

# Suppressing Errors in W-CDMA Mobile Devices

**As the final specs for W-CDMA near completion, handset designs offering wireless Internet access with voice and data capabilities are close behind. But to make these products a reality, designers must first get a grip on minimizing BER in the RF front end**

By Thomas Gee

[Communication Systems Design](#)

(03/01/01, 02:31:27 PM EDT)

The promise of third-generation (3G) cellular handsets, which marry multimedia applications with wireless Internet and telephony functions incorporating voice and data services, is poised to come to fruition. With the specifications for the first commercial deployment nearly complete, phone designers are working feverishly to finish their handset designs in time for the anticipated rollout of W-CDMA in Japan around April 2001.

The 3rd Generation Partnership Program (3GPP) global standards body is preparing the necessary standardization documents employing the wideband CDMA (W-CDMA) protocol for both the universal terrestrial radio access frequency division duplex (UTRA FDD) and UTRA time division duplex (TDD) standards. New mobile radio performance requirements go hand in hand with these new standards.

Designers of RF handset equipment and other mobile devices need to understand how to extract measurable parameters from the system specifications which are given in terms of bit error rate (BER) in both the radio transmission and reception specification<sup>1</sup> and the terminal conformance specification.<sup>2</sup> This is especially true for new standards such as W-CDMA, since most RF designers don't have the luxury of a completed baseband modem, which would allow them to measure their radio performance in terms of BER.

Deriving the RF design parameters for an UTRA FDD (hereafter referred to as W-CDMA) mobile receiver requires transmission/reception specifications, but also a number of performance requirements that are driven by the physical implementation of the handset's design. As is the case with many radio standards, these design-oriented constraints may prove more significant than the specification itself.

The assumptions will be that the handset is a power class <sup>3</sup> device operating in the IMT-2000 set of frequencies (mobile Tx: 1920 to 1980 MHz, mobile Rx:

2110 to 2170 MHz), and that fixed-duplex offsets of 190 MHz are implemented.

### A sensitive topic

Receiver sensitivity is specified as the minimum input power of a W-CDMA signal measured at the antenna at which the BER does not exceed 0.001. For this BER, the received downlink (base station to handset) signal  $\hat{I}_{\text{tot}}$  power level shall be less than or equal to -106.7 dBm/3.84 MHz and the DPCH\_Ec (average energy per PN chip for the dedicated physical channel) shall be less than or equal to -117 dBm/3.84 MHz.  $\hat{I}_{\text{tot}}$  is the level of the composite downlink signal and therefore may contain data going to many different handsets in the cell or sector.

The DPCH\_Ec is the power level of the signal intended for the receiver under test. It is, therefore, the power level that will be used for the sensitivity calculation. The downlink signal is defined as having a user data rate of 12.2 kbps and a spread chip rate of 3.84 Mcps. The goal is to take this receiver sensitivity requirement and convert it into a required input referred noise figure.

Before this can be done, however, several other parameters need to be calculated. The first is the processing gain (Gp) of the system. This represents the improvement in signal-to-noise ratio (SNR) achieved during demodulation given coding gains and the reduction in signal bandwidth. For the defined downlink signal this can be calculated using [Equation 1](#):

(1)

$$G_p = 10 \times \log \left( \frac{3.84 \text{ Mcps}}{12.2 \text{ Kbps}} \right) \approx 25 \text{ dB}$$

Next, the  $E_b/N_o$  required by the baseband receiver for a BER of 0.001 must be calculated. This important figure can be derived given the results of early simulations which showed that the required DPCH\_Ec/ $\hat{I}_{\text{tot}}$  (the ratio of the average transmit energy per PN chip for the dedicated physical channel to the total transmit power spectral density) for a 0.001 BER is -18.8 dB.<sup>3</sup> From this result the  $E_b/N_o$  can be calculated as follows:

(2)

$$\frac{E_b}{N_o} = \frac{\frac{\text{DPCH\_Ec}}{\hat{I}_{\text{tot}}} \times \frac{\text{Chip rate}}{\text{User data rate}}}{\frac{I_{\text{tot}}}{\hat{I}_{\text{tot}}}} = 5.2 \text{ dB}$$

Where:

(3)

$$\frac{I_{sc}}{I_{cr}} = 1 \text{ dB from section 8.2.3 of Reference 1.}$$

Within the 3GPP Radio Access Networks Technical Specification Group (RAN4 TSG), it was decided that a 2-dB implementation margin would be added to the theoretical value of 5.2 dB. Therefore, the  $(E_b/N_o)_{IMP} = 7.2 \text{ dB}$ .

Now that the processing gain and  $E_b/N_o$  have been calculated, the maximum input referred noise figure for a W-CDMA handset device can be found as follows:

(4)

$$\left( \frac{E_b}{N_o} \right)_{IMP} = DPCH\_E_c + G_p - (10 \log(kT_o B) + NF_{MAX})$$

$$NF_{MAX} \approx 9.0 \text{ dB}$$

Where:

K = Boltzmann's constant =  $1.38 \times 10^{-20} \text{ mJ/K}$

To = 290K

B = W-CDMA signal bandwidth = 3.84 MHz

DPCH\_Ec = -117 dBm/3.84 MHz.

[Equation 4](#) assumes that the only sources of noise present during the receiver sensitivity test are those of thermal noise and noise generated by the receiver circuitry. However, given that W-CDMA handsets operate in full-duplex mode and the receiver sensitivity test setup requires that the transmitter be active during the test, transmitter noise that falls into the receiver's band of frequencies is also a factor.

Transmitter noise can find its way into the receiver circuitry in many locations, based on the physical layout of the RF circuitry. However, assuming that the isolation between the receiver and transmitter is adequate in the IF and RF stages, the dominant coupling mechanism is through the duplexer.

[Figure 1](#) shows how transmitter noise can be coupled through the handset's duplexer and into the receive circuitry. Since the transmitter noise is independent of the thermal noise found in the receive (Rx) band, the powers of the two are added logarithmically, thereby artificially raising the noise floor.

As an example, assume that the noise floor out of a W-CDMA handset's power amplifier is no higher than -140 dBm/Hz (measured with an RF filter at the power amplifier input and at full output power) in the Rx band. If the isolator insertion loss and duplexer transmit (Tx) to Rx isolation in the Rx band are 0.5 and 45 dB, respectively, the maximum noise figure for the handset can be recalculated including this extra source of noise. But first, the transmitter Rx band noise power in the receive band must be calculated.

(5)

$$P_{TNN} = P_{PAN} - Loss_{ISO} - Isolation_{Dup} = -185.5 \text{ dBm/Hz}$$

Where:

$P_{TXN}$  = The noise power in the Rx band due to the handset's transmitter

$P_{PAN}$  = The noise at the output of the power amplifier that falls in the Rx band

190 MHz away = -140 dBm/Hz

$Loss_{ISO}$  = The insertion loss of the isolator in the Rx band = 0.5 dB

IsolationDup = 45 dB.

This noise power can now be converted to a noise temperature and summed with the ambient noise temperature of the system to come up with an effective noise temperature given the Tx noise contribution:

$$-185.5 \text{ dBm/Hz} = kTT_x$$

$$T_{TX} = 20.4 \text{ K}$$

$$T_{EFF} = 20.4 + 290 = 310.4 \text{ K}$$

Where:

$T_{TX}$  = The temperature of the Rx band noise generated by the transmitter

$T_{EFF}$  = The effective noise temperature of the system given Tx and thermal noise.

Now that an effective noise temperature has been calculated, a new maximum noise figure for the handset's receiver can be found. This new noise figure will include the effects of thermal noise, receiver component noise, and Tx noise:

(6)

$$\left( \frac{E_b}{N_o} \right)_{BMP} = DPCH\_E_c + G_p - (10 \log(kT_{eff}B) + NF_{MAX})$$

$$NF_{MAX} = 8.64 \text{ dB}$$

As expected the maximum noise figure for the handset has reduced given the effects of transmitter noise.

Historically, carriers rolling out new systems have always placed pressure on handset designers to exceed this specification by as much as possible. This, coupled with the designers need for manufacturing margin will result in nominal noise figures for W-CDMA handsets in the 6-dB range.

Achieving these types of noise figures will be in line with the performance of handset components for single-mode designs, but will be much more difficult for the designer of multimode terminals (W-CDMA/GSM/ DCS) due to increases in front end losses. Handsets may be designed with two antennas allowing better noise figures and transmitter power-added efficiency while in

W-CDMA mode.

## Dynamic range

Stringent dynamic range specifications place large signal handling requirements on the W-CDMA receiver. Here, the handset's BER can not exceed 0.001 when an average input power of -25 dBm/3.84 MHz is applied at the antenna. Given a peak-to-average power ratio of about 7 dB for the standard defined W-CDMA downlink signal, the peak power at the antenna could approach -18 dBm/3.84 MHz. As the level of the downlink signal approaches a components input 1-dB compression point (P1dB), the amount of signal distortion increases thus reducing the  $E_b/N_o$  and increasing the BER.

For IS-95, the Rx automatic gain control (AGC) is commonly designed such that at the maximum input signal level, less than 0.25 dB of desensitization occurs. This requirement, in part, limits the amount of error introduced to the open loop power calculation. The amount of backoff needed for 0.25 dB of desensitization can be calculated using the power series and an input signal equal to  $A \cos \omega t$  as follows:<sup>4</sup>

(7)

$$\begin{aligned}y(t) &\approx \alpha_1 x(t) + \alpha_2 x(t)^2 + \alpha_3 x(t)^3 \\x(t) &= A \cos \omega t \\y(t) &= \alpha_1 A \cos \omega t + \alpha_2 A^2 \cos^2 \omega t + \\&\alpha_3 A^3 \cos^3 \omega t \\y(t) &= \frac{\alpha_2 A^2}{2} + \left( \alpha_1 A + \frac{3\alpha_3 A^3}{4} \right) \cos \omega t + \\&\frac{\alpha_2 A^2}{2} \cos 2\omega t + \frac{\alpha_3 A^3}{4} \cos 3\omega t\end{aligned}$$

From the above, the gain at  $\omega$  is:

(8)

$$\alpha_1 \left( 1 + \frac{3\alpha_3 A^2}{4\alpha_1} \right)$$

0.25 dB of desensitization occurs when the input signal is backed off of the compression point of a device by:

(9)

$$\begin{aligned}20 \log \left( 1 + \frac{3\alpha_3 A^2}{4\alpha_1} \right) &= -0.25 \text{ dB} \\A &= 0.195 \sqrt{\frac{\alpha_2}{\alpha_1}} \\20 \log(0.195) &= -14.22 \text{ dB}\end{aligned}$$

In practice, a bypassable low-noise amplifier (LNA) is often used to help minimize the effects of this requirement on the Rx AGC (see [Figure 2](#)). When

the low-noise amplifier (LNA) is in the bypass mode, the input signal level at the AGC is reduced by about 17 dB in typical implementations. Using this feature, the linearity and current consumption of the AGC can be reduced. Also, many LNAs with this bypass feature don't consume any current in the bypass mode, thereby further reducing the required power of the receiver chain.

Adjacent channel selectivity is defined as a measure of a receiver's ability to receive a W-CDMA signal at the assigned channel frequency, in the presence of an adjacent modulated channel signal at a 5-MHz offset from the center frequency of the assigned channel. For this test example, the power of the wanted signal is -103 dBm/3.84 MHz and the power of the modulated interferer is -52 dBm/3.84 MHz. In general, the adjacent channel selectivity of a receiver can either be filter or phase-noise limited.

Filtering at the IF or baseband determines how much of the adjacent channel interferer leaks through the receiver and is present at the demodulator. Phase noise from the RF local oscillator can be reciprocally mixed in band by the adjacent channel interferer after the downconversion process, introducing another source of noise to the demodulation process (see [Figure 3](#)).

### Turning down the noise

The approach here is to solve for the amount of adjacent channel filtering that is needed in the IF and at baseband given the phase noise performance of off-the-shelf voltage-controlled crystal oscillators (VCOs) designed for the W-CDMA handset market. In doing so, the phase noise from the RF local oscillator can be artificially reflected back to the input of the receiver and the amount of selectivity can be calculated in a manner similar to the one used to calculate the noise figure of the receiver.

Reflecting the phase-noise levels at a 5-MHz offset back to the input is dependent on the receiver's front-end gain; for this calculation the gain lineup shown in [Figure 2](#) is assumed. Therefore, if the phase noise of the W-CDMA VCO is -140 dBc/Hz at a 5-MHz offset, it will be mixed in band at the output of the downconversion mixer by the adjacent channel interferer at a level of -105.2 dBm/3.84 MHz (adjacent channel interferer = -31 dBm/3.84 MHz). This can then be reflected to the input of the receiver at a level of -126.2 dBm/3.84 MHz:

(10)

$$\left(\frac{E_b}{N_o}\right)_{\text{MFP}} = DPCH\_E_c + G_p -$$

$$(10 \log(kT_{\text{eff}} B) + NF_{\text{MAX}}) - P_{\text{ADJ}}$$

$$-85.20 = -99.2 - P_{\text{ADJ}}$$

$$P_{\text{ADJ}} = -85.4 \text{ dBm} / 3.84 \text{ MHz}$$

Here,  $P_{\text{ADJ}}$  is the total amount of additional interference power that can be handled by the system while still maintaining a BER of 0.001. Subtracting out the phase noise contribution leaves:

(11)

$$P_{adj} = P_{Phase} + P_{Filter}$$

$$-85.4 = -126.2 + P_{Filter}$$

$$P_{Filter} = -85.4 \text{ dBm} / 3.84 \text{ MHz}$$

Where:

$P_{Filter}$  is the amount of interference power that needs to be eliminated by filtering at IF and baseband.

$P_{Phase}$  is the amount of noise power added to the system from the phase noise of the local oscillator (LO).

Now, the amount of adjacent channel selectivity required by the receivers channel select filters can then be calculated as follows:

(12)

$$Selectivity = -52 + 85.4 = 33.4 \text{ dB}$$

Since the wanted signal for this test is elevated from -117 dBm/3.84 MHz to -103 dBm/3.84 MHz, the noise figure of the receiver and phase noise of the RF local oscillator have little effect on the required selectivity of the system.

In typical W-CDMA receivers, channel select filtering occurs at both IF and baseband. IF SAW filters designed for W-CDMA handsets normally provide about 30 dB of rejection at the adjacent channel while the baseband low pass filters provide an extra 20 dB. The cascade selectivity of 50 dB easily surpasses the system requirements.

Intermodulation response rejection is a measure of the receiver's capacity to receive a wanted signal on its assigned channel frequency in the presence of two or more interfering signals, which have a specific frequency relationship to the wanted signal. In this particular instance, there are two defined interference signals. One is a continuous wave (CW) interferer at a 10-MHz offset, with a level of -46 dBm. The other is a W-CDMA modulated signal at a 20-MHz offset, with a level of -46 dBm/3.84 MHz. Mixing of the two signals in a non-linear circuit creates third-order products, one of which falls in band with the desired receive signal (see [Figure 4](#)).

Using the above information, along with the level of the wanted signal (DPCH\_Ec = -114 dBm/3.84 MHz), the phase noise of the RF LO at a 10-MHz (-145 dBc/Hz) and 20-MHz (-150 dBc/Hz) offset, and the power of the two interferers at the demodulator allows calculation of the receivers input third-order intercept point (IIP3). This is similar to the calculations for adjacent channel selectivity and relies upon the phase noise of commercial W-CDMA VCOs and the selectivity of commercial IF SAW filters and W-CDMA mixed signal ICs to calculate the required value for the IIP3:

(13)

$$\left(\frac{E_b}{N_s}\right)_{\text{MFP}} = DPCH\_E_c = G_p -$$

$$(10\log(kT_{\text{eff}}E) = NF_{\text{MAX}}) - P_{\text{INT}}$$

$$-96.2 = -99.2 - P_{\text{INT}}$$

$$P_{\text{INT}} = -99.2 \text{ dBm} / 3.84 \text{ MHz}$$

Where:

$P_{\text{INT}}$  is the total interference power allocated to the inband third-order product along with the accompanying inband phase noise and the power of both interferers at the demodulator.

The level of the phase noise can once again be referred to the input of the radio similar to the manner used for adjacent channel selectivity. In this case, there is the phase noise that is reciprocally mixed in via the 10- and 20-MHz interferers. This is summarized in [Table 1](#).

<b>Table 1: Phase Noise Level Comparisons</b>				
	<b>Phase Noise at LO output</b>	<b>Interferer level at mixer output</b>	<b>Phase noise at mixer output</b>	<b>Phase noise at receiver input</b>
<b>Phase noise at 5 MHz</b>	-145 dBc/Hz	-25 dBm	-104.2 dBm/ 3.84 MHz	-125.2 dBm/ 3.84 MHz
<b>Phase noise at 10 MHz</b>	-150 dBc/Hz	-25 dBm/3.84 MHz	-109.2 dBm/ 3.84 MHz	-130.2 dBm/ 3.84 MHz

The two interfering signals are both assumed to see 80 dB of selectivity given the IF and baseband channel select filters. The power of both these signals at the demodulator can also be referred to the input of the receiver so that the amount of interference power caused by the in-band third order product can be solved for:

(14)

$$P_{\text{INT}} = P_{\text{Phase10}} + P_{\text{Phase20}} + P_{\text{10 MHz}_c}$$

$$+ P_{\text{10 MHz}_c} + P_{\text{20 MHz}_c} + P_{\text{Int3}} - 99.2 =$$

$$-125.2 - 130.2 - 118 - 118 + P_{\text{Int3}}$$

$$P_{\text{Int3}} = -99.33 \text{ dBm} / 3.84 \text{ MHz}$$

Where:

$P_{\text{Phase10}}$  is the phase noise power at an offset of 10 MHz mixed in band = -125.2 dBm/3.84 MHz

$P_{\text{Phase20}}$  is the phase noise power at an offset of 20 MHz mixed in band = -130.2 dBm/3.84 MHz

$P_{10\text{MHz}}$  is the inband input referred power of the interferer offset by

10 MHz at the demodulator = -118 dBm

$P_{20\text{MHz}}$  is the inband input referred power of the interferer offset by 20 MHz at the demodulator = -118 dBm/3.84 MHz

$P_{\text{IM3}}$  is the power of the third order product that falls in the desired Rx frequency.

Once again the phase noise is negligible. Solving for IIP3 we get:

(15)

$$\text{IIP3} = -46 + \frac{-46 + -99.33}{2} = -19.33 \text{ dBm}$$

Here is another example where the physical implementation of the handset drives the design requirements. In this particular case, the amount of transmitter leakage into the receiver front end desensitizes the LNA if its linearity is insufficient (see [Figure 5](#)). To prevent this desensitization, the LNAs IIP3 or input P1dB must be increased above those requirements set by the intermodulation test. Desensitization by a strong blocking signal (in this case, the transmit signal) can also be explained using a power series representation.

The apparent gain of a circuit can be calculated given an input signal that is the summation of a weak wanted signal ( $A_1 \cos \omega_1 t$ ) and a strong blocking signal ( $A_2 \cos \omega_2 t$ ) as follows: <sup>4</sup>

(16)

$$\begin{aligned} y(t) &\approx \alpha_1 x(t) + \alpha_2 x(t)^2 + \alpha_3 x(t)^3 \\ x(t) &= A_1 \cos \omega_1 t + A_2 \cos \omega_2 t \\ y(t) &= \alpha_1 A_1 \cos \omega_1 t + \frac{3}{2} \alpha_2 A_1 A_2 \cos \omega_1 t + \dots \end{aligned}$$

From above the gain at  $v_1$  is:

(17)

$$\text{Apparent gain} = \alpha_1 \left( 1 + \frac{3\alpha_2 A_2^2}{2\alpha_1} \right)$$

The apparent gain of the circuit is now a function of  $A_2$ . If  $\alpha_3$  is negative, the gain of the device at  $v_1$  goes to zero as  $A_2$  gets larger.

For a single-band power class 3 handset, about +27 dBm of power is required out of the power amplifier in order to insure that +24 dBm is available at the antenna. Typical W-CDMA duplexers provide 50 dB of Tx to Rx isolation in the Tx band. Therefore, an average signal level of about -23.5 dBm (-20 dBm peak) could reach the input of the LNA.

The effects of desensitization can be seen in the lab by measuring the noise figure of an LNA versus interferer level. For this particular measurement, the noise figure of a variable bias LNA (MGA-72543) was measured as the power of a reverse link W-CDMA signal was increased. The results show the degradation in noise figure of the LNA for two different bias (linearity) settings. As shown in [Figure 6](#), as the peak power of the interferer approaches the amplifiers input P1dB, the noise figure increases, or gain decreases.

With the assumption that the noise figure or gain of the LNA should not be affected by the transmitter leakage, an input P1dB of -7 dBm or IIP3 of 4 dBm is selected as the correct linearity setting for the LNA. This does not affect the mixer requirements, due to the higher linearity of the device and the attenuation of the Tx signal by the RF image reject filter.

## System calculations

Referring once again to [Figure 2](#), the cascade parameters of this receiver are calculated to see if they meet or exceed those required by the 3GPP Technical Specification 25.101 V3.4.1 also address the implementation issues examined here. [Table 2](#) compares the receiver in [Figure 2](#) to the requirements calculated above.

<b>Table 2: Calculated Receiver Performance</b>		
<b>Parameter</b>	<b>Receiver</b>	<b>Requirement</b>
Noise figure	5.6 dB	8.64 dB
Adjacent channel selectivity IIP3	50 dB -16.0 dBm	33.4dB -19.3 dBm
LNA input P1dB	-7 dBm	-7 dBm
LNA IIP3	4 dBm	4 dBm

We've looked at some of the requirements placed upon W-CDMA receivers given the minimum performance standards and some of the implementation issues that designers are forced to consider. Blocking and spurious response requirements found in the 3GPP Technical Specification 25.101 V3.4.1 can be calculated in a similar manner to the parameters discussed above given the additional filtering information that is required.

There will be many challenges for 3G handset designers as more handsets are required to be multiband and multimode, and as features such as GPS and Bluetooth are added. The success of the 3G handset market will depend on the design community's ability to design small, highly integrated, low-cost, low-power solutions.

**Thomas Gee** is a senior member of the technical staff with Agilent Technologies Wireless Semiconductor Division. He obtained a B.S.E.E. from the University of Virginia and an M.S.E.E. from Virginia Tech and can be reached at [tom\\_gee@agilent.com](mailto:tom_gee@agilent.com).

--

## References

1. 3GPP Technical Specification 25.101 V3.4.1, "UE Radio Transmission

*and Reception (FDD)."*

2. *3GPP Technical Specification 34.121 V3.0.0, "Terminal Conformance Specification; Radio Transmission and Reception (FDD)."*
3. *TSGR4#8(99)99689, 3GPP/RANWG4 contribution "Simulation results for UE downlink performance requirements." Source: Motorola.*
4. *Meyer, R.G. and Wong, A.K., "Blocking and Desensitization in RF Amplifiers," IEEE Journal of Solid-State Circuits, Vol. 30, No. 8, August 1995.*



[Print this story](#)



[Send as e-mail](#)



[Back Home](#)

*Return to: [Communications Systems Design](#)  
[525 Market Street Suite 500](#)  
[San Francisco, Ca 94105](#)*

*Phone: +1 (415) 278-5300*

*Fax: +1 (415) 538-3858*

*Send comments to: [Webmaster](#)*

*Copyright © 2001*

*CMP Media Inc.*