

Figure 2. Simplified Compensation Concept

present in the transmitted signal and compare it to the desired signal. Correction coefficients are calculated to counteract distortion within the PA, and these are applied to the digital baseband signal. There are numerous techniques available for creating the coefficients. These techniques are beyond the scope of this paper since they do not impact the ADC selection.

The transmit path can contain a single- or dual-channel DAC depending on the goals of the specific system being designed. Selection of the transmit architecture does not have a major impact on the observation receiver. However, once the observation path has been included it can be used to correct certain imperfections in the transmit path unrelated to the predistortion operation. For example, direct conversion architectures suffer from imperfect sideband suppression and local oscillator (LO) feedthrough. These artifacts can be reduced by correcting the gain, phase and offset imbalances between the quadrature signal paths.

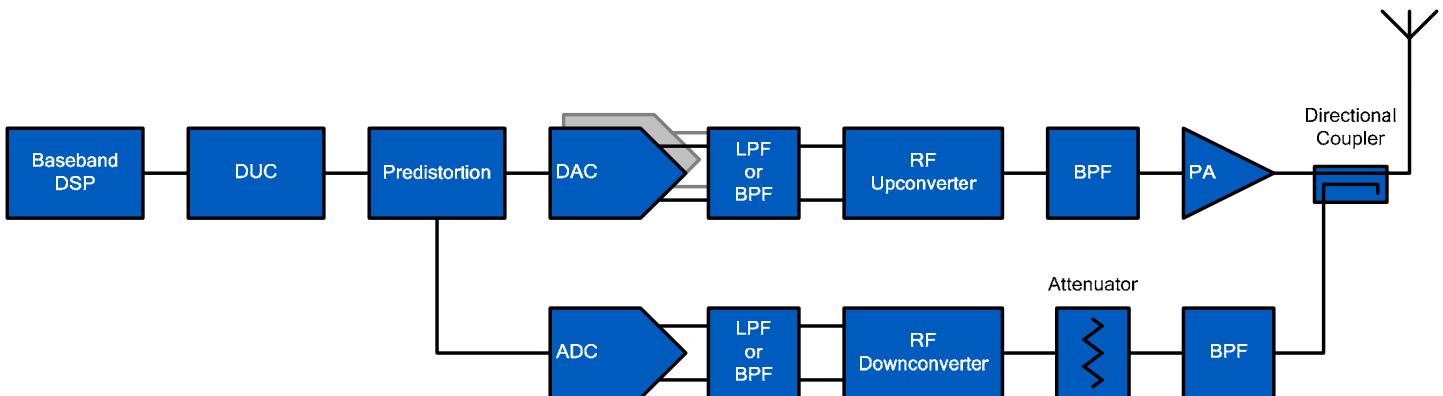


Figure 3. Generic DPD Architecture

Such adjustments can be difficult to implement in real time with a standard transmitter, since performance changes must be monitored and corrected in real time. The required measurement and control features are already present in a DPD transmitter, making implementation of a direct conversion architecture more manageable.

The most common architecture for the observation receiver is a real intermediate frequency (IF) with a single or double downconversion from RF². The main reason for selecting this architecture is to avoid the aforementioned issues with direct conversion.

2. Peter Kenington, *RF and Baseband Techniques for Software Defined Radio* (Artech House, 2005), p. 269.

ADC Sample Rate

The primary figure of merit for WCDMA transmitters is Adjacent Channel Leakage Ratio (ACLR), which compares the integrated power in a spread spectrum carrier to the integrated noise power in an adjacent band of equal bandwidth. One of the main sources of ACLR degradation immediately adjacent to the carrier is odd-order intermodulation products, since they fall within the transmitted carrier band and can't be filtered. The occupied bandwidth of the resulting distortion is the carrier bandwidth multiplied by the intermodulation order. For example, the IM5 distortion would occupy five times the carrier bandwidth. A four-carrier WCDMA transmitter producing a 20MHz BW would therefore require 100MHz from the feedback path if 3rd and 5th order intermodulation (IM) terms were being canceled.

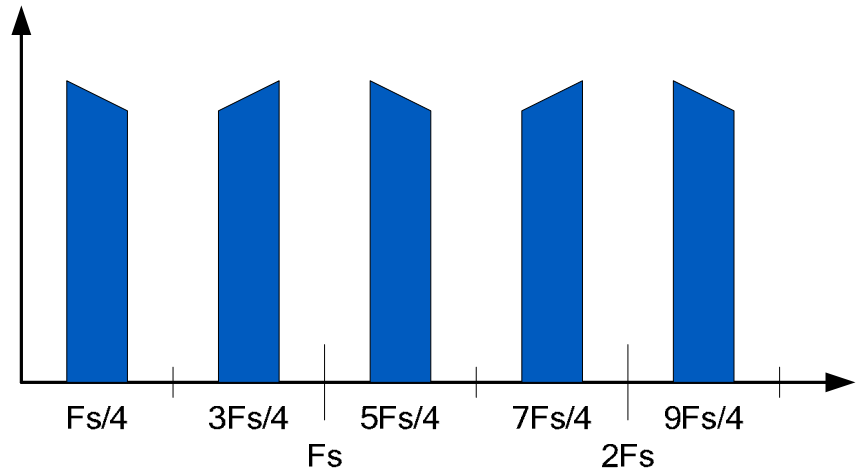


Figure 4. Sampling Zones. F_s is the sampling rate.

Signal processing in the basestation is generally performed at integer multiples of the chip rate, and 2^N multiples are particularly attractive due to the computational efficiencies that can be obtained. For WCDMA the base chip rate is 3.84 Mcps (mega chips per second). This is the rate at which unique orthogonal sequences are transmitted. IF sampling is often employed to reduce the sample rate required of the ADC. A good choice is to place the signal band in the 3rd Nyquist zone centered about $5F_s/4$, which after sampling appears centered at $F_s/4$ without frequency inversion (see Figure 4). Table 1 shows possible sample rates and IFs for WCDMA and CDMA2000.

WCDMA Magic Frequencies					CDMA2000 Magic Frequencies				
Chip Rate	3.84				Chip Rate	1.23			
Multiplier	F_s	$F_s/4$	$3F_s/4$	$5F_s/4$	Multiplier	F_s	$F_s/4$	$3F_s/4$	$5F_s/4$
16	61.44	15.36	46.08	76.80	48	58.98	14.75	44.24	73.73
20	76.80	19.20	57.60	96.00	64	78.64	19.66	58.98	98.30
24	92.16	23.04	69.12	115.20	96	117.96	29.49	88.47	147.46
32	122.88	30.72	92.16	153.60	128	157.29	39.32	117.96	196.61
40	153.60	38.40	115.20	192.00	192	235.93	58.98	176.95	294.91
48	184.32	46.08	138.24	230.40	256	314.57	78.64	235.93	393.22
64	245.76	61.44	184.32	307.20					
80	307.20	76.80	230.40	384.00					

Table 1. Typical Sample Rates and IFs for WCDMA and CDMA2000

Approximately 100MHz of spectrum will be downconverted to allow for fifth-order IM correction. Sample rates of 245.76MSPS ($64 \cdot f_{CHIP}$) for WCDMA or 235.93MSPS ($192 \cdot f_{CHIP}$) for CDMA2000 satisfy the Nyquist criteria while allowing for reasonable analog filtering requirements.

ADC Linearity

The ultimate linearity achieved through the DPD technique is only as good as the estimation of the nonlinearity being created by the PA. As mentioned previously, the primary contributor to ACLR is odd-order intermodulation products. To accurately identify PA nonlinearities, the observation receiver must be more linear than the desired outcome from the PA.

The 3GPP specification requires a minimum of -45dB ACLR in the first adjacent channel (at 5MHz offset) and -50dB in the alternate channel³ (10MHz offset). To minimize ACLR degradation, the observation receiver should exhibit 6 to 10dB better ACLR, therefore the cascaded ACLR of the observation receiver should be -55dB at a 5MHz offset.

3. 3GPP Specification: TS 25.104 V7.4.0 (2006-06), *Base Station (BS) radio transmission and reception (FDD)* (Release 7)

The observation receiver linearity required increases with bandwidth. The necessary third-order IM distortion (IMD3) for a given level of ACLR performance can be estimated as⁴:

$$\text{ACLR}_n = \text{IMD3} + C_n$$

where C_n is a correction factor based on the number of carriers.

# Carriers	1	2	3	4	9
C_n (dB)	+3	+9	+11	+12	+13

This relationship associates the required two-tone IMD with the ACLR performance of a spread-spectrum carrier with the same total power. For a 4-carrier WCDMA signal, the observation receiver would need to exhibit -67dB IMD3 (-55dBc ACLR, 12dBc correction factor) at an input power equal to the backoff, typically driven by the peak-to-average ratio (PAR). ADC performance is generally specified just below the full-scale level, typically at -1dBFS. Devices such as amplifiers and mixers will show an improvement in IMD performance as the input power is reduced, with the IMD3 improving 2dB for every 1dB of signal reduction. Although IMD performance of an ADC generally improves with lower input power, it does not necessarily follow the same behavior. Therefore the IMD performance at -1dBFS is not easily extrapolated to lower input power levels. The best practice is to obtain IMD performance data at the specific power level of interest.

In a properly designed system the composite linearity of the observation receiver will typically be dominated by the ADC.

ADC SNR

For frequency offsets greater than 5MHz, the ACLR is dominated by the overall noise performance of the observation receiver. To calculate the SNR requirement one must consider the PAR of the input waveform, the bandwidth of the signal and the ACLR requirement. We will use WCDMA as an example. First the required noise power spectral density is calculated from the signal power, bandwidth and ACLR requirement. Then this noise floor is translated to SNR based on the sample rate of the ADC.

A single carrier WCDMA signal has PAR of 10.54dB⁵. Combining four carriers together without regard to the relative phase between the carriers can result in PAR as high as 15.79dB. Careful selection of spreading codes and time offsets can reduce the 4-carrier PAR to 11.15dB, only 0.61dB higher than the single carrier case. Additional reduction in PAR can be achieved through the use of crest factor reduction (CFR). PAR of 6dB for a four-carrier WCDMA signal has been reported⁶.

As discussed previously, the 3GPP specification requires -50dB ACLR at a 10MHz offset. With a performance margin of 10dB the total alternate channel ACLR requirement for the ADC is -60dBc.

Therefore, with the average signal reduced by the PAR, the ADC signal-to-noise-and-distortion ratio (SINAD) for a full-scale input must be such that the SNR in the next-adjacent channel is greater than 60dB, i.e.,

$$\text{SNR}(\text{dB}) = \text{SNR}(\text{FS}) + 10\log[\text{Fs}/(2\text{BW})] - \text{PAR} > 60\text{dB}.$$

The second term represents that processing gain from oversampling the signal bandwidth. For $\text{BW} = 20\text{MHz}$ and $\text{Fs} = 245.76\text{MHz}$ the second term is 7.9dB. As discussed above, the PAR = 6 to 11dB, so the minimum ADC SNR requirement is 58.1 to 63.1dBFS.

4. AN-3902: *Adjacent Channel Leakage Ratio (ACLR) Derivation for General RF Devices*, Maxim Integrated Products

5. AN-807: *Multicarrier WCDMA Feasibility*, Analog Devices, Inc.

6. GC1115 Programmable Wideband Crest Factor Reduction Engine Datasheet: www.ti.com/gc1115

Summary

The minimum ADC requirements for a DPD observation receiver in a 4-carrier WCDMA transmitter are as follows:

- Sample Rate > 240MSPS
- SNR = 58.1 to 63.1dBFS (depending on PAR)
- IMD3 > 67dBc at -6dBFS to -11dBFS input power (depending on PAR)

The KAD5512P-25 12-bit, 250MSPS ADC exceeds the requirements for a DPD receiver while exhibiting low power dissipation:

- SNR = 67.8dBFS at 125MHz, 67.5dBFS at 200MHz
- IMD3 = -82dBc at 125MHz, -78dBc at 200MHz (at -1dBFS input power)

A pin-compatible 14-bit ADC, the KAD5514P-25, provides 2.5dB additional SINAD with comparable IMD performance. Thus a simple upgrade path exists for future standards with more demanding performance requirements.