Measuring single-tone desensitization for CDMA receivers

This article sheds light on two important important contributors to single-tone desensitization in CDMA receivers; namely reciprocal mixing and cross-modulation. It also presents a practical, low-cost method for measuring single-tone desensitization performance in a CDMA receiver.

By Jinku Kim and Dave Devries

The CDMA cellular radio system was designed to operate within the same radio frequency spectrum as the older (preceding) advanced mobile phone system (AMPS) system in the U.S. cellular band. The RF scheme for AMPS employs many closely spaced and relatively narrowband FM channels. By contrast, the RF scheme for CDMA employs fewer, and relatively wideband RF channels. As a result, CDMA channel planning has to consider existing AMPS channels, which act as interferers, degrading the CDMA link performance.

We will discuss two primary mechanisms that impact the design and performance of a cellular band CDMA handset. Reciprocal mixing, where the local oscillator (LO) phase-noise ‘jams’ the desired incoming RF, and cross-modulation, where the transmitter leakage overdrives the receiver's low-noise amplifier (LNA). To demonstrate good performance, the article provides measurements on an actual system.

Cellular background

AMPS service exists in band segments of the 850 MHz U.S. cellular band:
- 824 MHz to 849 MHz uplink ‘reverse’ channel band (transmitter on the handset).
- 869 MHz to 894 MHz downlink ‘forward’ channel band (receiver on the handset).

Channels are spaced 30 kHz apart, with each occupying roughly 24 kHz (at peak FM deviation).

CDMA service is intended to coexist in the same U.S. cellular band, and the channels are similarly aligned on a 30 kHz raster—but each channel occupies 1.23 MHz of bandwidth. To manage this, CDMA service providers are allocated 12.5 MHz band segments with the nearest AMPS channel set 285 kHz away (9 AMPS channels + 15 kHz to channel center) from the edge of the nearest CDMA channel at the band segment boundary.

Given this, the nearest AMPS channel acts as single-tone interferer to the CDMA channel when it is much stronger than the CDMA signal level. The interferer frequency offset can be calculated as

\[
\text{offset} = \frac{1.23 \text{ MHz} \times \text{channel bandwidth}}{2} = \frac{615 \text{ kHz}}{2} = 307.5 \text{ kHz}
\]

which is the offset from the nearest interfering AMPS channel to the center of the desired CDMA channel.

The relative power level of this interferer compared to the desired CDMA channel sensitivity level (-101 dBm) is established in the 3GPP2 air-interface standard as a test tone at -30 dBm (worst case).

Single-tone desensitization specs for CDMA handsets

Single-tone desensitization performance is a measure of a cell phone receiver’s ability to receive a CDMA signal at its assigned channel frequency in the presence of a nearby narrow-band jammer spaced at a given frequency offset from the center frequency of the assigned channel. The receiver desensitization performance is measured by the frame error rate (FER)².

In CDMA systems, a primary advantage lays in the ability of many (more than 25) handsets to operate directly on top of each other (i.e., on the very same channel center). For this frequency plan, each handset’s uplink and downlink carrier is assigned a different and orthogonal spreading code, for code-division multiplexing (i.e., channel differentiation).

To accomplish this, the CDMA base station must accurately power control each handset’s transmitter so that all user signals are received at (close to) the same incident power level. Conversely, the handset’s receiver must operate over a very wide gain control range. The forward path gain of the CDMA handset receiver needs to handle typically -110 dBm signals when farthest from the base station.

However, a problem arises because the adjacent AMPS system does not manage the cell phone’s uplink power in the same way, and, therefore, it is possible (especially at...
cell-site boundaries) to have a nearby AMPS base station send a strong interferer while the CDMA handset is receiving at or near its sensitivity limit.

Fortunately, because of the downlink spreading code properties, the CDMA handset receiver is relatively immune to near-channel interferers. This is because the narrowband AMPS interferer is “spread” in the handset’s correlator and, therefore, its impact is reduced by the processing gain (about 25 dB). However, the interference is considerable and a test is specified to ensure that the CDMA receiver can adequately manage this.

The 3GPP2 CDMA2000 standard specifies the following test conditions for single-tone desensitization test.

For CDMA systems in United States, the cellular band test requirement specifies minimum effective isotropic radiated power of +23 dBm. PCS band test requirement specifies minimum effective isotropic radiated power of +15 dBm (tests 1 and 2) and +20 dBm (tests 3 and 4)\(^1\).

When testing a CDMA front-end IC (or a zero-IF receiver) for single-tone desensitization performance, it is important to note the interference components created by the single-tone jammer and recreate the effects in the test setup. There are two main contributors to single-tone desensitization performance: reciprocal mixing and cross-modulation.

### Reciprocal mixing

Reciprocal mixing occurs when the single-tone jammer mixes with the receiver’s local oscillator (Rx LO). Rx LO has finite phase noise that mixes with single-tone jammer and creates an interference component at the intermediate frequency (IF) (or baseband in case of zero-IF systems). This is illustrated in Figure 1.

It can be seen that the receiver single-tone desensitization specification is a key performance parameter that sets the LO phase noise requirement. For accurate single-tone desensitization measurement, it is important to note that the single-tone jammer’s own phase noise also contributes to the overall interference level. Therefore, for lab tests it is necessary to choose a low phase noise RF signal source so that the main contributor to single-tone desensitization comes from the receiver LO’s phase noise and not the RF signal generator’s phase noise.

As an example, Maxim’s version 3.5 superheterodyne CDMA reference design using MAX2538 front-end IC and MAX2308 IF demodulator IC has a cascaded noise figure (referred to LNA input) of less than 3 dB in the cellular band. If we assume duplexer/diplexer loss of about 3 dB in a mobile handset, we have:

- Receiver noise floor = -174 dBm/Hz (thermal noise floor) + 3 dB (duplexer loss) + 3 dB (LNA input-referred system NF) = -168 dBm/Hz

If the RF signal generator’s phase noise is 10 dB below the receiver noise floor, then

- New receiver noise floor = -168 dBm/Hz - 10 dB = -178 dBm/Hz

Therefore, the impact of a -178 dBm/Hz RF signal generator phase noise is a relatively small rise (only 0.4 dB degradation) in the receiver sensitivity.

The CDMA handset standard calls for a minimum phase noise of -144 dBc/Hz at the 900 kHz offset frequency. Assuming a flat far phase noise response (i.e., -144 dBc/Hz across the band of interest) the preceding calculations result in a -167 dBm/Hz receiver noise floor. This is 1 dB worse than the -168 dBm/Hz noise floor with no interferer.

In summary, the receiver (Rx) sensitivity and desensitization performance is permitted (by the

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Tests 1 and 3</th>
<th>Tests 2 and 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tone offset from Carrier</td>
<td>SR1, SR3</td>
<td>-900 (BC 0, 2, 3, 5, 7 and 9)</td>
<td>-900 (BC 0, 2, 3, 5, 7 and 9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+1250 (BC 1, 4 and 8)</td>
<td>-1250 (BC 1, 4 and 8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+3300 (SR3)</td>
<td>-1350 (SR3)</td>
</tr>
<tr>
<td>Tone Power</td>
<td>dBM</td>
<td>-30 (Tests 1 and 2)</td>
<td>-101</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-40 (Tests 3 and 4)</td>
<td>-101</td>
</tr>
<tr>
<td>( I_w )</td>
<td>dBM/1.23MHz</td>
<td>-101</td>
<td>-101</td>
</tr>
<tr>
<td>( \frac{Pilot E_c}{I_w} )</td>
<td>dB</td>
<td>-7</td>
<td>-7</td>
</tr>
<tr>
<td>( \frac{Traffic E_c}{I_w} )</td>
<td>dB</td>
<td>-15.6 (SR1)</td>
<td>-15.6 (SR1)</td>
</tr>
</tbody>
</table>

Table 1. Minimum requirements for handset single-tone desensitization\(^2\)

Figure 2. Cellular single-tone desensitization setup.
Cross-modulation interference

Cross-modulation occurs when a strong transmitter leakage signal is present at the receiver’s LNA input. This (modulated) interferer is cross-modulated with 900 kHz AMPS tone by the third-order non-linearities in the LNA. The result of cross-modulation is an increased noise power at the desired received RF channel. Even though the receiver IP3 is dominated by the mixer’s IP3, most of the cross-modulation occurs in the LNA because Tx leakage signal at mixer input is very small due to the bandpass filter (BPF) between the LNA and the mixer.[2]

In order to include this effect in a receiver test setup, it is necessary to inject a CDMA reverse-channel modulated signal into the receiver. For cellular band, the Tx power injected into the LNA input should be:

\[
T_x \text{ (LNA input-referred) } = +23 \text{ dBm (antenna referred) } + 2 \text{ dB (dualplexer loss)} -52 \text{ dB (dualplexer Tx to Rx isolation)} = -27 \text{ dBm assuming Tx rejection of 52 dB at Rx port of the dualplexer and 2 dB of loss from antenna to Tx port of the dualplexer.}
\]

Example test using the CNR method

Figure 2 shows the complete single-tone desensitization setup for testing a CDMA receiver in the cellular band. For PCS band testing, the same setup can be used but the jammer offset and jammer and Tx signal levels have to be set according to the test specification shown in Table 1.

In this test setup, we use the carrier-to-noise ratio (CNR) method to measure single-tone desensitization performance.

Sensitivity is defined as minimum received power at which the frame error rate (FER) is \( \leq 0.5\% \) for 95\% of the time. In the CNR measurement, we note that for Radio Configuration 1 in the 3GP2 standard, the Traffic Ec/Io is -15.6 dB, and that Traffic Eb/Nt = 4.5 dB for 9600 bps data rate.

Processing gain is 10 log (1.2288 Mcps/9600 bps) = 21.072 dB, so:

\[
N_t \text{ (total noise power) } = -101 \text{ dBm (sensitivity requirement in presence of single-tone jammer) } + 15.6 \text{ dB (Traffic Ec/Io) } + 21.072 \text{ dB (processing gain for 9600 bps data) } - 4.5 \text{ dB (required Traffic Eb/Nt) } = -100 \text{ dBm}
\]

Therefore, the required CNR for demodulating CDMA signal is -1 dB, measured in the 1.23 MHz channel bandwidth. For the purpose of our test setup, we will use RBW setting of 3 kHz and compare the beat-note test tone power at 250 kHz to total integrated channel noise power over the 615 kHz I-channel bandwidth.

Since received wanted signal power is -101 dBm and our total allowed noise power is -100 dBm, we observe that a CNR of -1 dB is required to satisfy the sensitivity requirement in the system.

As an example demonstrating this method, a measurement taken on Maxim’s N-CDMA V4.1 reference design using MAX2585 single-chip Rx IC with on-chip VCO is shown in Figure 3. The green trace shows the wanted signal without the presence of jammer or the Tx signal (instead of a CDMA downlink channel modulated signal, we used a single-tone injected at 250 kHz offset from the channel frequency at -101 dBm). The blue trace shows the noise-rise when the jammer and CDMA Tx signal are turned on. The following procedure outlines the test setup:

1. Adjust the system gain to receive -101 dBm input (referred to the input of 3 dB pad, which simulates duplexer loss). For MAX2585, we set the gain for 8.5 mVRms or -28.5 dBm (into 50 Ohm) nominal output signal level.
2. Turn on the CDMA Tx signal at -24 dBm and 45 MHz below the Rx channel frequency (referred to the input of 3 dB pad).
3. Turn on the CW jammer tone at -30 dBm (referred to the input of 3 dB pad). Observe the noise floor rise.
4. Adjust the CW jammer level until the noise floor rise is such that the total integrated noise power from baseband to 615 kHz is 1 dB above the wanted signal level. In this example, we integrated from 25 kHz to 615 kHz to avoid the dc leakage from the analyzer.
5. Record the jammer level at -1 dB CNR and calculate the single-tone desensitization margin.

In this example, the total noise power integrated from 25 kHz to 615 kHz is -27.5 dBm and the received tone at the output is -28.5 dBm, satisfying the -1 dB CNR requirement. At the -1 dB CNR point, the single-tone jammer level was recorded at -27 dBm, indicating that MAX2585 meets single-tone desensitization with 3dB of margin at the tested frequency.

Summary

In this article, we have discussed the single-tone desensitization specification per 3GP2 standard, discussed important contributors to single-tone desensitization and presented a practical method for measuring single-tone desensitization performance in a CDMA receiver handset.

References


ABOUT THE AUTHORS

Jinku Kim is a senior RF engineer working in Maxim Integrated Product’s RF systems applications group.

Dave Devries is an RF engineer with 25 years industry experience, working in Maxim’s RF engineering group.