms. Recent advances in both high speed DAC and ADC technology operating at clock rates well above 1.5 GSPS are now making it possible to synthesize and digitize QAM signals at high IFs with exceptional accuracy to support 4096 QAM and beyond. Besides eliminating the need for any quadrature error correction required for traditional analog I/Q implementations, the high dynamic range along with high oversampling ratio allows the majority of the filtering to be performed in the digital domain, thus reducing the amount of analog filtering and digital equalization required to compensate for them. For the transmitter signal path, high speed DACs like the AD9142 and AD9136 are already beginning to replace the traditional dual DAC and I/Q modulator implementations in order to synthesize the wideband QAM signals with exceptional EVM performance, but without the need for transmitter calibration. For the receiver signal path, the availability of 1.5+ GSPS ADCs well-suited for these applications has lagged until the recent release of the AD6676.

MS-2739



Figure 1. Block Diagram of the AD6676 IF Rx Subsystem

The AD6676 is the industry's first wideband IF receiver subsystem (Figure 1) based on a band-pass Σ - Δ ADC supporting IF signal bandwidths up to 160 MHz while operating with an internal clock rate of up to 3.2 GHz. It is the high oversampling capability of the Σ - Δ ADC that greatly simplifies the IF analog filtering requirements required in lower sampling ADCs to suppress adjacent channels (and interference/blockers) that would otherwise alias back onto the IF signal, thus reducing the receivers sensitivity performance. Also, it is the ADC's high dynamic range with an NSD floor of -160 dBFS/Hz (for narrow-band QAM channels) that reduces the diplexer transmitter-toreceiver isolation requirement or analog AGC range that compensates for fading. The AD6676 includes an on-chip 27 dB digital attenuator with 1 dB resolution that can be used to calibrate the static gain error due to initial component tolerances and the variation in coaxial cable loss.

Let's first examine how the AD6676 IF receiver subsystem along with a high speed DAC like the AD9136 can be used to greatly simplify a traditional IDU transceiver while enhancing its performance. Referring to Figure 2, the top transceiver lineup shows a direct conversion implementation used to support typically low receiver and transmitter IFs of 140 MHz and 400 MHz respectively. The challenges of direct conversion transceiver architectures are well documented, but could be overcome with I/Q balance calibration, dc offset correction, tunable baseband I/Q filtering, and careful design of the diplexer to suppress the transmitter leakage. While legacy IDU transceivers supporting maximum channel bandwidths of 56 MHz and 256 QAM are in production today, increasing the channel bandwidth by $2\times$ and the QAM level by up to $8\times$ for higher capacity poses significant challenges to the direct conversion architecture. Recent advances in high speed ADC/DAC technology are poised to displace classic approaches with a digital IDU as

illustrated in Figure 2. The bottom transceiver implementation requires only four ICs to deliver near perfect performance with significantly relaxed filtering requirements.



Figure 2. Comparison Between Legacy "Direct Conversion" IDU Transceiver Architecture vs. IDU Transceiver Architecture Using High Speed DAC/ADC for Direct Digital Synthesis and Digitization of the Tx and Rx QAM Signals

On the transmitter side, a high speed DAC like the AD9136 operating at a clock rate of 1.6 GSPS can synthesize a 112 MHz, 1024 QAM signal centered at an IF with exceptional EVM performance so that the majority of the transmitter link error budget can be reserved for the ODU (where the additive effects of phase noise and linearity will result in most of the EVM degradation). While a low-pass filter is required to suppress the first DAC image falling at 1.2 GHz, it now can be relaxed by up to 12 dB relative to the LO harmonic reject filter needed to filter out the I/Q modulator's third-order LO image that also falls at 1.2 GHz. Transmit power control to overcome cable losses can be performed within AD9136 with negligible degradation of the QAM signal's EVM performance over a 15 dB range.

On the receiver side, the AD6676 digitizes the 112 MHz, 1024 QAM channel with exceptional dynamic range and accuracy even in the presence of a large amount of transmitter leakage from diplexer filter relaxation, as demonstrated in Figure 3. In this example, the AD6676 was configured to support 112 MHz of channel bandwidth with its attenuator set to 3 dB, such that the effective RTI NF into the HMC740 preamplifier remained around 10 dB. The left plot in Figure 3 shows the FFT response of the AD6676's Σ - Δ ADC data output (used for demonstration purposes only) where transmitter leakage of –26 dBm centered at

400 MHz is combined with a CW tone of -17.2 dBm at 143 MHz representing the signal. Note that the inherent noise shaping of the tunable band-pass Σ - Δ ADC is evident in the region of high dynamic range centered about the desired IF (up to -160 dBFS/Hz). The right plot in Figure 3 shows the FFT response of the 16-bit, 200 MSPS I/Q data centered about a zero IF after digital downconversion and $16\times$ decimation filtering. Note that the digital filter provides +85 dB rejection to remove the out of band noise and transmitter leakage signal from aliasing back into the 112 MHz pass band. The residual shaped noise falling outside the 112 MHz pass band is removed by the modem's RRC filters.

The inband noise (IBN) under this large CW signal test condition of –2 dBFS was –68.6 dBFS. If a full-scale 1024 QAM Rx signal having a peak-to-rms of 10 dB were to replace this CW tone, 7 dB additional backoff would be required to prevent ADC clipping. In this case, the receiver IDU input power would be at –9 dBFS (or –24.2 dBm), suggesting a CNR of nearly 60 dB. In terms of simplification of the diplexer filter design, the diplexer transmitter-toreceiver rejection would now be roughly 20 dB to suppress a –6 dBm transmitter signal such that it appears –26 dBm at the input of the receiver preamp. For deployment cases having shorter cable runs between the IDU and ODU, the AD6676's attenuator can be increased to tolerate higher QAM levels from the ODU.

The ability of the IDU receiver to still recover a QAM signal at very low sensitivity levels (BER < 10-6 with FFC enabled) in the presence of a nearby unwanted signal is an important specification. Perhaps the most demanding test (per ETSI EN 301 390 V1.2.1) is when a CW interferer tone (blocker) having 30 dB higher power than the QAM signal is placed at only a 2.5× channel offset from the desired QAM signal. Note that tunable or switched bank filters employed in today's receivers are mostly driven by this specification since the modem must support channel bandwidths from 3.5 MHz to 56 MHz. The previous example represents the next generation 112 MHz channel bandwidth case where it can be assumed that the adjacent CW interferer is sufficiently suppressed by a 112+ MHz fixed channel filter that also performs image rejection prior to the last downconversion stage within the RF chain of the ODU. In fact, this same filter should still provide sufficient blocker rejection at offsets of 70 MHz and 140 MHz for the 28 MHz and 56 MHz channel bandwidth cases. For channel bandwidths of 14 MHz or below, the CW tone would fall within this filter's pass band; thus would either need to be rejected by additional band-pass filtering at 140 MHz, or be digitized by the ADC and then filtered digitally.



Figure 3. Measured Dynamic Range Capability of Rx Lineup Consisting of HMC740 with the AD6676 Before and After Digital Downconversion to a Zero IF

MS-2739



Figure 4. The AD6676's High Dynamic Range Simplifies the Rx Filtering Requirements by Tolerating Large Adjacent Interferers

An AD6676-based IDU receiver architecture has the instantaneous dynamic range to support this scenario without extra filtering. Figure 4 shows the AD6676's FFT frequency response of the same exact receiver lineup used in Figure 3 with the exception that the Σ - Δ ADC's tunable bandwidth was reduced to 56 MHz. In this example, a -32 dBm CW tone at 175 MHz (or 35 MHz offset) was added to the ever present -26 dBm transmitter leakage signal at 400 MHz. This CW tone corresponds to a -17 dBFS input level seen by the AD6676 and is set to be 30 dB higher than a -47 dBFS, 1024 QAM at minimum sensitivity (CNR = 36 dB). The CW interferer tone can be increased by an additional 15 dB, thus highlighting the excess design margin that can be allocated to the μ W/RF circuitry's noise contribution. In the absence of the blocker, the desired 1024 QAM signal level can be increased by 38 dB, offering additional dynamic range for the IDU receiver to deal with fading.



Figure 5. The AD6676 IF Receiver Can Also Be Leveraged in the Design of a High Performance ODU Rx Lineup.

The same high dynamic range benefits that the AD6676 offers for the IDU design can also be leveraged for a full ODU receiver design. Figure 5 shows how AD6676 can be used in a receiver lineup for an 18 GHz to -23 GHz capable ODU when combined with a lineup consisting of a balanced

RF mixer such as the ADL5801, a µW image reject mixer such as the HMC966, and an RF VGA such as the ADL5246. Note that other µW bands in the 6 GHz to 43 GHz range can be supported with the selection of different μW image reject mixers, µW PLLs, and possibly first IF frequency. In the full ODU case where there is no cable to limit the IF choices, the AD6676 can be set to a higher IF such as 300 MHz to further simplify the RF filtering requirements for image rejection. Should any of the larger mixer spurious components require additional suppression, the AD6676 can interface to the RF mixer directly or via a simple third-order, low-pass roofing filter. The RF filter at 1960 MHz is specified to support channel bandwidths up to 112 MHZ. With the AD6676's attenuator set to 0 dB, the combined noise floor of the ADL5801 and AD6676 is below -157 dBFS/Hz for channel bandwidths of 56 MHz resulting in an equivalent NF of 17 dB. The default total conversion gain from the ADL5246 and HMC966 can be initially optimized with the instantaneous dynamic range of the ADL5801/AD6676 such that the digital modem tracks initial fading (from nominal receiver input power levels). The AGC threshold of the ADL5246 can be set such that it starts increasing its gain at a level when the modem's receiver BER drops below a predetermined level for a specified QAM signal level. This hybrid approach would only activate RF AGC under very low input levels to improve the receiver's minimum sensitivity level.

SUMMARY

The next generation µW point-to-point receivers need to support channel bandwidths ranging from 3.5 MHz to 112 MHz operating with higher dynamic range to support increasingly higher M-QAM levels over wider fading margins. The AD6676 IF receiver subsystem enables a common µW point-to-point platform that supports legacy IDU/ODU split systems as well as the newer ODU platforms. For the IDU/ODU split systems, its exceptionally high dynamic range ensures that excellent modulation accuracy (EVM) can be maintained while in the presence of adjacent interferer signals without the need of complicated tunable or bulky switched bank filters. For full ODU systems, its high instantaneous dynamic range (with direct interface to a mixer) reduces the RF AGC range required to track fading and eases the RF filtering requirements. The AD6676 is available in a small footprint 4.3×5.0 mm, 80-lead WLCSP package and operates off 2.5 V and 1.1 V supply.

ABOUT THE AUTHOR

Paul Hendriks is a staff applications engineer and manager for the Analog Devices high speed converter product line based in Wilmington, MA. His focus for the past 20 years has been on the use and product definition of high speed converters in both wireless and wireline communication applications. Since joining Analog Devices in 1989, he has authored numerous articles, application notes, design ideas, and product data sheets. Paul received his B.S.E.E. in 1986 from McGill University.

RESOURCES

Share this article on



One Technology Way • P.O. Box 9106 • Norwood, MA 02062-9106, U.S.A. Tel: 781.329.4700 • Fax: 781.461.3113 • www.analog.com Trademarks and registered trademarks are the property of their respective owners. TA12800-0-11/14

